2019

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

Victor Fannam Nunfam
Edith Cowan University

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

This thesis is presented for the degree of

Doctor of Philosophy

Victor Fannam Nunfam

Edith Cowan University

School of Arts and Humanities

2019

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

i. incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;

ii. contain any material previously published or written by another person except where due reference is made in the text of this thesis; or

iii. contain any defamatory material; and

iv. that the Library of Edith Cowan University has my permission to duplicate copies of my thesis as required

Candidate's Signature: [redacted]

Date: 13/12/2019

ABSTRACT

Excessive heat exposure due to rising temperatures associated with climate change adversely affects workers' health, safety, productivity, and psychosocial well-being in occupational settings. In the hot and tropical regions of developing countries, long hours of physically demanding work, coupled with inadequate adaptation policies to climate change, increases the occurrence of heat-related illnesses and injuries, and contributes to the loss of productive capacity, poor decision making, and other negative effects on the social well-being of workers.

Based on the theories of social impact assessment, risk assessment, adaptation and resilience planning, this study assesses the social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana, and thus fills a significant gap in the existing literature. Guided by the pragmatists' research philosophical paradigm, this study adopted the convergent mixed methods approach by utilising data obtained from four temperature and humidity data loggers, 346 surveys of mining workers, two focus groups and three in-depth interviews. The quantitative data was processed with Microsoft Excel 2016, XLSTAT 2019, and analysed using Statistical Product and Service Solutions (SPSS) version 25 while the qualitative data was processed utilising NVivo version 11 and thematically analysed.

The findings suggest that the use of convergent mixed methods showed adequate corroboration and complementarity between the qualitative and quantitative data and helped to obtain credible data relevant for policy decisions on heat stress management, workplace health and safety, and adaptation strategies. Supervisors' climate change risks perception was adequate, workplace heat exposure risks concerns were moderate and their views of workers' heat stress experiences were heat-related illness and minor injuries. The differences in supervisors' climate change risk perceptions and occupational heat stress risk experiences across job experience and adaptation strategies across educational status were significant ($p<0.05$). Workers' concerns about climate change effects and workplace heat exposure risks; heat-related morbidities experienced by workers; and their use of heat stress prevention measures significantly differed between Small-Scale Mining (SSM) and Large-Scale Mining (LSM) ($p<0.001$). The disparity in heat exposure risk factors across workers' gender, education level, workload, work hours, physical work exertion, and proximity to heat sources was significant ($p<0.05$). Thermal assessments demonstrated that workers were exposed to high ambient heat conditions that raise their heat stress risk. Workers' adaptation strategies, social

protection measures, and barriers to adaptation strategies differed significantly across the type of mining activity ($p<0.001$).

Based on the seven publications related to the social impacts of climate change and occupational heat stress and adaptation strategies of mining workers, this study recommends that there needs to be a concerted global effort at providing adequate and effective heat exposure and adaptation policies to promote workers' health and safety, productive capacity and psychosocial well-being; to reduce their vulnerability to heat stress, improve their adaptive capacity and resilience; and enlighten policy decisions and enforcement in the mining industry.

ACKNOWLEDGEMENTS

In everything always give thanks with a grateful heart, and trust in the Lord with all your heart, and lean not on your own understanding. In all your ways acknowledge Him, and He shall direct your paths (Proverbs 3:5-6). Therefore, I wish to extend my profound gratitude to God for his protection, guidance and grace throughout my life, this PhD journey and the research knowledge arising from it. I am also most thankful to the following individuals and institutions for their contributions towards the successful completion of this project.

I want to acknowledge the financial support of the Edith Cowan University (ECU) Postgraduate Research Scholarship (International) towards my study and living expenses and the Human Research Ethics Committee (HREC) of ECU (Project Number 17487) for ethical approval. My sincere gratitude also goes to the team of excellent supervisors comprising Dr Kwadwo Adusei-Asante (Principal Supervisor), Professor Jacques Oosthuizen (Associate Supervisor), Dr Eddie John Van Etten (Associate Supervisor), and Dr Kwasi Frimpong (Senior Adjunct Supervisor) for their diverse expertise, contributions and counsel during this PhD journey. I am equally grateful to the Takoradi Technical University (TTU) for granting me study leave, which has been very supportive in the pursuit of this PhD journey with a sound mind.

I am grateful to the research participants for the informed consent and invaluable information on their perceptions and lived experiences of climate change and occupational heat stress risks and adaptation strategies. I also thank the mining companies, the Ghana Chamber of Mines (GCM), the Ghana National Association of Small-Scale Miners (GNASSM), and the Ghana Minerals Commission (GMC) for their support. I further recognised the valuable suggestions of the anonymous reviewers and the editors of the international journals for the privilege to publish my research findings.

It is worth stating the support of my dear family including Mr David S. Nunfam (late father), Mrs Margaret Nunfam (mother) and my siblings, Mr Gordon Biduki Nunfam, Ms Beatrice Nanchaa Nunfam, Ms Diana Yobe Nunfam and Ms Patience Moimaak Nunfam. I sincerely appreciate their prayers, patience, and inspiration for this feat. I wish to thank my friends and associates here in Australia, namely, Dr E.A. Adama, Mr I.B. Nabubie and Wibele for their exceptional friendship; Dr F.A. Kuranchie, Mrs Isabella Kuranchie and Mrs Elizabeth Adusei-Asante for their motivation; Dr W. Sefah, Dr P. Aboagye-Sarfo, Dr E. Adua, Dr Janet Boateng, Dr Daniel Doh, Mrs Norman Crampton, Mr Michael Crampton, Lawyer James Nurokina, Mrs Assibi Nurokina, Mrs Victoria Michael-Narh, Mr Eric Narh, Mr Kwame Ango-

Tandoh, Mrs Betty Hunter, Rev. Father John Paul Baalaboun, Dr Kwabena Ayim, Dr Isaiah Awidi and the staff of RockyBay (Girrawheen) for their encouragements. To all my PhD colleagues, namely, Bright, Isaac, Jonas, Lisa, James, David, Senyo, Umile, Caroline, Dale, Mary, Claire, Clare, Kourosh and Senali (B.10.102) as well as Emmanuel Baah, Yakubu, Enoch, Alex, Hayford, Ebenezer, Albert, Michael Aseidu, Kwadjo Appiagyei, Reindolf, and many more who may not have been mentioned here, I appreciate their encouragements.

Finally, I thank T.B. Joshua for the prayers, hope-filled and inspiring words of God: “pray as if all depends on God and study as if all depends on you,” “better is not good enough; the best is yet to come” and many testimonies of God’s grace on Emmanuel.tv., which motivated and spurred me on to finish this project. Emmanuel; God with us! Good morning! To God, be all the glory!

DEDICATION

To my family, the Nunfams

PUBLICATION OUTPUTS ARISING FROM THE RESEARCH

The research outputs that emerged from this thesis comprised four published peer-reviewed articles in high impact international journals and three manuscripts submitted to similarly reputable journals for review and publication. The following papers were included in this thesis with publication format:

Published peer-reviewed papers

1. **Nunfam, V. F**., Adusei-Asante, K., Van Etten, E. J., Oosthuizen, J., & Frimpong, K. (2018). Social impacts of occupational heat stress and adaptation strategies of workers: A narrative synthesis of the literature. *Sci Total Environ, 643*, 1542-1552.
2. **Nunfam, V. F**., Van Etten, E. J., Oosthuizen, J., Adusei-Asante, K., & Frimpong, K. (2019). Climate change and occupational heat stress risks and adaptation strategies of mining workers: Perspectives of supervisors and other stakeholders in Ghana. *Environ Res, 169*, 147-155.
3. **Nunfam, V. F**., Oosthuizen, J., Adusei-Asante, K., Van Etten, E. J., & Frimpong, K. (2019). Perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. *Sci Total Environ, 657*, 365-378.
4. **Nunfam, V. F.**, Adusei-Asante, K., Van Etten, E. J., Oosthuizen, J., Adams, S., & Frimpong, K. (2019). The nexus between social impacts and adaptation strategies of workers to occupational heat stress: a conceptual framework. *Int J Biometeorol, 63*(291), 1-14.

Manuscripts under review

1. **Nunfam, V. F**., Adusei-Asante, K., Oosthuizen, J.,Van Etten, E. J., & Frimpong, K. (Submitted for review). Mixed methods study into social impacts of occupational heat stress on mining workers in Ghana: A dynamic research approach. *Journal of Mixed Methods Research,* Manuscript ID: JMMR-19-138 https://mc.manuscriptcentral.com/jmmr
2. **Nunfam, V. F**., Adusei-Asante, K., Oosthuizen, J., Van Etten, E. J., & Frimpong, K. (Under review). The risk and magnitude of heat exposure on mining workers in Ghana. *Sci Total Environ,* Manuscript Number: STOTEN-D-19-13292. https://ees.elsevier.com/stoten/default.asp

3. **Nunfam, V. F**., Adusei-Asante, K., Van Etten, E. J., Oosthuizen, J., & Frimpong, K. (Under review). Barriers to occupational heat stress risk adaptation of mining workers in Ghana. *Int J Biometeorol*, Manuscript ID: IJBM-D-19-00345. https://www.editorialmanager.com/ijbm/

STATEMENT OF CONTRIBUTION OF OTHERS

I, Victor Fannam Nunfam, declare that I contributed a substantial proportion (>75%) of the research publication outputs emanating from this thesis and duly acknowledge that the rest were contributions of the other authors, namely, Dr K. Adusei-Asante, Professor J. Oosthuizen, Dr E.J.Van Etten, Dr K. Frimpong, and Professor S. Adams.

TABLE OF CONTENTS

LIST OF TABLES

Chapter two

Chapter three

Chapter four

Chapter five

Chapter six

Chapter seven

Chapter eight

LIST OF FIGURES

Chapter one

Chapter two

Chapter three

Chapter four

Chapter five

Chapter six

Chapter seven

Chapter eight

LIST OF ACRONYMS

A	Agree
ACGIH	American Conference of Governmental Industrial Hygienists
AFOLU	Agricultural Forestry and other Land Use
ANOVA	Analysis of Variance
ASSM	Artisanal and Small-Scale Mining
CDC	Centre for Disease Control
CDCP	Centre for Disease Control and Prevention
CH_4	Methane
CM	Centimetres
CO_2	Carbon Dioxide
COP	Conference of Parties
D	Disagree
ECU	Edith Cowan University
Eg	For example
EIA	Environmental Impact Assessment
FGD	Focus Group Discussion
GCM	Ghana Chamber of Mines
GDP	Gross Domestic Product
GHC	Ghana Cedi
GHG	Greenhouse Gas
GoG	Government of Ghana
GMC	Ghana Minerals Commission
GSS	Ghana Statistical Service
HDRS	Higher Degree by Research Scholarship
HFCs	Hydrofluorocarbons
HIA	Health Impact Assessment
HOTHAPS	High Occupational Temperature Health and Productivity Suppression
HREC	Human Research Ethics Committee
HSI	Heat Stress Index
IDMC	Inspectorate Division of the Minerals Commission
ILO	International Labour Organisation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation

JBI	Joanna Briggs Institute
LI	Legislative Instrument
LSM	Large-Scale Mining
M	Mean
MK	Mann-Kendall
MM	Millimetres
MMR	Mixed Methods Research
Mt	Million tons
$MtCO_2e$	Million tons Carbon Equivalent
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NIOSH	National Institute for Occupational Safety and Health
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PFCs	Perfluorocarbons
PhD	Doctor of Philosophy
PICO	Population Intervention Comparator Context Outcome
PPE	Personal Protective Equipment
PPM	Part per million
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
P-value	Probability value
RCP	Representative Concentration Pathway
RH	Relative Humidity
RQ	Research Question
SA	Strongly Agree
SD	Standard Deviation
SD	Strongly Disagree
SDGs	Sustainable Development Goals
SF_6	Sulphur hexafluoride
SIA	Social Impact Assessment
SPSS	Statistical Product and Service Solutions
SSM	Small-Scale Mining
Ta	Air temperature
Td	Dewpoint

Tg	Globe temperature
TLVs	Threshold Limit Values
Tnwb	Natural Wet Bulb Temperature
U	Undecided
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children’s Fund
US	United States
USD	United States Dollars
UTCI	Universal Thermal Climate Index
WBGT	Wet Bulb Globe Temperature
WHO	World Health Organisation
WMO	World Meteorological Organisation
Ws	Wind speeds

SECTION I: THE RESEARCH FRAMEWORK

Overview

This thesis investigated the 'Social impacts of climate change and occupation heat stress and adaptation strategies of mining workers in Ghana' and is a unique and timely contribution to the research and literature on the impacts of climate change on society and the environment. This is a thesis by publication, and thus presents previously published or under review articles that this author has researched and written, in collaboration with other colleagues, in the effort to contribute to the literature on adaptation to climate change, with a particular focus on the way the mining sector in Ghana is able to adapt to the social impacts of climate change and occupation heat stress. Thus, this study yielded four published articles and three articles currently under review with relevant journals. These seven research outputs will be presented as evidence of this thesis in sections and chapters.

The research framework, as presented in chapter one, constitute SECTION I of five sections in this thesis. Chapter One is the overall introduction of the thesis, which provides a contextual account, the theoretical basis of the study, and the statement of the research problem. This chapter also describes the objectives of this study, outlines the research questions, proposes the hypotheses, scope, methodology, ethical consideration and schematic framework of the study.

CHAPTER ONE: GENERAL INTRODUCTION

Background and justification for the study

The overarching goal of sustainable development intervention is to satisfy the needs of present generations without adversely compromising the needs of future generations (Brundtland, 1985). Sustainable development has emerged as the primary policy goal in assessing impacts of interventions such as policies, programmes, plans, and projects. Accordingly, aspects of the agenda for improving global well-being of people, as encapsulated in the 2030 sustainable development goals (SDGs), relate to ending poverty (SGD 1), guaranteeing healthy lives and promoting well-being (SDGs 3), ensuring decent jobs and economic growth (SDGs 8), and combating intensifying temperature and climate change impacts (SDGs 13) (United Nations [UN], 2015).

As evident over the last two decades, increased impacts of excessive heat exposure as a result of climate change, have gradually emerged as one of the existential threats to humanity and the social, economic, health, and environmental well-being of diverse working populations (UN, 2009). Climate change refers to a change in average temperatures, precipitation, and wind conditions resulting from increases in greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6), and commonly ascribed to direct and indirect human actions (United Nations Framework Convention on Climate Change [UNFCCC], 2010). It also includes an increase in observable variability of natural climate or extreme weather events such as droughts, floods, and storms over a relatively long period of time, usually over a decade (UNFCCC, 2010). Devastating storms, frequent rainfalls and floods, rising sea levels, prolonged droughts, and high temperatures are significant proximate determinants of the social vulnerability and risks associated with climate change (UN, 2011).

Heat stress is a physical health condition in which the human body exhibits inadequate physiological capacity to tolerate excessive heat generated within and/or outside the body (Kjellstrom *et al*., 2016a). Heat stress emanates from three broad contextual categories of heat exposure, namely: environmental, personal, and occupational-related. The environmental-related heat factors include ambient temperature, relative humidity, air velocity, and radiant temperature (Kjellstrom *et al*., 2009b; Parsons, 2014; Schulte & Chun, 2009). The occupational-related heat factors are clothing, muscular physical activity, mechanical cooling systems, work-rest regimes, break hours, access to shade, and availability of drinking water. Personal mediating factors comprise age, sex, body size, pre-existing disease, acclimatisation level, type of work, lifestyle, use of medication, drugs, alcohol and rehydration (Haines & Patz, 2004; Kjellstrom *et al*., 2016a; McMichael *et al*., 2006; Parsons, 2014).

Generally, intensive work in an environment characterised by high heat exposure due to rising temperatures beyond 35°C, coupled with inadequate rehydration, creates heat stress-related morbidity. These heat related diseases include rashes, cramps, excessive sweating, headaches, dizziness, nausea, confusion, weakness, exhaustion, and heat stroke (Bridger, 2003; Parsons, 2014). High heat exposure is also linked to increased risk of prolonged disease, incidents of clinical injury to organ function, accidents, and mortality (Centers for Disease Control & Prevention [CDCP], 2008; Lucas *et al*., 2014a; National Institute for Occupational Safety and Health [NIOSH], 2010).

Both the impact of climate change and associated occupational heat stress impacts has engendered diverse and multidisciplinary research interest, resulting in numerous reports, and international and national conferences. This interest has also sparked cooperation with and between UN agencies and intergovernmental organisations, and has resulted in the development of several international frameworks, conventions, protocols, and agreements intended to combat the wide-ranging impacts of climate change on the world’s population.

The central focus of prior research and reports has been related to: (1) dimensions and impacts of climate change, extreme heat exposure, heat weaves, and occupational heat stress on peoples’ health, labour productivity, human performance, and workplace health and safety (Kalkstein *et al*., 2009; Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2016b); (2) experiences and perceptions of climate change and work-related heat stress; (3) climate change and heat stress mitigation and adaptation strategies (Intergovernmental Panel on Climate Change [IPCC], 2014; Kjellstrom *et al*., 2009b; Lundgren *et al*., 2013; Lundgren *et al*., 2014; Venugopal *et al*., 2015; Xiang *et al*., 2016).

Following the First World Climate Conference in Geneva in 1979, the establishment of the IPCC in 1988, UNFCCC in 1992, and Conferences of Parties (COP 1) in Berlin in 1995, 24 conferences have been organised with the last one (COP 24) held on December 2-16, 2018 in Katowice, Poland. Examples of notable conventions, protocols, agreements and actions on climate change include the UNFCCC, Kyoto Protocol, Paris Agreement, and the Marrakech Action. The main goal of the UNFCCC was to stabilise concentration levels of GHGs to prevent unsafe human-induced interference with the climate system. The level of GHG mitigation should be achieved within a time frame that will permit natural adaptability of ecosystems to climate change and to promote food production and viable socioeconomic development. The Kyoto protocol was an international treaty meant to set a mandatory boundary for 36 industrialised countries and the European Union to stabilise the emissions of GHGs into the atmosphere to control global warming and climate change. The Paris Agreement in 2015 sought to inspire member countries to contribute equitably based on common but varied national circumstances to hold global temperature increases below 2°C above pre-industrial levels and to direct efforts at limiting temperature increases to 1.5°C. It also sought to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to climate change, and commit to fostering adaptation (IPCC, 2014c; Roberts, 2016; Rogelj *et al*., 2016; UNFCCC, 2006).

Basically, the evidence of climate change are manifested in the rising average temperature and humidity of the earth, erratic precipitation, sea level rise, and prolonged drought due to human activities such as burning fossil fuels, industrialisation, and deforestation, resulting in GHG emissions. Radiated heat from the earth is trapped by GHGs within the atmosphere, and as concentrations of GHGs increase, more heat is retained resulting in warmer climates. This results in extreme weather conditions such as hot and humid environments, heatwaves, extended periods of drought, a rise in sea levels, increased storm frequency and severity, and frequent rainfalls and floods. These conditions severely impact the socioeconomic, health, and environmental well-being of people. The deterioration of socioeconomic and health impacts of climate change and occupational heat stress is assumed to have the prospects of reducing the productive capacity of working people and thwarting cooperative efforts at attaining the SDGs (Kjellstrom *et al*., 2016b). Hence, preventive and control strategies have been advocated to address occupational heat stress threats and to reduce susceptibility, improve resilience and adaptive capacity of working people and their families, socioeconomic units, and communities to ensure sustainable well-being (IPCC, 2014c; Kjellstrom *et al*., 2016b). Notably, mitigation, adaptation, and social protection strategies are recognised as appropriate and viable strategies at managing climate change and occupational heat stress (Spector & Sheffield, 2014; Venugopal *et al*., 2016a; Venugopal *et al*., 2015; Xiang *et al*., 2016). Preventive and control interventions of climate change-related occupational heat stress from the perspective of coping mechanisms, adaptation, and social protection strategies include engineering solutions, administrative controls, education and training regimes (Kjellstrom *et al*., 2016b). It also involves the reinforcement of procedures and policies, changes in structures of economies to non-outdoor work, compensation for productive losses, and social protections for workers (Davies *et al*., 2009; Giovannetti, 2010; Kjellstrom *et al*., 2016b; Lundgren *et al*., 2013).

Workers in occupations characterised by their high intensity of work in hot environments and poor rehydration are highly vulnerable to heat stress-related adverse impacts. Examples of workers at high risk of heat exposure include outdoor workers in the construction, agriculture, firefighting, armed forces, manufacturing, oil and gas, and mining industries (Lucas *et al*., 2014a; Xiang *et al*., 2014a). Globally, the risk of working populations from heat stress can be attributed to the rapid rise in the magnitude of heat exposure because of rising temperatures and humidity (Kjellstrom *et al*., 2009). The potential consequences of climate change and occupational heat stress impacts on working people extremely vulnerable to heat exposure are substantial and diverse and have been well studied. They include physiological, psychological, behavioural, health and safety concerns as well as social, productivity, and economic consequences (Campbell-Lendrum *et al*., 2014; Costello *et al*., 2009; Dunne *et al*., 2013; Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2009b; Lucas *et al*., 2014a; McMichael *et al*., 2003; Smith *et al*., 2014; Venugopal *et al*., 2016a; Xiang *et al*., 2016).

Previous studies on impact assessment of climate change, heat stress and adaptation seem to have marginalised and neglected a social impact assessment (SIA) and focused more on an environmental impact assessment (EIA) and a health impact assessment (HIA) of climate change and heat stress on working people. Most of these studies have occurred in temperate and tropical countries such as the USA, Canada, Australia, India, Costa Rica, and Thailand. Social impact refers to the direct or indirect perceptual or physical effect of a phenomenon on the lives, culture, cohesion, political system, environment, health and well-being, rights, and fears of individuals, social units, and communities (Vanclay, 2003; Vanclay *et al*., 2015). Accordingly, SIA is a process of evaluating, monitoring, and managing direct or indirect corporeal and perceptual social consequences, both positive and negative, of planned and unplanned actions, events or interventions on the lives, culture, cohesion, political system, environment, health and well-being, rights, and fears of individuals, socioeconomic units, and communities. It also involves any process of social change associated with the action, event or intervention leading to a sustainable and equitable biophysical and human environment (Vanclay, 2003; Vanclay *et al*., 2015). HIA is a process of predicting and managing the potential positive and negative health effects of policies, plans, programmes and projects on people, while EIA is a recognised process used to predict the potential positive or negative environmental consequences of a plan, policy, programme, or project on people and/or the natural environment prior to their operation, usually as part of the regulatory procedure (Adam-Poupart *et al*., 2013; Costello *et al*., 2009; Kjellstrom *et al*., 2009c; Kjellstrom *et al*., 2016b; Langkulsen *et al*., 2010; McMichael *et al*., 2003). However, SIAs relating to climate change and heat stress are gradually emerging as critical concerns in strengthening global research and cooperative efforts at combating the threats of rising temperatures (Kalkstein *et al*., 2009; Scheffran & Remling, 2013; UN, 2011). This is because the impacts of heat exposure due to climate warming, affects people both directly and indirectly.

Furthermore, while people are the victims of the adverse impacts of climate change-related occupational heat stress, they are also the agents of climate change and the subsequent rising temperatures, and the resultant development trajectories (UN, 2011). Thus, the mediating role of people as victims of and also agents of climate change, and thus associated problems such as occupational heat stress, are critical in reforming the approach to and success of climate change adaptation policies, planning and implementation.

Despite this connection, the human factor is often unduly ignored in social impact-climate change discourse and research (UN, 2011). For instance, the social impacts of extreme heat within planning and impact assessment have largely been neglected in the literature. Excessive heat, like climate change more generally, seems to be controversial as a policy and impact assessment issue (Dessler & Parson, 2019; Esteves Gonçalves da Costa & Cukerman, 2019). Significant evidence of the social implications of occupational heat stress due to climate change on workers, their families, and the economy is limited. Moreover, there is no evidence of mixed method empirical studies, systematic reviews and syntheses of the literature, and conceptual frameworks describing the social impacts of occupational heat stress and adaptation strategies of workers in the context of increasing temperature and climate change. Also, availability of evidence of social consequences of occupational heat stress to integrate into policies meant to protect workers from negative impacts and improve adaptive capacity in the context of climate change has been ignored in the literature (Miller, 2014; Venugopal *et al*., 2016a).

Like the majority of outdoors workers, the occupational working environment for most mining workers in low-and middle-income developing regions of tropical Africa, such as that in the West African state of Ghana, is associated with heat stress caused by high temperatures, radiant heat, humid conditions, lack of air movement, heavy physical activity, individual acclimatisation, the need to wear protective clothing, and inadequate access to cooling mechanisms while at rest (Kjellstrom *et al*., 2009b; Lucas *et al*., 2014a).

The actions, events and interventions typically associated with both surface and underground mining activities, in both small-scale mining (SSM) and large-scale mining (LSM), puts miners at this risk of heat stress. While the SSM and the LSM sectors and their activities have received considerable recent media, policy and research action world-wide, especially in Africa (Hilson, 2019; Hilson & McQuilken, 2014; McQuilken & Hilson, 2016; Moretti & Garrett, 2018), this focus has more often been on the impact this sector is having on the environment, and less so the impact on the workers themselves.

The LSM sector and its operations involve mainly multinational companies operating in Ghana, and using more advanced technology, while SSM usually involves licensed and/or unlicensed local people with inadequate funding and expertise, often using basic equipment, ranging from shovels, pickaxes and sluice, to semi-mechanised mining operations involving pumps, generators, small excavators and washing plants (McQuilken & Hilson, 2016). The SSM sector is thus more vulnerable to heat stress of its workers and this will be worsened by the predicted rise in temperatures in tropical developing countries such as Ghana, which is also associated with poverty, low adaptive capacity, lack of economic resources, inadequate innovative technology and knowledge of heat stress adaptations strategies. This ultimately affects the health and safety, productive capacity, and social lives of mining workers leading to loss of productivity and employment opportunities.

However, with the exception of a few studies, as exemplified by Miller (2014) and Venugopal *et al*. (2016a), there appears to be no specific empirical studies focusing on assessing the social impact of climate change and occupational heat stress (and their adaptation strategies) of mining workers. This is particularly so in low-and middle-income tropical developing countries in Africa, nor Ghana, where it is clear there is both a problem and a need for further research and policy directions.

Thus, one of the major challenges to the sustainable development of the global ecology and the working conditions for people in the 21st century is intense heat exposure, because of rising temperatures and the frequency of heat wave events. While the parameters of climate change impacts clearly stretch beyond just mining projects, and affect human livelihoods in various other ways, such as with access to clean water, energy, health and safety. Climate change has also made people vulnerable and this has also had an impact on their human rights. This raises germane questions of global and intergenerational equity (UN, 2011; White, 2011). Therefore, assessing the experiences, perceptions and physical impact of occupational heat stress and climate change and adaptation strategies of workers in the mining industry in Ghana, within the framework of the theories of SIA, social risk assessment, and adaptation and resilience planning is appropriate and timely (Adger, 2006; Miller, 2014 Mahmoudi *et al*., 2013).

The mining industry has contributed to the social and economic development of various regions of the world. In recent years (2013-2017), the mining and quarrying sector has served as a significant source of Ghana's employment, foreign exchange, internal revenue and gross domestic product (GDP). For example, while the SSM sector directly employs an estimated one million people and indirectly supports almost 4.5 million people (McQuilken & Hilson, 2016), employment in the LSM sector increased from 10,503 workers in 2016 to 11,628 in 2017 (Ghana Chamber of Mines [GCM], 2018). Corporate tax revenue increased by 39% from Ghc 696.9 million in 2016 to Ghc 969.6 million in 2017 (Ghana Revenue Authority, 2018), and this was because gold exports increased by 20% from 3.84 million ounces to 4.61 million ounces between 2016 and 2017 (Bank of Ghana, 2018). The sector accounted for a decrease in GDP from 13.6% in 2013 to 8.5% in 2016, however GDP increased to 13.6% in 2018 (Ghana Statistical Service [GSS], 2019). Beyond its socioeconomic contributions, surface and underground mining activities in Ghana are inextricably linked to diverse and adverse impacts on the environment, health, economic, and sociocultural well-being of vulnerable people. Thus, the significance of mining operations exemplified in its socioeconomic benefits are attained at substantial adverse environmental, health, and socioeconomic risk to people, that is, the working population, socioeconomic units, and communities (Amponsah-Tawiah & Dartey-Baah, 2011).

However, existing research attention to Ghana's mining industry seems to focus on issues pertaining to health and environmental impact assessments of mining activities in relation to air and water pollution, and ecosystems and land degradation. Other studies focus on the impact of mining activities on mining communities, workplace health and safety risks, disease, injuries, accidents, and associated fatalities, but most of these studies have avoided examining the relevance of researching climate change and associated heat stress impact on workers (Amponsah-Tawiah & Dartey-Baah, 2011; Aryee *et al*., 2003; Basu *et al*., 2015; Mensah *et al*., 2014; Tenkorang & Osei-Kufuor, 2014).

Thus, assessment of the interrelated impact of mining operations, climate change, and occupational heat stress on the health, productivity, social cohesion and well-being of the working population in the mining industry in Ghana has been overlooked. The impacts of intensifying heat stress on outdoors workers in the mining industry can be substantial particularly in hot environments of tropical developing countries like Ghana. It has the potential to aggravate the existing precarious ecological, health, economic and social consequences of surface and underground mining on workers' health and safety, loss of productive capacity, social well-being, and productivity of mining companies. Sustainable development may be unattainable if the scope and intensifying climate change and heat stress exposure impacts on the health, safety, economic, and social lives and systems of the population are not adequately managed through appropriately improved mitigation, social protection, and adaptation policies (UN, 2011). Without considerable investment and research effort directed at climate change and occupational heat stress mitigation and adaptation, global development efforts and the present multidimensional attempts at attaining the SDGs (1, 3, 8, & 13) will be weakened. It is, therefore, appropriate and imperative to research, highlight and disseminate evidence of social impacts of climate change and occupational heat stress and adaptation strategies of workers in the mining industry.

Theoretical framework

The nexus between social impacts, occupational heat stress, and adaptation strategies of workers because of perceived, actual, and predicted rises in temperatures and associated climate change is the focus of this study. Generally, occupational heat stress and climate change have interrelated environmental, socioeconomic, and health impacts. The concepts of SIA, risk assessment, and adaptation and resilience planning served as the foundations of this study. The basis of contemporary SIA may be traced in part to the U.S. National Environmental Policy Act (NEPA) of 1969 as an essential part of the planning and decision-making process of policies, programmes and projects (Esteves *et al*., 2012). The concept of SIA was seen as a process for predicting social impacts, and is closely integrated with EIA. This concept emerged in the 1970s as exemplified by Finsterbusch (1977) and Wolf (1975), and has developed over the last three decades as an effective paradigm, method and framework for assessing the social impacts of climate change. The essence of SIA is to improve the analysis, monitoring and management of the social dimensions and consequences of planned and unplanned interventions as well as the intended and unintended actions for sustainable development (Esteves *et al*., 2012; Vanclay *et al*., 2015). Worldwide, practitioners, researchers and other stakeholders have used SIA in various ways and degrees (Esteves *et al*., 2012; Vanclay *et al*., 2015). Given that the social impact is basically, anything that affects people, it is conceived as the totality of social and cultural consequences on people as a result of a collective or individual activity which modifies the way they live, work, play, interrelate, and organise to satisfy their desires to cope as socioeconomic units. The term SIA consists of changes to individual values, norms and beliefs that govern people's reasoning, and their communities (Burdge, *et al*., 1995; Burdge & Vanclay, 1995). It is also perceived as the perceptual or physical social effects, both positive or negative, of a phenomenon (e.g., policies, programmes, plans, projects), which directly or indirectly influences the way of life, culture, cohesion, political system, environment, health and well-being, rights, and fears of individuals, socioeconomic units and communities (Vanclay, 2003; Vanclay *et al*., 2015). Illness, injuries, reduced productive capacity, loss of employment, reduced income and disruption of social lives and comfort are examples of these negative social impacts.

Accordingly, SIA refers to the process of ascertaining the predicted outcome of immediate or intended action related to individuals, social units and systems in general (Becker, 2001). The interpretation of SIA includes the process of assessing, monitoring and managing the positive and negative social effects of proposed and unplanned interventions (e.g., policies, programme, plans, and project) and any process of social change linked to the intervention resulting in a more sustainable and equitable biophysical and human environment (Vanclay, 2003). Essentially, SIA is a process of evaluating, monitoring, and managing the direct or indirect perceptual or physical effect of a phenomenon on the lives, culture, cohesion, political system, environment, health and well-being, rights, and fears of individuals, social units, and communities (Vanclay, 2003; Vanclay *et al*., 2015). The fundamental implication is that SIA can commonly be used in ex-ante and ex-post assessment of policies, programmes, plans, and projects as well as natural and social risk occurrences (Mahmoudi *et al*., 2013; Vanclay, 2006).

As an emerging contemporary participatory approach and paradigm to impact assessment, SIA essentially emphases the facilitation of decision-making based on a holistic cost-benefit analysis of an intended action and improving the planning and management of policies and programmes to reduce its weaknesses and maximise its benefits (Finsterbusch, 1977). It is also valuable in helping policymakers and stakeholders in setting the agenda for project developments, optimising beneficial outcomes and reducing undesirable consequences of policies and programmes (João *et al*., 2011; Vanclay, 2003). Furthermore, SIA increases understanding of social change and adaptive capacity to react to changes, avoid or reduce risks and negative impacts, and promote positive benefits throughout the entire phase of developments, and enhance the lives of vulnerable and less privileged people (Esteves *et al*., 2012; João *et al*., 2011).

However, the nature of social phenomena is multifaceted. Hence, an accurate and comprehensive SIA may be unlikely because socioeconomic units are dynamic and social phenomenon involves adaptive relations (Finsterbusch, 1995). The process of SIA is criticised as being politically influenced by stakeholders' values and interests; challenged by limited participation of individuals and communities with inadequate capacity; influenced by the interests of proponents who provide the financial and logistical investment support for SIA; and being responsive to institutional requirements other than helping to mitigate social risk and impacts of policies and projects (Burdge & Vanclay, 1996; Lockie, 2001; Takyi, 2014).

Risk assessment has been an important part of the natural sciences since the 1970s, but is a relatively new concept in the social sciences (Goldman & Baum, 2000). The core components and assumptions of a risk assessment have been recognised to include: identifying risk by establishing its cause-effect connections; assessing the level of exposure and/or susceptibility by showing the magnitude of diffusion, exposure and effect on risk targets; and estimating risk by determining the strength of the cause-effect linkage (Renn & Walker, 2008). Human behaviour is often influenced by perceptions and not necessarily by realistic information. Hence, the conceptualisation of risk assessment in the context of the social sciences is underscored by the principle that causes and consequences of risk are often mediated by social processes (Renn, 2008). Therefore, risk is the uncertainty about the outcomes and severity of the consequences of an activity on something that is of human value (Aven & Renn, 2009). The principle of risk assessment is to identify and explore the nature, intensity and risk related to the consequences of an event that is of human value (Renn & Sellke, 2011). It also involves applying appropriate action for the management of the consequences of risks (Mahmoudi *et al*., 2013). Accordingly, social risk assessment is conceptualised as a process of analysing, monitoring and managing uncertain outcomes (both positive and negative) of actions (e.g., planned interventions) and events (e.g., extreme environmental hazards) (Rosa, 1998; Zinn, 2008).

Furthermore, the theoretical perspectives of adaptation and resilience planning are an essential response option to mitigation in managing climate change and heat exposure risks and impacts on social and ecological systems. In global climate change risk prevention and control literature, the concepts of adaptation and resilience are interrelated and have varied applications in different fields, usually in connection with vulnerability, exposure, sensitivity, and adaptive capacity (Adger, 2006; Smit & Wandel, 2006). Adaptation has significant historical antecedents in the natural sciences concerning developments in biology and other fields. However, it is a relatively new concept for some in the global climate change discourse. In human dimensions, adaptation is a course of action or an outcome with the potential of enabling people to cope with, manage or adjust to a changing condition, stress, vulnerability, risk or opportunity (Smit & Wandel, 2006). In the context of global climate change, adaptation is conceptualised as a process by which human and natural systems respond to perceived or actual climate risks and effects aimed at moderating the unavoidable adverse effects of climate change, or maximising its benefits. Various types of adaptation include proactive, spontaneous or deliberate action in response to the risk and impact of climate change (IPCC, 2007).

The conceptual perspective of resilience differs significantly across various fields of discipline and practice but is also gaining significant interest in climate change literature (Aldunce *et al*., 2014; Bhamra *et al*., 2011). Arguably, resilience as a theory became popular with the description of ecological resilience as the capacity of a system to persist and absorb perturbations (Hoiling *et al*., 1997; Holling, 1973). Resilience is conceptualised as the capacity of a social-ecological system to function by the process of reacting and adjusting to climate variability, change, and hazards, and to take advantage of opportunities. The underlying assumption is that systems should consist of social and ecological components whose relationships are intense and complex and should also be well defined and subjectively specified in research for practical purposes (Aldunce *et al*., 2014).

Examples of adaptation and resilience strategies in moderating climate change and high-temperature risks and impacts on the social and ecological systems are: engineering controls; administrative controls; education and training regimes; regulation and policy controls; and social protection (Kjellstrom *et al*., 2016b; Lucas *et al*., 2014; Lundgren *et al*., 2013; UN, 2011). However, reducing climate change and heat exposure vulnerability and improving coping and adaptive capacity in adaptation and resilience planning and implementation, also depends on the availability of resources, the perception of risks, competing socio-cultural values, governance, and research (IPCC, 2014c).

Enhancing the coping and adaptive capacity of social and environmental systems for adaptation and building resilience is crucial in combating the global risks and the adverse impacts of climate change and heat exposure. The contention is that the current amounts of GHG emissions are enormous, and the negative effects are not entirely avoidable in the short term, even with the most determined emission reductions efforts. Also, the benefits of adaptation planning and implementation for building resilience are immediate, while the gains in mitigation take several years to accomplish. Furthermore, the execution of adaptation strategies is much easier at the individual and local levels of a social and ecological system without necessarily depending on international cooperation. Lastly, adaptation policies and a resilient system moderate the risks and adverse effects of current climate variability as a significant hazard in most regions of the world (Fussel & Klein, 2006).

However, unlike adaptation and resilience, mitigation as the traditional focus of the climate change community is that its impacts are realised on all social and ecological climate-sensitive systems while adaptations strategies are limited. Also, from systematic and policy perspectives, reduction in GHG emissions is relatively easier to monitor quantitatively compared to adaptation and resilience (Fussel & Klein, 2006). For instance, critics point to ambiguity in the conceptual definition of resilience and the difficulty in applying it within the policy monitoring context of climate change (Amundsen, 2012; Frommer, 2013; Sovacool *et al*., 2012; Walker *et al*., 2002). Furthermore, the polluter pays principle applies to mitigation as compared to adaptation and resilience planning (Fussel & Klein, 2006).

The purpose of adopting the theories of SIA, social risk assessment, and adaptation and resilience planning in this study is part of an emerging trend towards more integrated approaches in analysing, monitoring and managing the social consequences from development (Mahmoudi *et al*., 2013; Slootweg *et al*., 2001; Vanclay, 2004). An integrated approach involves a more holistic method of impact assessment, which provides an avenue for improving the process of SIA as a form of risk assessment. It also provides a contextual understanding of SIA in managing risks and impacts of policies, programmes, plans and projects as well as natural hazards such as occupational heat stress as a result of climate change (Dreyer *et al*., 2010; Esteves *et al*., 2012; Esteves & Vanclay, 2009; Mahmoudi *et al*., 2013). Moreover, adequate exchange of information between SIA and various forms of impact assessment such as EIA, risks and hazard (e.g. climate change and heat stress exposure) assessment, and HIA, enhances SIA and the overall success of sustainable development (Dreyer *et al*., 2010; McMichael *et al*., 2006; Slootweg *et al*., 2001; Vanclay, 2004; Vanclay & Esteves, 2011). However, integrated approaches to impact assessment are characterised by the challenges of reducing bias and requirements of specific assumptions, ideologies and methodological orientation related to various fields of study and schools of thoughts and practitioners (Mahmoudi *et al*., 2013; Rattle *et al*., 2003).

Statement of the problem

Globally, mining operations are associated with valued socioeconomic benefits such as direct foreign and local investments, source of foreign exchange, employment, income and revenue for development. The potential interrelated concerns of mining operations and climate change expressed as occupational heat stress has substantial adverse effects on workers' occupational health and safety, productive capacity and social cohesion, which ultimately affects the economic productivity of mining companies. In tropical developing countries like Ghana, the projected increase and intensity of temperature and humidity levels, coupled with high vulnerability, and substantial outdoor physical activity has the potential to impact negatively on workers' social lives, comfort and productive ability, as well as sustainable development. Similarly, high levels of poverty, low adaptive capacity, inefficient use of economic resources, inadequate innovative technology, and a lack of knowledge about heat stress adaptations strategies can intensify the existing precarious situation of occupational heat exposure on mining workers. Even so, concerns of heat stress and reduced social and economic performance are often overlooked in climate change-SIA discourse (Kjellstrom *et al*., 2016a; Miller, 2014).

Socioeconomic dimensions and the impact of heat stress and climate change on workers, workplace safety, health, and loss of productivity hours as a result of repeated breaks and self-paced working regimes are varied and recognised. However, it has not been adequately researched among SSM and LSM workers in Africa, especially Ghana, and thereby not duly integrated into climate change adaptation policy and execution of national and international institutions (Kjellstrom *et al*., 2016b; UN, 2011; Venugopal *et al*., 2016a). Also, the socioeconomic role and scope of SSM in job creation, income generation, taxation and investments, both globally and in Ghana, are substantial.

Occupational heat stress extends beyond project impacts to include diverse global social dimensions and impacts on health, productivity, and the social lives of working populations, and this is especially of concern in the tropical and sub-tropical regions of low-and middle-income developing countries, particularly in the African region (Venugopal *et al*., 2016a). Even though tropical areas of the world have been described as high risk to heat stress due to the increasing higher temperatures, there are less extensive studies in these developing regions of Africa (Lucas *et al*., 2014; Lundgren *et al*., 2013; Spector & Sheffield, 2014). The issues that remain unanswered in the literature and relative to Ghana are the (1) Perceptions of climate change and occupational heat stress risks and adaptation strategies of workers in the mining industry; (2) Risk and magnitude of ambient temperatures in the working and living environments of workers in the mining industry; and (3) Adaptation strategies to climate change and occupational heat stress in the mining industry in Ghana. Therefore, research and the quest for answers to these questions are pertinent, particularly as occupational heat stress vulnerability is projected to increase in low-and middle-income tropical and sub-tropical regions with the predicted increase in temperature, coupled with low adaptive capacity in the context of poverty and low technological advancement (Kjellstrom *et al*., 2016b; Lucas *et al*., 2014; Venugopal *et al*., 2016b).

Objectives of the study

The general objective of this present study is to assess the social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana. The specific objectives of the study are to:

1. Examine evidence of social impacts of occupational heat stress and adaptation strategies of workers for policy decisions;
2. Suggest a conceptual framework to illustrate the link between social impacts and adaptation strategies of mining workers to occupational heat stress in the context of climate change and the SDGs;
3. Use convergent mixed methods to assess and exemplify evidence of occupational heat stress impacts on mine workers in Ghana to inform policy decisions;
4. Assess the perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers among supervisory personnel and other stakeholders in Ghana;
5. Assess climate change perceptions and occupational heat stress risks and adaptation strategies of Ghanaian mining workers;
6. Assess the risk and extent of heat exposure in the working and living environments of Ghanaian miners based on the ISO 7243[1] standards;
7. Assess the barriers to occupational heat stress adaptation and social protection strategies of mining workers in Ghana; and
8. Make recommendations to improve climate change-social impacts of occupational heat stress analysis and for the planning and implementation of adaptation policy decisions.

Research questions

The fundamental research question underpinning this study is: What are the social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana? Accordingly, the following specific research questions are posed to provide relevant information required to achieve the specific objectives of the study.

1. What is the evidence of the social impacts of occupational heat stress and adaptation strategies of workers that will inform policy options?

[1] ISO 7243 is a method for assessing the heat stress to which a person is exposed, and for establishing the presence or absence of heat stress. It applies to the assessment (of indoor and outdoor occupational environments) of the effect of heat on a person during his or her total exposure over the working day (up to 8 hours).

2. To what extent are conceptual frameworks adopted to illustrate the linkage between social impacts and adaptation strategies of mining workers to occupational heat stress in the context of climate change and the SDGs?
3. To what extent are convergent mixed methods useful to assess and exemplify evidence of occupational heat stress impacts on mine workers in Ghana to inform policy decisions?
4. How do supervisory personnel and other stakeholders perceive climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana?
5. How do Ghanaian mining workers perceive climate change and occupational heat stress risks and adaptation strategies?
6. To what extent is the risk and magnitude of heat exposure in the working and living environments of Ghanaian miners exceed that of the ISO 7243 standards?
7. What are the barriers to occupational heat stress adaptation and social protection strategies of mining workers in Ghana?

Research hypotheses

Consistent with the mixed methods approach involving both qualitative and quantitative research strategies, the study sought to test the following research hypotheses:

1. There is no significant difference in social impacts of occupational heat stress on mining workers across the type of mining activity.
2. There are no significant differences in the distribution of climate change risks perceptions, occupational heat stress risks, and adaptation strategies among background characteristics of the supervisory personnel.
3. There is no significant difference in demographic and work characteristics, climate change risks perceptions, occupational heat stress risks, and adaptation strategies between the two types of mining workers (SSM and LSM).
4. There is no significant difference in the trend and variability of climate change indices (temperature, humidity and rainfall) data (1967-2017) obtained from the Ghana Meteorological Agency within the study setting in Ghana.
5. There is no significant difference in heat exposure risk factors among background characteristics of SSM and LSM workers.

6. There is no significant difference in the adaptation strategies, social protection measures and the barriers to occupational heat stress adaptation between the two types of mining workers (SSM and LSM).

Scope of the study

The study was delimited by focusing on issues of the social dimensions and impacts of climate change, occupational heat stress, and adaptation strategies of workers in the mining industry in Ghana. In Ghana, there are two classifications of mining activities, namely, formal and informal as defined by the Ghana Minerals Commission (GCM). However, this present study was conducted with recourse to mining operations in only the licensed and legal mining sectors of Ghana, because the informal mining operations sector is unlicensed and mining activities are unlawful, while formal mining activities are licensed and legally registered mining operations.

The study thus focuses on utilising the mixed methods approach based on the pragmatists' research philosophy to assess mining workers and stakeholders' perspectives of the social impacts of climate change and occupational heat stress risks and adaptation strategies of miners, and the trends and variability of climate change data (1967-2017) to provide a contemporary perspective. This study also assesses the likelihood and magnitude of heat exposure in the working and living environments of mining workers, the social impacts of occupational heat exposure, and the barriers to occupational heat stress adaptation strategies of mine workers.

Methodology

This study combines various data collection methods. In addition to a systematic review and narrative synthesis of the literature, this study utilised a convergent mixed methods strategy and involved obtaining thermal data by deploying four heat and humidity data loggers, 346 surveys (supervisors and mining workers), two focus groups (SSM and LSM workers) and three in-depth interviews (officials of Inspectorate Division of Mineral Commission [IDMC], GCM and GNASSM). The quantitative data was processed with Microsoft Excel 2016, XLSTAT 2019, and SPSS version 25 and then analysed with descriptive and inferential statistics, while the qualitative data was processed by using NVivo version 11 and analysed thematically.

Ethical considerations

The integrity of research outputs depends on whether or not the methodology employed in the conduct of the research adhered to an ethical research ethos. Human social research could result in significant risk to the participants and the researcher when the extent of human interactions, data security and maintenance is not guided by research ethics. This study was conducted by conforming to the requirements of ethical research standards. Before the commencement of this study, ethics approval was obtained from the Human Research Ethics Committee (HREC) of Edith Cowan University (ECU) (Project Number 17487) (see APPENDIX B). The ethics approval for this research project was granted from 16th August 2017 to 11th June 2019, and its progress was subjected to monitoring conditions which comprised the completion of an annual report and a final report. Both reports were duly completed and submitted to the HREC of ECU. The GMC-the regulatory authority of mining companies also gave approval (Ref.: MC.10) for the research to be conducted among mining companies in Ghana (see APPENDIX C).

Following the ethics approval and consent from the GMC, mining companies were contacted and provided with information letters and consent forms (see APPENDICES D & E), their informed consent was sought to begin recruiting participants to the study. Similarly, with the support of the human resource officers of the SSM and LSM companies and regulatory authorities, the individual participants (e.g., mining workers, supervisory personnel and the officials of the regulators on mining activities) were contacted and participants who met the inclusion criteria were recruited, after having read and signed the information letters and consent forms (see APPENDICES D & E). The recruited participants willingly agreed to participate in the study by either filling out a survey questionnaire for mining workers and supervisory personnel (see APPENDIX F) or taking part in focus group discussions for LSM and SSM workers (see APPENDIX G) or an in-depth interview for officials of GCM, IDMC and GNASSM (see APPENDIX G) at an appointed time. Before the start of each activity for data collection, the purpose and impact of the study were both explained to the participants to assure respondents of their rights to informed consent and voluntary participation, and also reiterated the researcher's willingness to ensure anonymity and confidentiality for the data being collected. During the data collection the researcher made sure that no participant was adversely affected.

While this research was being conducted in the field, in Ghana, the data collected was sealed and stored safely in a lockable cabinet in the chief researcher's house and subsequently transported to ECU in Australia for further processing and analysis. During the fieldwork, access to preliminary data was restricted to members of the research team, and electronic files were secured with a password using the researcher's personal computer and laptop. Identifiable data of participants were made de-identifiable or non-identifiable, and any data and/or codes with identifying information were stored in separate lockable filing cabinets.

Also, data collected during the research project were kept in locked facilities in the School of Arts and Humanities through which the project was being conducted. At all times, the confidentiality of data was maintained by ensuring that access to computer files was made available to named researchers only. Similarly, the anonymity of participants was ensured by concealing their identity with the use of pseudonyms. The principal researcher and the principal supervisor were responsible for maintaining the security of the data. Besides the investigators named in the application, participants were allowed access to their own interview transcripts. The process of data collection, processing and analysis, use, security and maintenance were based on the terms and conditions approved by the HREC of ECU.

The researchers have offered to provide participants with copies of any publications emanating from this study upon request. The non-identified data collected after completion of the research project will be stored in a locked filing cabinet in the School of Arts and Humanities at the ECU. The principal researcher and the principal supervisor will be responsible for maintaining the security of data for the minimum recommended retention period (5 years). After the 5 years of post-publication storage, data will be destroyed in accordance with the policies of ECU.

Schematic framework of the study

The study is organised into five sections and nine chapters as shown in Figure 1.1. SECTION I outlines the research framework, which comprises the general introduction to the study. Chapter One highlights the background, theoretical perspectives, the problem, objectives, research questions, hypotheses, scope, and structure of the study. SECTION II is devoted to the literature review and consists of Chapters Two and Three. SECTION III describes the research methodological approach, as indicated in Chapter Four of the study. SECTION IV focuses on the results of the research as shown in Chapters Five, Six, Seven and Eight while SECTION V consists of Chapter Nine, which highlights the synthesis and conclusions of the study.

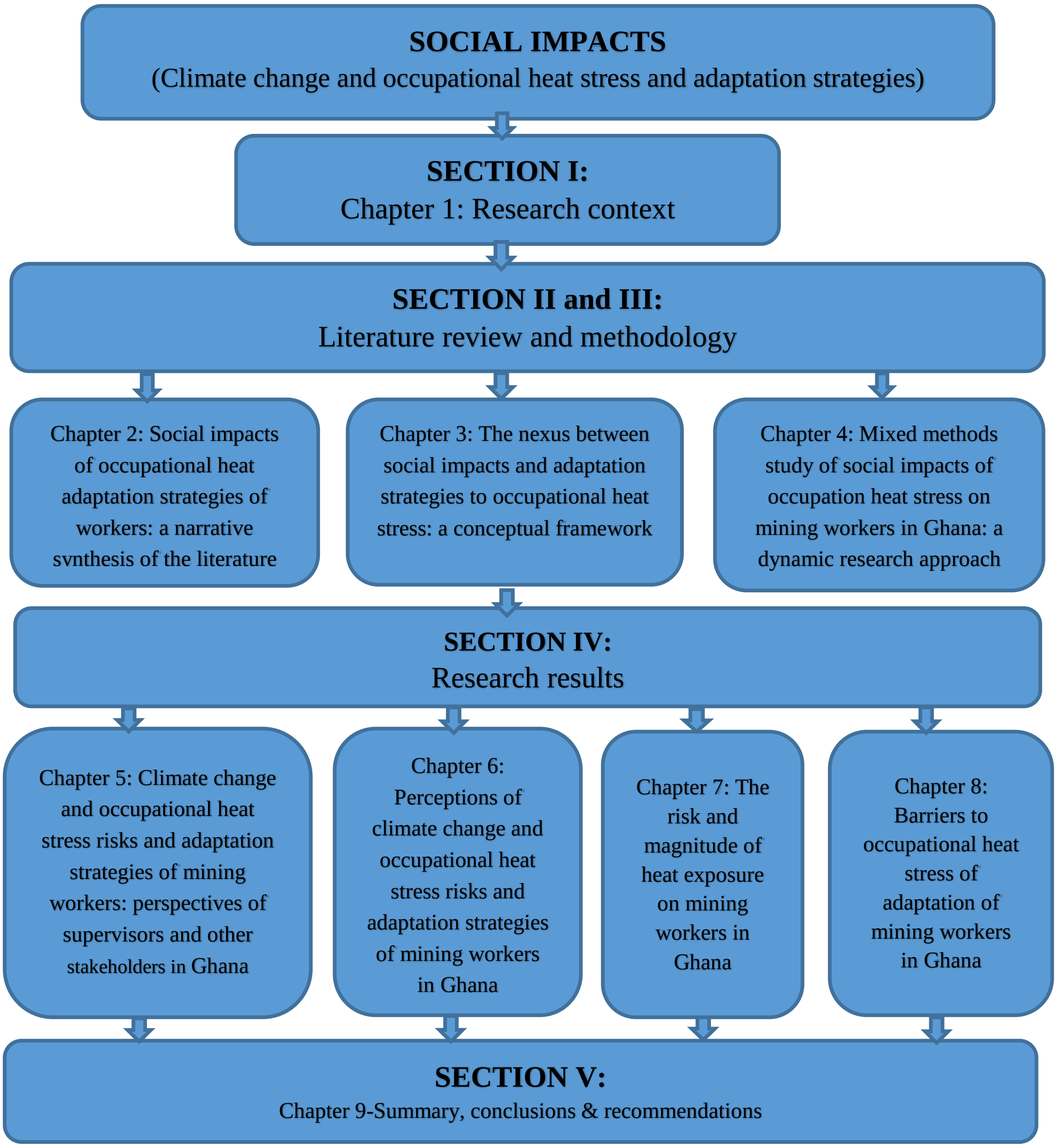


Figure 1.1: Schematic structure of the study

SECTION II: LITERATURE REVIEW

Overview

SECTION II provides details of literature review which is described in Chapters Two and Three. Chapter Two is a systematic review and narrative synthesis of the literature on social impacts of occupational heat stress and adaptation strategies of workers while chapter three is a conceptual framework, which shows the linkage between social impacts and adaptation strategies of workers to occupational heat stress.

The informaton exemplified in chapter two emanated from a systematic review and narrative synthesis of 25 peer-review studies (2007-2017) based on the philosophy of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) and the Joanna Briggs Institute (JBI) framework. The review centred on social impacts of occupation heat stress and adaptation strategies of workers and the process yielded three syntheses, namely, (1) workers' awareness of occupational heat stress; (2) social impacts of occupational heat stress; and (3) adaptation to occupational heat stress. The research output of chapter two is a peer-reviewed article published online in the Science of the Total Environment on July 4, 2018. There are no material changes between this chapter and the published paper except for few changes in the layout to maintain consistency throughout the thesis.

The research results of chapter three arose from a systematic review and synthesis of the literature with the focus on developing a conceptual framework illustrating the nexus between social impacts and adaptation strategies of workers to occupational heat stress. The review resulted in three syntheses, namely, (1) work-related heat risk; (2) social impacts due to work-related heat stress risk; and (3) work-related heat stress adaptation. The synthesis served as the basis to offer a framework which established a linkage between social dimensions and impacts and adaptation strategies to occupational heat stress and the SDGs. The research output of this chapter was also published online as a peer-reviewed article in the International Journal of Biometeorology on August 5, 2019. No specific changes have been made to this chapter that is different from the published paper aside from the changes in the layout to ensure consistency throughout the thesis.

CHAPTER TWO: SOCIAL IMPACTS OF OCCUPATIONAL HEAT STRESS AND ADAPTATION STRATEGIES OF WORKERS: A NARRATIVE SYNTHESIS OF THE LITERATURE

Abstract

Dimensions of risks and impacts of occupational heat stress due to climate change on workers' health and safety, productivity, and social well-being are significantly deleterious. Aside from empirical evidence, no systematic review exists for policy development and decision making in managing occupation heat stress impacts and adaptation strategies of workers. This study sought to synthesise evidence on the social impacts of occupational heat stress and adaptation strategies of workers. From a review of existing literature, eight categories were obtained from 25 studies and grouped into three syntheses: (1) awareness of occupational heat stress, (2) social impacts of occupational heat stress and (3) workers' adaptation to occupational heat stress due to changing climate. Awareness of occupational heat stress among workers varied and their social impacts were related to workers' health and safety, productivity and social well-being. Sustainable adaptation to occupation heat stress due to climate change hinges on financial resource availability. Adequate investment and research are required to develop and implement policies to combat the threat of rising temperature and climate change to enhance workers' adaptive capacity, boost resilience and foster sustainable development.

Keywords: Adaptation policies, literature review, work-related heat stress, social well-being, synthesis, workers

Introduction

Excessive heat exposure due to intensifying temperature and climate change has emerged as one of the existential threats to humanity and the socio-economic, health, and environmental well-being of working populations (United Nations [UN], 2009). Hence, the global agenda for improving the well-being of people, as embodied in the 2030 Sustainable Development Goals (SDGs), reiterates the need for combating rising temperature and climate change impacts (SDG 13) (UN, 2015).

Intensive physical work in an environment of high heat exposure due to the temperature rising beyond 37 ^{o}C and inadequate rehydration creates heat stress-related morbidity and mortality (CDCP, 2008; Lucas *et al*., 2014; Parsons, 2014). Workers in the construction, agriculture, firefighting, armed forces, manufacturing, oil and gas, and mining industries are examples of workers at risk of adverse impacts related to heat stress (Lucas *et al*., 2014; Xiang *et al*., 2014). Climate change and occupational heat stress risks and impacts on working people prone to heat exposure include, but are not limited to, physiological, psychological, health and safety, socio-economic and productivity consequences (Dunne *et al*., 2013; Kjellstrom *et al*., 2016a; Lucas *et al*., 2014; Xiang *et al*., 2016). Climate change-related occupational heat stress is a condition in which heat stress is induced by intensive physical work, rising temperature and climate change or is being exacerbated by intensive physical work, rising temperature and climate change (Kjellstrom *et al*., 2016a).

Climate change, occupational heat stress risks and associated impacts have engendered multidisciplinary research, cooperation, frameworks and protocols to combat its consequences for the world's population. Prior studies focusing on impact assessment of climate change, heat stress and adaptation have neglected social impact assessment (SIA) and focused mainly on environmental impact assessment (EIA) and health impact assessment (HIA) of climate change and heat stress on working people. Social impacts refer to the direct or indirect perceptual or physical effect of a phenomenon (e.g., policies, projects, natural and social risk) on the lives, culture, cohesion, political system, environment, health and well-being, rights, and fears of individuals, social units, and communities (Vanclay, 2003; Vanclay *et al*., 2015). SIA as conceptualised by Vanclay *et al*. (2015) focuses on resource and capital projects, a practice that Adusei-Asante (2017) has criticised. Current thinking in SIA is calling for the need to focus on policies and phenomena such as climate change and work-related heat stress to augment global efforts at combating rising temperature and climate change threats (Adusei-Asante, 2017; Kalkstein *et al*., 2009; Miller, 2014; Scheffran & Remling, 2013; UN, 2011).

Except for a few studies such as Miller (2014) and Venugopal et al. (2016a), there seems to be no specific empirical studies, systematic review or synthesis that have assessed the social impacts of occupational heat stress and adaptation strategies of workers. Accessible systematic reviews have tended to focus on adaptation to heat-related mortality and illness, and heat-related mortality and climate change other than on social impacts of climate change, occupational heat stress and adaptation strategies of workers (Boeckmann & Rohn, 2014; Huang *et al*., 2011). Considering the importance of systematic reviews to evidence-based policy making, there is a need for this review to collate findings from available published and unpublished studies.

Given the socio-economic and health implications of climate change and occupational heat stress, it is appropriate and timely to conduct this review to update and expand the literature on the risks and impacts of occupational heat stress due to climate change on workers' health and safety, productivity, and social well-being. It will also inform occupational heat stress adaptation and resilience planning and policies, the ongoing rising temperature and climate change-social impact discourse and future research needs. This review examines available evidence on social impacts of occupational heat stress driven by climate change and adaptation strategies of workers with emphasis on the research design and methodology, study setting, and significant findings based on three research questions: (1) What are workers' perceptions and experiences of occupational heat stress (RQ1)? (2) What are the effects of occupational heat stress on workers' health and safety, productivity, psychological behaviour, and social well-being (RQ2)? (3) What are the adaptation strategies of workers to occupational heat stress (RQ3)?

Materials and methods

This review was guided by the philosophy of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) and the Joanna Briggs Institute (JBI) framework for systematic review, synthesis, and reporting (JBI, 2014; Moher *et al*., 2015; Popay *et al*., 2006). A systematic review and synthesis of the literature were adopted in this study because it is scientific and provides the basis for describing the patterns, similarities and differences among the results of the included studies based on well-defined selection criteria (JBI, 2014; Petticrew & Roberts, 2008; Popay *et al*., 2006). The mixed-methods approach was employed to provide answers to enhance understanding of the research questions. The use of the textual approach to narrative synthesis was informed by the heterogeneous nature of findings from multiple studies on risks and impacts of occupational heat stress and adaptation strategies of workers in the context of rising temperature and climate change. Synthesising empirical qualitative and quantitative evidence is warranted because there is a mutual interest in aggregating empirical studies (Dixon-Woods *et al*., 2005; Noblit & Hare, 1988). Moreover, mixed method studies are amenable to the narrative method of synthesis and the most suitable in systematic reviews in which the studies were not exactly similar to warrant meta-analysis (Mays *et al*., 2005). Narrative synthesis allows the combination of various types of evidence from multiple studies of different nature to answer a range of different research questions (Gough et al., 2017; Petticrew & Roberts, 2008).

The concept of Population, Intervention, Comparator Context Outcome (PICO) informed the scoping of the review (Cooke *et al*., 2012). The scope covered: workers of both sexes above 18 years; workers' perceptions and experiences of occupational heat stress and adaptation strategies; effects of occupational heat stress on workers' health and safety, productivity, psychological behaviour, and social well-being based on a series of inclusion and exclusion criteria (Table 2.1).

Table 2.1: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Studies using quantitative, qualitative and mixed-method approaches	Comments, letters, editorials, viewpoints, reviews, reports, and correspondence
Peer-reviewed journal publications of original studies in English	Studies published in other languages except for English
Studies on workers' perceptions and experiences of occupational heat stress, and adaptation strategies	Studies on climate change-related storms, rainfall, drought, cyclones, and rising sea levels other than climate change-related temperature, humidity, air movement, and heat radiation
Studies measuring ambient temperature at work and resting environment of workers	Studies unrelated to objectives, population, intervention/exposure, outcome, and context of the study
Studies assessing the effect of occupational heat stress on workers' health and safety, productivity, psychological behaviour, and social well-being	Studies on the effect of climate change and heat stress on people, communities, plants, animals, and crops, other than workers' health and safety, productivity, psychological behaviour, and social well-being
Studies on barriers of workers to occupational heat stress adaptation	Studies using only secondary data without primary data
Studies in the local and international context	Studies on mitigation to climate change and occupational heat stress

Source: Authors

Search criteria

The authors conducted a systematic search of Web of Science, PubMed, Science Direct, Google Scholar, ProQuest, Taylor and Francis Online, and the reference lists of included studies for evidence of peer-reviewed published studies in English from 2007 to 2017 to provide a contemporary outlook. 'Assessment', 'perceptions', 'experiences', 'social impact', 'climate change', 'occupational heat stress', 'health and safety', 'productivity', 'psychological behaviour', 'social well-being', 'adaptation strategies', and 'workers' were search terms used as part of the search strategy. The assessment process was guided by the JBI critical appraisal checklist for systematic reviews and research syntheses (Supplemental Table 1) (JBI, 2014). Five researchers independently assessed the quality of included studies and any differences resolved through consensus. The search process yielded 25 studies based on the selection criteria out of 23,352 studies identified (Figure 2.1).

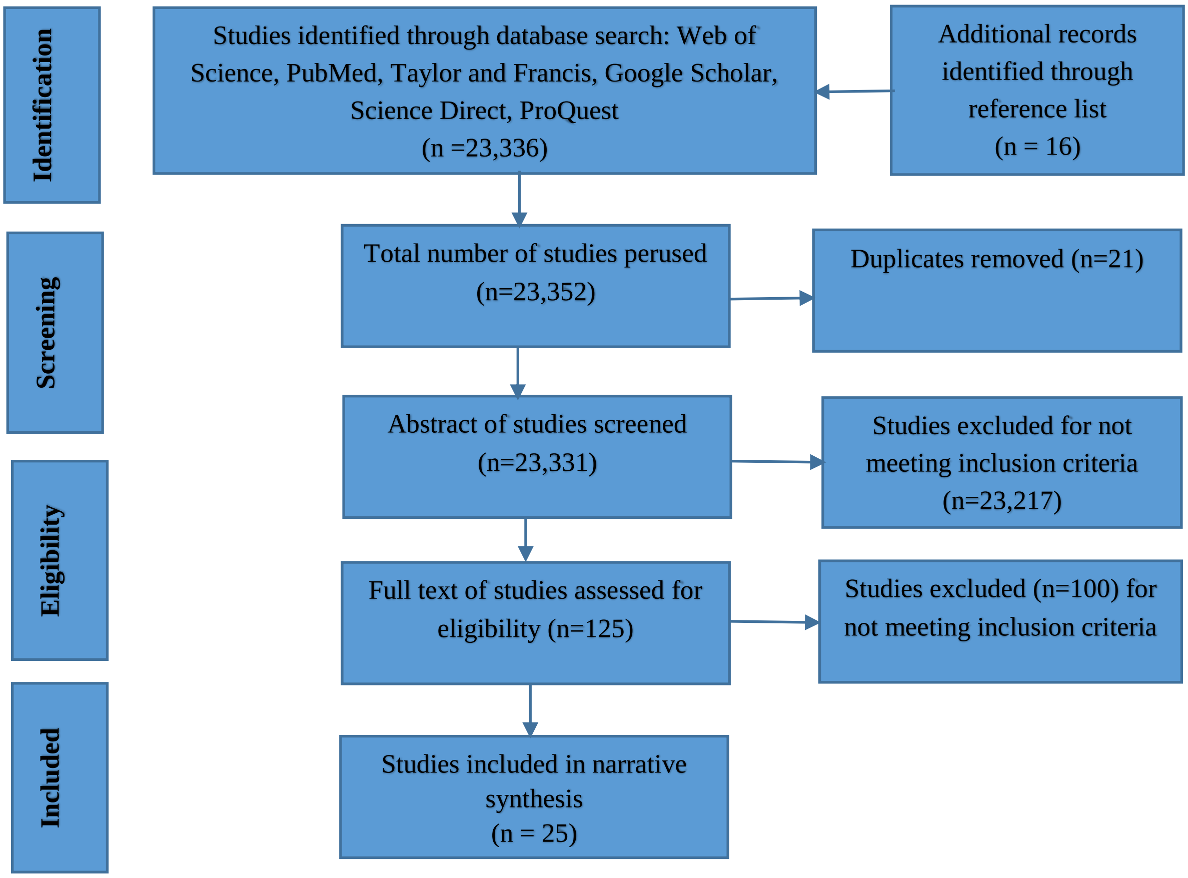


Figure 2.1: Flowchart illustrating a summary of included studies

Characteristics of included studies

Descriptive characteristics of included studies were illustrated by the name of the author(s), year of publication, study location, study design, population and sample size, methods, data analysis, and conclusions. The studies were organised according to the research questions and methodology. Some studies addressed either one or a combination of two or three research questions. Tables 2.2 to 2.6 provide an overview of the 25 included studies. Of the 25 studies, five addressed Research Question 1 (RQ1), eight answered RQ2, four focused on RQ1 and RQ2, seven addressed RQ1 and RQ3, while one centred on RQ1, RQ2, and RQ3. However, 17 studies were on issues related to RQ1 (Tables 2.4, 2.5 & 2.6), 13 studies were associated with RQ2 (Tables 2.3, 2.4 & 2.6), and eight studies focused on issues based on RQ3 (Tables 2.5 & 2.6).

Table 2.2: Details of papers addressing workers' perceptions and experiences of occupational heat stress

Author, year & title	Study location	Study design	Population/ sample size	Methods	Data analysis	Author(s)' conclusions
Balakrishnan *et al*. (2010). Case studies on heat stress related perceptions in different industrial sectors in southern India	India	Case study	242 manufacturing workers	Questionnaires and Wet Bulb Globe Temperature (WBGT) index	Correlation analysis	Given the potential implications of future climate change-related increases in ambient heat stress that are likely to translate into workplace exposures in developing country settings
Crowe *et al*. (2013). Heat exposure in Sugarcane harvesters in Costa Rica	Costa Rica	Descriptive study design	105 harvesters	WBGT and non-participatory observation	Descriptive analysis using WBGT data, metabolic rate and Threshold limit values	Sugarcane harvesters are at risk of heat stress for the majority of the work shift. Immediate action is warranted to reduce such exposures
Flocks *et al*. (2013). Female Farmworkers' Perceptions of Heat-Related Illness and Pregnancy Health	Central Florida	CBR approach using narrative interviews	35 female farmworkers	Focus group discussion	Thematic analysis	Participants believe that heat exposure can adversely affect general, pregnancy, and fetal health, yet feel they lack control over workplace conditions and that they lack training about these specific risks
Crowe *et al*. (2010). Heat exposure in sugarcane workers in Costa Rica during the non-harvest season	Costa Rica	Exploratory observational study	45 sugarcane workers	WBGT	Descriptive analysis	It is therefore important to take action to decrease current and future heat-related risks for sugarcane workers in both harvest and non-harvest conditions and in all sugarcane growing regions in Costa Rica. It is also necessary to improve guidelines and occupational health standards for protecting worker health and productivity in the tropics
Stoecklin-Marios *et al*. (2013). Heat-related illness knowledge and practices among California hired farm workers in The MICASA study	California	Comparative study design	467 hired farm workers	structured interviews questions	Statistical analysis using multivariate survey logistic regression	The study suggests important areas to target for heat illness prevention in farmworker population, and that gender-specific approaches may be needed for effective heat illness

Table 2.3: Details of papers addressing effects of occupational heat stress on workers' health and safety, psychological behaviour, productivity and social well-being

Author, year & title	Study location	Study design	Population/ sample size	Methods	Data analysis	Author(s)' conclusions
Tawatsupa *et al*. (2013). Association between heat stress and occupational injury among Thai worker: Findings of the Thai cohort studies	Thailand	Cohort studies	58495 workers	Mail out health questionnaires	Logistic regression using STATA version 12	The study provides useful evidence linking heat stress to occupational injury in tropical Thailand and identifies factors that increase heat exposure
Tawatsupa *et al*. (2012). Association between occupational heat stress and kidney disease among 37816 workers in the Thai cohort studies (TCS)	Thailand	Cohort studies	37816 workers	Self-reported questionnaires	Logistic regression	There is an association between self- reported occupational heat stress and the self-reported doctor diagnosed kidney disease in Thailand. There is a need for occupational health interventions for heat stress among workers in tropical climates
Sett and Sahu (2014). Effects of occupational heat exposure on female brick workers in West Bengal, India	India	Evaluative study design	120 brick moulders and carriers	WBGT and questionnaires	Statistical analysis using t-test and ANOVA	High heat exposure in brickfields during summer caused physiological strain in both categories of female brickfield workers
Luo *et al*. (2014).Exposure to ambient heat and urolithiasis among outdoor workers in Guangzhou, China	China	Correlational Case-control study design	190 cases and 760 control shipbuilding workers	2003–2010 health check data	Conditional logistic regression	Significant association between exposure to ambient heat and urolithiasis among outdoor working populations

Langkulsen *et al*. (2010). Health impact of climate change on occupational health and productivity in Thailand	Thailand	Descriptive cross-sectional study	21 workers	WBGT and questionnaires	Descriptive and trend analysis	Climate conditions in Thailand potentially affect both the health and productivity in occupational settings
Sahu *et al*. (2013). Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: Implications for a climate change future	India	Comparative study design	124 rice harvesters	WBGT and an interviewer-administered questionnaire	Trend and Statistical analysis using a t-test	High heat exposure in agriculture caused heat strain and reduced work productivity. This reduction will be exacerbated by climate change and may undermine the local economy
Krishnamauthy *et al*. (2017). Occupational Heat Stress Impacts on Health and Productivity in a Steel Industry in Southern India	South India	Cross-sectional study design	84 steel worker	WBGT and structured questionnaires	Statistical analysis	High heat exposures and heavy workload adversely affect the workers' health and reduce their work capacities. Health and productivity risks in developing tropical country work settings can be aggravated by temperature rise due to climate change, without appropriate interventions
Tawatsupa *et al*. (2010). The association between overall health, psychological distress, and occupational heat stress among a large national cohort of 40,913 Thai workers	Thailand	Cohort studies	40913 workers	Self-reported questionnaires	Descriptive statistical analysis	This association between occupational heat stress and worse health needs more public health attention and further development of occupational health interventions as climate change increases Thailand's temperatures

Table 2.4: Details of papers addressing workers' perceptions and experiences of occupational heat stress risk and effects of occupational heat stress on workers' health and safety, psychological behaviour, productivity and social well-being

Author, year & title	Study location	Study design	Population/ sample size	Methods	Data analysis	Author(s)' conclusions
Delgado-Cortez (2009). Heat stress assessment among workers in a Nicaraguan sugarcane farm	Nicaragua		22 sugarcane workers	data loggers and data collection sheet	Descriptive statistics and Chi-square analysis	Productivity improved with the new rehydration measures. Awareness among workers concerning heat stress prevention was increased
Venugopal *et al*. (2016b). Occupational heat stress profiles in selected workplaces in India	India	Experimental study design	442 workers	WBGT and questionnaires	Statistical analysis using Z-test a chi-square for bivariate	Reducing workplace heat stress benefits industries and workers via improving worker health and productivity. Adaptation and mitigation measures to tackle heat stress are imperative to protect the present and future workforce as climate change progresses
Dutta *et al*. (2015). Perceived heat stress and health effects on construction workers	Gandhinagar-Western India	A cross-sectional survey using mixed method approach	219 construction workers	WBGT, focus group discussion and survey questionnaires	Thematic analysis using grounded theory approach for qualitative data and descriptive statistical analysis and trend analysis	This study suggests significant health impacts on construction workers from heat stress exposure in the workplace, showed that heat stress levels were higher than those prescribed by international standards and highlights the need for revision of work practices increased protective measures, and possible development of indigenous work safety standards for heat exposure.

Venugopal *et al*. (2016a). The social implications of occupational heat stress on migrant workers engaged in public construction: a case study from Southern India	India	Both quantitative and qualitative studies	142 migrant workers	WBGT and questionnaires	Quantitative and qualitative analysis	In an increasingly warmer global climate and with increasing construction demand, stronger policies to prevent morbidity/mortality among vulnerable migrant workers in the construction sector is imperative. Better health, literacy rates, and decreased crime statistics among migrant community are potential positive implications of protective policies

Table 2.5: Details of papers addressing workers' perceptions and experiences of occupational heat stress risk and adaptation strategies

Author, year & title	Study location	Study design	Population/ sample size	Methods	Data analysis	Authors' conclusion
Pradhan *et al*., (2013).Assessing climate change and heat stress response in the Tarai Region of Nepal	Nepal	Case Study household survey	120 household factory workers	Data loggers, questionnaire and observation checklist	Comparative analysis of quantitative data	More quantitative measurement of workers' health effect and productivity loss will be of interest for future work
Xiang *et al*. (2015). Perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialists in Australia	Australia	Cross-sectional research design	180 occupational hygienists	Questionnaire	Descriptive analysis using STATA and Excel	The findings suggest a need to refine occupational heat management and prevention strategies

Fleischer *et al*. (2013). Public health impact of heat-related illness among migrant farmworkers	Georgia	cross-sectional survey research design	405 farmworkers	in-person interview	Statistical analysis using logistic regression	Migrant farmworkers experienced high levels of HRI symptoms and faced substantial barriers to preventing. Heat-Related Illness may be reduced through appropriate training of workers on HRI prevention, as well as regular breaks in shaded areas these symptoms
Mirabelli *et al*. (2010). Symptoms of heat illness among Latino farm workers in North Carolina	Carolina	Cross-sectional study	300 farm workers	Interviewer-administered questionnaires	Descriptive statistical analysis using log-binomial regression	These findings suggest the need to improve the understanding of working conditions for farm workers and to assess strategies to reduce agricultural workers' environmental heat exposure
Ayyappan *et al*. (2009).Work-related heat stress concerns in automotive industries: a case study from Chennai, India	India	Quantitative research design		WBGT	Descriptive statistical analysis	The study re-emphasises the need for recognising heat stress as an important occupational health risk in both formal and informal sectors in India. Making available good baseline data is critical for estimating future impacts
Xiang *et al*. (2016).Workers' perceptions of climate change related extreme heat exposure in South Australia: a cross-sectional survey	Australia	Cross-sectional research study	479 workers	Questionnaire survey	Bivariate and multivariate analysis	Need to strengthen workers' heat risk awareness and refine current heat prevention strategies in a warming climate. Heat education and training should focus on those undertaking physically demanding work outdoors, in particular, young and older workers with low education

Lao *et al*. (2016). Working smart: An exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia	Australia	A qualitative case study design	32 council male workers	focus groups	Thematic analysis and Interpretative Phenomenological Analysis	The results showed the importance of workplace management and training, and an understanding of the need for workers to be able to self-pace during hot weather

Table 2.6: Details of paper simultaneously addressing workers' perceptions and experiences of occupational heat stress risk, effects of occupational heat stress on workers' health and safety, behaviour, productivity and social well-being and adaptation strategies

Author, year & title	Study location	Study design	Population/ sample size	Methods	Data analysis	Authors' conclusion
Mathee *et al*. (2010). Climate change impacts on working people (the HOTHAPS initiative): findings of the South African pilot study	South Africa	Grounded theory	151 workers	Focus group discussion and interviews	STATA for quantitative data analysis and thematic analysis for qualitative data	People working in sun-exposed conditions in hot parts of South Africa currently experience heat-related health effect, with implications for their well-being and ability to work and that further research is warranted

Regarding research methodology, 19 out of the 25 selected studies used quantitative techniques, three employed qualitative techniques, and three studies applied the mixed methods approach. The quantitative studies used descriptive, cross-sectional, cohorts, comparative, evaluative, correlational, and experimental research designs. They also applied descriptive statistics, trend analysis, bivariate logistical regression, and multivariate logistical regression as methods of data analysis. The qualitative studies used narrative, exploratory observation, and case study research designs while thematic and interpretive phenomenology were used as the techniques of data analysis. Cross-sectional survey, quantitative, qualitative, and grounded theory research designs as well as a combination of STATA, thematic analysis, descriptive, trend, qualitative, and quantitative analysis were used in the mixed method studies as methods of data analysis.

Geographically, the study locations of the 25 articles, varied widely across countries from the continental regions of Asia, Africa, North America, and Central America. Out of the included studies, 14 articles were from India, Thailand, China and Nepal in Asia (56%), four studies were from the States of Florida, California, Georgia, and Carolina in North America (12%), three papers were from Costa Rica and Nicaragua in Central America (16%), three studies from Australia (12%), and one from South Africa (4%) (Figure 2.2). These are tropical and sub-tropical regions with moderate to high risk of heat exposure (Hyatt *et al*., 2010; Lucas *et al*., 2014). Based on the selection criteria, it appears no primary studies, other than reports and reviews, focusing on occupational heat stress was found from Europe. This may be due to its low risk of heat exposure, adequate adaptation capacity, and technological advancement. However, there have been occasions of injuries and deaths related to heat waves in Europe. For instance, in 2003 excess mortality of 30,000 deaths occurred in France as part of the more than 70,000 deaths during the extreme heat wave event in Europe (Robine *et al*., 2008). An analysis of the period of publication of the included studies showed that seven articles were published between 2007 and 2011, while 18 studies were published from 2012 to 2017. This indicates an increasing trend of interest by researchers on issues related to occupational heat stress due to climate change and adaptation in the last decade.

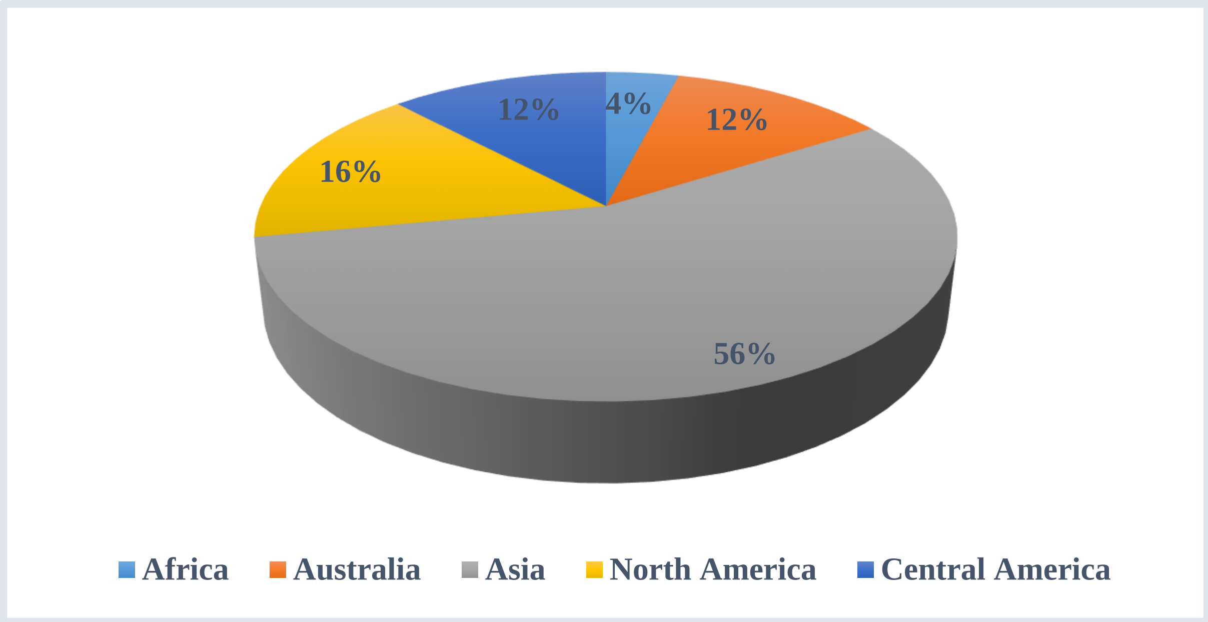


Figure 2.2: Continental location of included studies

Abstraction of findings from included studies

The findings of each study were used as the basis for data extraction for categorisation and narrative synthesis using tables and figures where appropriate (JBI, 2014; Popay *et al*., 2006). The value of extracted data of included studies was determined by using JBI's interpretation of degree of evidence (Supplemental Table 2) (JBI, 2014). Abstraction of data from the 25 included studies (Supplemental-Tables 3 to 27) were presented according to their findings, an illustration of evidence and degree of evidence.

Results

Narrative synthesis and categorisation of findings from included studies

The results of the data abstraction process yielded 121 findings which were grouped into eight categories and then synthesised into three themes based on observed emerging patterns, similarities and differences. The findings were categorised as: perceptions of occupational heat stress risk; experiences of occupational heat stress risk; magnitude of heat exposure risk; health and safety effects of occupational heat stress; productivity effects of occupational heat stress; social well-being effects of occupational heat stress; adaptation strategies to occupational heat stress; and barriers to implementation of occupational heat stress adaptation. The eight categories were then synthesised into three themes: (1) workers' awareness of occupational heat stress; (2) social impacts of occupational heat stress; and (3) adaptation to occupational heat stress.

Synthesis One: Workers' awareness of occupational heat stress

Workers' awareness of occupational heat stress constitutes Synthesis One. It is the result of aggregating three categories with similar attributes of describing workers' awareness of occupational heat stress (Figure 2.3).

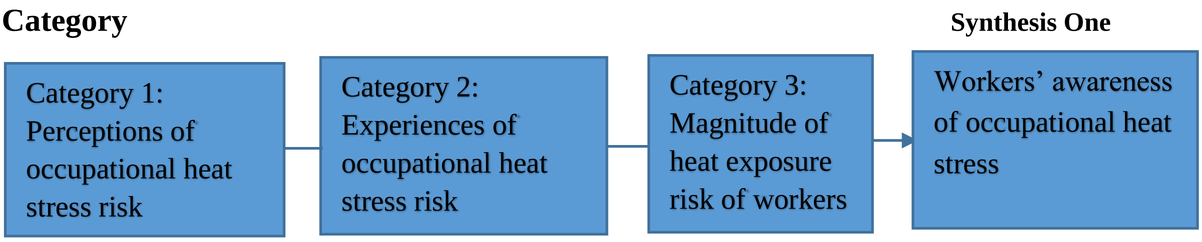


Figure 2.3: Synthesis One: Workers' awareness of occupational heat stress

Category One describes workers varied perceptions of occupational heat stress risk. Thirteen findings were grouped into Category One. Findings from category one indicated that although workers' awareness of trends of weather patterns varied widely, occupational heat stress risk is perceived as a seasonal condition associated with symptoms (e.g., dehydration, skin rashes, and itchy skin) (Balakrishnan *et a*l., 2010), and occupational heat stress risk is recognised as an issue of serious concern in summer (Venugopal *et al*., 2016b). Also, heat stress is perceived by workers to affect productivity and ability to work due to dehydration, lack of insulation (deficiency in reducing heat loss or gain), and inadequate ventilation (Balakrishnan *et al*., 2010), workers' perceptions of heat stress concerns was moderate to severe and was related to age and work that require heavy physical efforts (Xiang *et al*., 2016). Similarly, management is conscious of heat stress risk as evident in the routine assessment and monitoring, management knowledge of heat stress risk is on account of several heat-related worker incidents during summer month, and workers' perceived provision of water, electrolytes, and fans as ways of controlling heat stress (Balakrishnan *et al*., 2010) (Supplemental Fig. 1).

Category Two describes workers' experiences of occupational heat stress. The review yielded 16 findings in this category. For example, studies reported experiences of heat stress conditions (e.g., fainting, tension, and irritation, nausea, hot and dry skin, cramps, and confusion) among workers (Fleischer *et al*., 2013; Pradhan *et al*., 2013). Furthermore, widely prevalent heat-related issues among workers were fatigue and sweating excessively (Krishnamurthy *et al*., 2017). Experiences of occupational heat stress were also reported in other studies as heat stress resulted in various occupational injuries (Tawatsupa *et al*., 2013).

Heat stress conditions were common among males, labourers, low income and low education workers (Tawatsupa *et al.*, 2010). Workers' experiences of heat-related health effects were headaches, dehydration, and heat stroke (Lao *et al.*, 2016). Heat-related training was received by almost half of the workers, and workers within ages of 25 and 54 years with experiences of heat-related illness or injury had a positive attitude towards heat-related training (Xiang *et al.*, 2016) (Supplemental Fig. 2).

Category Three relates to the magnitude of heat exposure risk of workers. This category resulted from aggregation of 33 findings. Findings on the magnitude of heat exposure risks were identified as being higher during peak hot months, when the average temperature reached over 39 ^{o}C and when environmental conditions in selected factories were too hot for continuous work in summer months (Pradhan *et al.*, 2013). Heat stress exposure values at most locations of industrial units exceeded recommended levels (Tawatsupa *et al.*, 2012), and values of Wet Bulb Globe Temperature (WBGT) increased sharply in most mornings at about 7:00 am to 12:00 noon (Crowe *et al.*, 2013). Similarly, working conditions of four out of five study sites were within the likelihood of 'extreme caution' or 'danger' of heat stress conditions (Langkulsen *et al.*, 2010). Furthermore, workers' exposure to heat levels of WBGT per hour were 26-32 ^{o}C and air temperatures (30-38 ^{o}C), exceeding international standards (Sahu *et al.*, 2013), with WBGT values (90%) also exceeding recommended threshold values (27.0 ^{o}C - 41.7 ^{o}C) for heavy and moderate workloads (Krishnamurthy *et al.*, 2017). Also, workers' exposure to heat stress settings was above approved American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs) for heavy workloads (Venugopal *et al.*, 2016a). Factors with the potential of affecting workers' level of heat exposure included personal protective equipment (PPE), relative humidity, access to cold water and shade, type of work, and location of work (Lao *et al.*, 2016) (Supplemental Fig. 3).

Synthesis Two: Social impacts of occupational heat stress

Social impacts of occupational heat stress due to climate change constitute Synthesis Two. It is the outcome of combining Categories Four, Five, and Six (Figure 2.4).

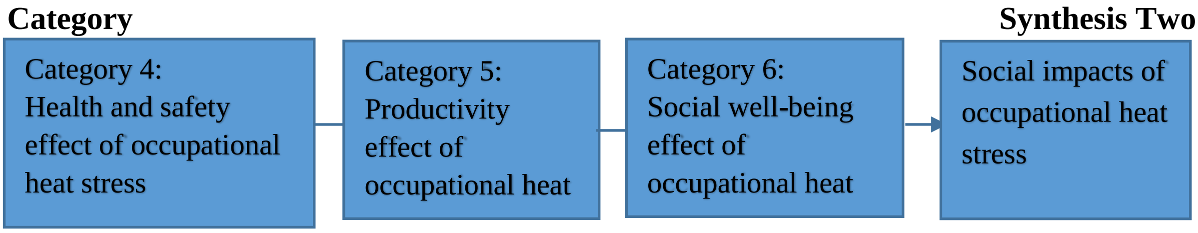


Figure 2.4: Synthesis Two: Social impacts of occupational heat stress

The remaining categories (4, 5 & 6) emanated from aggregating 37 findings of included studies. Category Four centred on the mixture of 25 findings related to the health and safety effects of occupational heat stress on workers. Some findings of studies in category four included the following: occupational injury risks decrease with age for both sexes, but increases with lower income, physical workload, sleeping fewer hours, existing disease and fast work pace (Tawatsupa *et al*., 2013). Also, heat stress-related occupational injury was worse for males, younger aged workers with lower income and physical jobs, and occupational injury effect was experienced by more males and females exposed to heat stress than those unexposed (Tawatsupa *et al*., 2013). The associated effect of heat stress on the incidence of kidney disease for men with experience of heat exposure is significant (Tawatsupa *et al*., 2012). Similarly, workers' reported adverse health impact of heat stress (e.g., excessive sweating, nausea, prickly heat, infection, headaches, dehydration, increased thirst, tiredness, itchy skin, burning eyes, backache, leg pains, and nose bleeds). These were attributed to climate-related hot and dry conditions (Crowe *et al*., 2013; Flocks *et al*., 2013; Venugopal *et al*., 2016a; Ayyappan *et al*., 2009) (Supplemental Fig. 4).

Category Five describes the productivity effects of occupational heat stress on workers. Eleven findings were grouped to form category five. Examples of findings in this category were that supervisors perceive work as strenuous and tiring in hot environment resulting in reduced productivity and optimal performance (Mathee *et al*., 2010), productivity losses were in the range of 10 to 60 percent of the construction and pottery workers (Langkulsen *et al*., 2010), farm workers' productivity increased with improved hydration (Delgado-Cortez, 2009). Workers exposed to direct heat reported significant production losses as compared to workers exposed to indirect heat (χ^2 = 26.13, df= 1, p = 0.001) (Krishnamurthy *et al*., 2017). Furthermore, heat stress impact on productivity losses was stated by 69 percent of workers as inability to finish task on time, absenteeism and wage loss due to illness (Venugopal *et al*., 2016a), and workers perceive heat to impede work efficiency, slow work pace and affect productivity (Lao *et al*., 2016) (Supplemental Fig. 5).

Effects of occupational heat stress on social well-being is the sixth and last category of Synthesis Two. The findings in category six showed that heat stress impact on workers' social lives was limited time for family care, household chores, and family disagreement due to fatigue, physical violence and interpersonal issues (Venugopal *et al*., 2016a) (Supplemental Fig. 6).

Synthesis Three: Adaptation to occupational heat stress due to climate change

Adaptation to occupational heat stress is the focus of Synthesis Three and was derived from the aggregation of 22 findings into Category Seven and Eight (Figure 2.5).

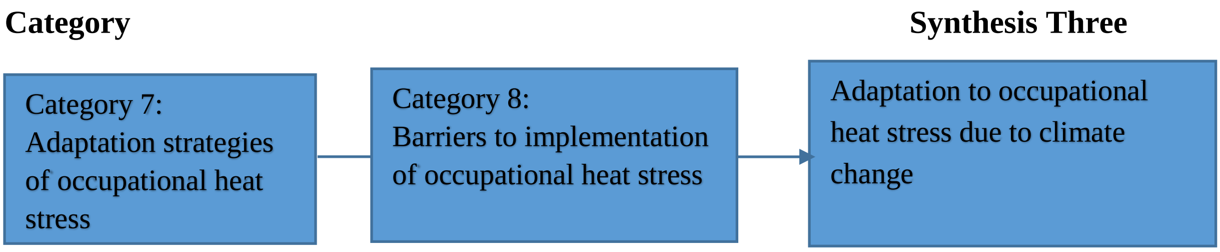


Figure 2.5: Synthesis Three: Adaptation to occupational heat stress as a result of climate change

Category Seven covers workers' adaptation strategies to occupational heat stress. It is derived from the aggregation of 18 findings. This is exemplified by analogous findings such as workers adapted coping measures such as fan, a shift in working time, wearing thin clothes and drinking water (Pradhan *et al.*, 2013). Also, workers' recognised heat protection strategies as drinking enough water, taking breaks, working at sites with less sun exposure, wearing a wide-brimmed hat, and use of fan and sunblock (Flocks *et al.*, 2013) (Supplemental Fig. 7). Heat adaptation measures were also identified as access to drinking water, heat stress training, rescheduling work time, provision of a central cooling system, electric fans use, and cease work in extreme heat (Xiang *et al.*, 2015). The provision of hydration breaks, improving ventilation and installing air cooling devices were the range of approved improvements in heat stress exposure locations (Ayyappan *et al.*, 2009). Also, personal coping strategies to heat exposure were self-pacing, wearing sun protective gear, drinking water, taking breaks, slowing down, work self-efficacy and modifying work practices, and the policy at helping workers to cope with heat exposure include provision of water, air-conditioned vehicles and PPEs (Lao *et al.*, 2016).

Finally, Category Eight consists of four findings combined to describe the barriers to implementation of occupational heat stress adaptation. Findings that typify category eight were identified as inadequate coping measures against heat stress due to poor housing designs (Pradhan *et al.*, 2013) and insufficient resources for protecting workers from heat stress (Dutta *et al.*, 2015). It also includes lack of awareness, lack of management commitment, lack of training, lack of financial resources, low compliance, and lack of heat-related guidelines (Xiang *et al.*, 2015). Similar barriers to heat illness prevention at work were a lack of prevention training, no regular breaks, no access to shade or medical attention (Fleischer *et al.*, 2013) (Supplemental Fig. 8).

Discussion

This study is the first and most recent systematic review and narrative synthesis examining the social impacts of occupational heat stress and adaptation strategies of workers in the face of rising temperature and climate change. The process culminated in aggregating 121 findings into eight categories and three syntheses based on patterns of significant similarities and differences. It was guided by the need to find evidence-based answers to three review questions related to workers' perceptions, social impacts, and adaptation strategies to occupational heat stress.

Workers' awareness of occupational heat stress

Evidence-based understanding of how workers perceive and experience heat stress risks based on the magnitude of workplace heat exposure may be useful in improving heat exposure risks management and occupation health and safety policies in the context of rising temperature and climate change. In this review, clear but varied awareness of heat stress, experiences of heat stress, and high magnitudes of heat exposure risks were reported among cohorts of workers, managers and key stakeholders (e.g., Balakrishnan *et al*., 2010; Mathee *et al*., 2010; Stoecklin-Marois *et al*., 2013; Xiang *et al*., 2015, 2016). This finding is consistent with the results of other studies in various industries in which varied awareness and experiences of heat-related morbidity and mortality as well as the magnitude of heat exposure risks were observed among workers, employers and other stakeholders (Jacklitsch, 2017; Lam *et al*., 2013; Singh *et al*., 2015). Also, excessive heat exposure in changing climate has been perceived and remained a significant concern for workers' health and safety, productivity, and workplace environmental conditions (Kjellstrom *et al*., 2016b; Lucas *et al.*, 2014).

The extent of workers' awareness and experiences of occupational heat stress, impacts and adaptation strategies can significantly define the attitude and collective effort of all stakeholders in acting conscientiously to manage the vulnerability and impact of occupational heat exposure risks. The vulnerability principle states that the extent of severity of climate change and heat exposure hazards define the extent of exposure of individuals, and the magnitude of adaptation to climate change and heat exposure stressors to individuals determine vulnerability levels (Davidson *et al*., 2003; Ford *et al*., 2006; Kelly & Adger, 2000). Hence, the severity and magnitude of occupational heat stress impact on workers and adaptation strategies may depend on workers having adequate knowledge and awareness of perceived and actual vulnerabilities, adaptive capacity and resilience planning. The varying heat stress risks awareness and experiences, and high magnitude of heat exposure may serve as the basis to inform policy decisions, future research, and the development of information, training and education on heat stress risks. These measures can boost workers' adaptive capacity and resilience planning for effective occupational heat stress management. It also holds the potential for managing the threats and worsening impacts of heat stress in the context of rising temperature and climate change on workers' health and safety, productivity, and social well-being.

Social impacts of occupational heat stress

The use of the SIA framework mostly in the assessment of resource and capital projects (Vanclay, 2003; Vanclay et al., 2015), other than concerns related to social impacts of policies, occupational heat exposure and climate change have been criticised (Adusei-Asante, 2017; Kalkstein *et al*., 2009; Miller, 2014; Scheffran & Remling, 2013; UN, 2011). Accordingly, the reported range of social impacts resulting from occupational heat stress on workers vulnerable to heat exposure included physical, mental, behavioural, health and safety, socio-economic and productivity consequences (Costello *et al*., 2009; Dunne *et al*., 2013; Hanna *et al*., 2011; Kjellstrom *et al*., 2009; Smith *et al*., 2014; Venugopal *et al*., 2016a; Xiang *et al*., 2014).

Similarly evidence from the review revealed the significant influences of occupational heat stress on the health, safety, productivity and social well-being of outdoor and indoor workers across a range of different industrial settings across the world (Ayyappan *et al*., 2009; Flocks *et al*., 2013; Tawatsupa *et al*., 2012; Venugopal *et al*., 2016b). Results of the review on impacts of occupational heat stress on health and safety of workers resonate with various studies (e.g., Acharya *et al*., 2018; Arbury *et al*., 2014; Kjellstrom & Crowe, 2011; Xiang, *et al*., 2014; Xiang *et al*., 2014) where heat-related illnesses and injuries of workers were attributed to occupational heat exposure factors. For instance, the 20 cases of heat illness and deaths among workers in the United States (U.S.) during the 2012-2013 review of Occupational Safety and Health Administration (OSHA) were attributed to heat exposure with a heat index in the range (29.0 ^{o}C-41.0^{o} C) (Arbury *et al*., 2014). Heat-related illnesses, injuries and deaths among workers reflect the prevalence of work-related heat exposure factors, individual-related vulnerability factors and worsened by climate change-related heat exposure factors such as rising temperature, high humidity, air speed, and radiant heat.

Furthermore, multiple studies (e.g., Delgado-Cortez, 2009; Krishnamurthy *et al*., 2017; Langkulsen *et al*., 2010; Lao *et al*., 2016; Mathee *et al*., 2010; Sahu *et al*., 2013; Venugopal *et al*., 2016a) in this review have demonstrated that, occupational heat stress results in reduced productivity in a variaty of workplaces and industries including construction (Venugopal *et al*., 2016a), agriculture (Delgado-Cortez, 2009; Sahu *et al*., 2013), and manufacturing (Krishnamurthy *et al*., 2017). Findings of the review relating to productivity impacts on workers corroborate other studies showing declines in productivity due to working under increasing heat exposure reported across a range of countries and regions (e.g., Dunne *et al*., 2013; Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2016b; Gibson & Pattisson, 2014; Singh *et al*., 2015), have continually been shown to decrease due to working under rising heat exposure conditions in a variety of workplaces and countries including, but are not limited to, Australia, U.S., Indonesia, Malaysia, China, Qatar, India, South Africa, and Bangladesh. Productivity losses, absenteeism, reduced work pace, and performance efficiency will be exacerbated by projected rise in temperature and climate change. For instance, international analysis of labour productivity loss over 1975-2200 showed that during the warmest period, there might be work capacity reduction (37% based on Representative Concentration Pathways [RCP]8.5 and 20% based on RCP4.5) in most humid months (Dunne *et al*., 2013). Also, reduction in work capacity and absenteeism caused by heat stress led to individual economic losses of US$655, and an overall financial loss of US$6.2 billion (Zander *et al*., 2015). Also, global analysis centred on national Gross Domestic Product (GDP) and annual mean temperatures indicated that countries would lose 23 percent of their GDP to rising temperatures and climate change by 2100 (Burke *et al*., 2015).

In addition, heat stress effect on workers' social lives and well-being as indicated in the review included inadequate time for task such as family care and household chores, as well as an increase in family breakdown due to fatigue, physical violence and interpersonal disputes (Venugopal *et al*., 2016a). The effect of extreme heat on workers' social lives and well-being also results in income erosion and loss of employment due to heat-related morbidity, absenteeism and productivity loss, thereby affecting workers' social network relationship with their families and co-workers, and access to community services (Venugopal *et al*., 2016a). Similarly, extreme heat events have been shown to present multi-stress vulnerabilities that affect people including their health and well-being, financial situation, mobility, social relations, and access to basic services (Miller, 2014; Bolitho & Miller, 2017). However, there is paucity of knowledge and research-based evidence on the social impact dimensions and the nexus between climate change-related heat exposure and its consequences on health, safety, productivity, and economic output, and adaptation strategies for workers' social lives, their families, coworkers, social units, and wider communities (Kjellstrom *et al*., 2016a; Miller, 2014; UN, 2011; Venugopal *et al*., 2016a). It is essential for the factors of social impacts of occupational heat stress to find expression in the letter and spirit of policy decisions and SIA frameworks at the global, national and local levels to reduce workers' vulnerability, boost adaptive capacity and resilience planning (Miller, 2014).

Adaptation of workers to occupational heat stress

Occupational heat stress based on rising temperature due to climate change has substantial socio-economic and health ramifications on working populations. Devoting significant resources in incorporating and enforcing mitigation, adaptation and social protection strategies in policy decisions are sustainable ways to reduce vulnerability, enhance resilience and adaptive capacity of working people to ensure viable well-being (Spector & Sheffield, 2014; Venugopal *et al*., 2016a; Venugopal *et al*., 2016b; Xiang *et al*., 2016). The need for mitigation, adaptation and social protection policies as preventive and control measures have been informed by protocols, frameworks, and targets to reduce vulnerability, risks, and sensitivity to climate change and heat stress, and to enhance resilience and adaptive capacity of workers (Brechin, 2016; IPCC, 2014a; Rhodes, 2016; UNFCCC, 2006; WMO & WHO, 2015).

Accordingly, several studies (e.g., Ayyappan *et al*., 2009; Flocks *et al*., 2013; Lao *et al*., 2016; Pradhan *et al*., 2013; Xiang *et al*., 2015) in the review addressed a variety of issues related to workers' coping and adaptation to occupational heat stress and barriers to adaptation strategies. The use of coping and adaptation strategies as suitable options for decreasing and managing risks, vulnerabilities and sensitivity to occupational heat stress impacts on workers' health, productivity, and social lives are diverse (Davies *et al*., 2009; Kjellstrom *et al*., 2016a; Venugopal *et al*., 2016a). Generally, interventions of occupational heat stress from the perspective of coping mechanisms, adaptation, and social protection strategies as encapsulated in the review include engineering solutions, administrative controls, and consistent education and training regimes. It can also be reinforced by implementing such regulations and policies, ensuring a shift in structures of economies to non-outdoor work, provide compensations for productive losses, and social protection for workers (Frimpong *et al*., 2015; Kjellstrom *et al*., 2016b; Lucas *et al*., 2014; Lundgren *et al*., 2013; UN, 2011).

However, workers encounter barriers (e.g., inadequate housing designs, inadequate resources, lack of awareness, absence of management commitment, lack of prevention training, low compliance, lack of heat stress guidelines, lack of regular breaks, and the limited access to shade or medical attention) in implementing adaptation strategies to occupational heat stress (Dutta *et al*., 2015; Fleischer *et al*., 2013; Pradhan *et al*., 2013; Xiang *et al*., 2015). Similarly, the 20 cases of heat illness and fatalities in the U.S. during the 2010-2013 review were linked to poor approach to heat illness risk identification in prevention programme, inadequate or no heat illness prevention programme, inadequate water management, failure to provide shaded rest areas, and no acclimatisation programme (Arbury *et al.*, 2014). The capacity to overcome the barriers to adaptation and risks to heat stress due to rising temperature and climate change depends on technological advancement and resource availability, especially in tropical developing countries. Policy analysts, decision makers, industrial hygienists, social risk and environmental health scientists ought to significantly consider these barriers in policy decisions and work with concerted effort to improve heat-related occupational safety and health administration and policies.

Conclusions

Workers' perceptions and experiences of occupational heat stress and adaptation strategies, epitomised as a natural and seasonal phenomenon, are clear but varied. The social impacts of occupational heat stress are associated with both perceived and actual risks and impacts on workers' health and safety, productivity and social well-being. Sustainable adaptation and social protection strategies to occupational heat stress depend on financial resource availability and cooperative effort to overcome the barriers to adaptation. The severity of occupational heat stress due to climate change depends on workers' sensitivity and vulnerability to heat exposure as well as the extent of adaptive capacity and resilience planning. The current synthesis shows that in the last decade, there has been inadequate research on social dimensions and impacts of occupational heat stress and adaptation strategies of workers in the context of rising temperature and climate change, especially in Europe and Africa (Lundgren et al., 2013). However, Africa is the region characterised by higher risk for negative occupational health outcomes than Europe because of lower adaptive capacity, increasing poverty and inadequate technological advancement to combat rising temperature and climate change. Studies of this nature are required among workers in such regions to highlight the state of knowledge to inform occupational heat stress adaptation and resilience policies for sustainable development. It will also be useful to integrate relevant knowledge-based evidence on social impacts of occupational heat stress into policy decisions, further development of the SIA framework, and inform the ongoing climate change social impact analysis aimed at combating intensifying temperature and climate change.

CHAPTER THREE: THE NEXUS BETWEEN SOCIAL IMPACTS AND ADAPTATION STRATEGIES OF WORKERS TO OCCUPATIONAL HEAT STRESS: A CONCEPTUAL FRAMEWORK

Abstract

Adverse effects of occupational heat stress in the context of changing climate on working populations are subtle but considerably harmful. However, social dimensions and impacts of climate change-related occupational heat concerns on workers' safety and health, productivity, and well-being are often overlooked or relegated as minor issues in social impact analyses of occupational heat exposure due to climate change. This paper offers a conceptual framework based on an appraisal and synthesis of the literature on social impacts of climate change-related occupational heat exposure on workers' safety and health, productivity, and social welfare and the quest to localise and achieve sustainable development goals. A sustained global, national, institutional, and individual collaborative involvement and financial support for research, improved adaptation and social protection strategies, predominantly in the developing world, where a large number of the people work outdoors, can reduce heat exposure and boost the resilience and adaptive capacity of workers to facilitate efforts to achieve sustainable development goals.

Keywords: Adaptive capacity, global warming, work-related heat exposure, social health, sustainable development goals, working populations

Introduction

Diverse working populations of the world are experiencing adverse effects of occupational heat stress risks due to global climate change. Rising temperatures result in increased heat stress risk (Haines *et al*., 2007; McMichael *et al*., 2006). Heating of the climate system from rising concentrations of human-enhanced greenhouse gases (GHGs) exemplified in carbon dioxide and methane emissions have increased global mean temperature by ~0.76 °C since the 1850s (Intergovernmental Panel on Climate Change [IPCC], 2014b). Based on climate change modelling using global climate change scenarios (Representative Concentration Pathways [RCPs]), average ambient temperatures of the world are estimated to increase within the range of 1.4 °C - 5.8 °C by the year 2100 (IPCC, 2014b).

The projected increase in the incidence and severity of heat stress and exposure events is expected to impact outdoor workers' health and will lead to a reduction in their work capacity or affect social well-being. Australia's climate change projections showed an increase in days with unsafe heat exposure from one day in the 1990s to 15-26 days for each year by the 2070s (Maloney & Forbes, 2011). Global labour productivity loss analysis over the period (1975-2200) showed that during hot and humid periods work capacity reduced by 37 % and 20 % based on RCP8.5 and RCP4.5 respectively (Dunne *et al*., 2013). However, intensifying temperature could help improve winter productivity in some regions. For instance, climate change had a positive consequence on winter wheat, spring wheat and barley production in northern and Siberian parts of Russia, but had adversely affected grain production in the southern part of the country (Belyaeva & Bokusheva, 2018).

Notably, there are records of heat impact on reduced work capacity, labour productivity and economic loss, social lives, forced migration due to loss of livelihood, and loss of GDP in India, Australia, U.S. and Africa (Burke *et al*., 2015; Kjellstrom, 2016; Kjellstrom *et al*., 2009b; Sahu *et al*., 2013; Venugopal *et al*., 2016a). For instance, absenteeism and reduced work performance due to heat exposure resulted in financial losses of US$655 per person and a total economic burden of US$6.2 billion in Australia (Zander *et al*., 2015). Furthermore, a global examination of yearly average temperatures and national Gross Domestic Product (GDP) for various countries indicated that up to 23 % of global GDP would be lost due to climate change by the year 2100 (Burke *et al*., 2015). Similarly, due to climate change impacts, Nigeria and Ghana lost 3.3 % and 3.2 % of GDP in 2010 and are expected to lose 6.4 % and 6.5 % of GDP in 2030 respectively (Kjellstrom, 2016). In addition, incidents of heat exhaustion, cognitive and psychological performance effects were recorded among South African mine workers and Australian and Thai farmers (Berry *et al*., 2010; Tawatsupa *et al*., 2010).

Increased heat exposure occasioned by climate change leads to more significant effects of occupational heat stress (e.g., mortality, morbidity, loss of productive capacity, and reduced network relationship) for workers (Kjellstrom *et al*., 2016a; Lundgren *et al*., 2013). Studies of heat exposure in hot areas of Africa, Asia, Latin America and Australia show that several billions of people including workers may be in danger of heat stress effects (Kjellstrom et al., 2016a). Similarly, there are recorded cases of heat stroke-related deaths at work among South African and Qatari mine workers (Gibson & Pattisson, 2014; Wyndham, 1994). Four hundred and twenty-three people, including 68 crop farmers, died from heat stroke from 1992-2006 in the United States (U.S.) (Centres for Disease Control & Prevention (CDCP), 2008). Furthermore, excessive heat exposure amongst U.S. military, Central American sugarcane workers, and migrant construction workers in Qatar has led to clinical damage to organs, heart overload and kidney damage due to heat exhaustion and dehydration (e.g., Gibson & Pattisson, 2014; Tawatsupa *et al*., 2012; Wesseling *et al*., 2013).

However, beyond safety and health, not much attention is being paid to the hazards of heat stress experiences in a changing climate on the productivity and social health of workers (Kjellstrom *et al*., 2016a; Schulte & Chun, 2009). For this reason, aspects of the 2030 Sustainable Development Goals (SDGs) recognised the importance of improving the well-being of people, including workers. The SDGs set an agenda to work toward global development over a 15-year period (2015-2030) (Pogge & Sengupta, 2015; United Nations [UN], 2015). The international development blueprint focuses on ending poverty (SGD 1), guaranteeing healthy lives and promoting well-being (SDGs 3), ensuring decent jobs and economic growth (SDGs 8), and combating intensifying temperature and climate change impacts (SDGs 13) (Pogge & Sengupta, 2015; UN, 2015). Climate change-related occupational heat stress refers to heat stress that is either driven by climate change or is aggravated by climate change. It is also a condition in which the human body exhibits inadequate physiological capacity to tolerate excess heat generated within and/or outside the body (Kjellstrom et al., 2016b). The risk and effect of heat stress on workers emanates from environmental, individual and occupational related heat exposure risks factors (Haines & Patz, 2004; Maté *et al*., 2016; Parsons, 2014; Schulte & Chun, 2009).

The social (e.g., network of relationships) and human (e.g., knowledge, skills, and abilities) capital embodied in workers are significant in reducing climate change and work-related heat stress vulnerability, and enhancing adaptive capacity. However, the occupational safety and health, productive capacity and social lives of outdoor workers are at risk due to increased ambient temperatures and higher relative humidity associated with climate change. Previous empirical and review studies attest to the effect of climate change and work-related heat exposure on the health, efficiency, social well-being, and adaptation strategies of people (Kjellstrom *et al*., 2016a; Schulte *et al*., 2016; Schulte & Chun, 2009; Venugopal *et al*., 2016a).

Much of the climate change and heat stress impact research focus on the health of the general population rather than occupational cohorts. However, the impacts of heat stress on workers' safety and health, efficiency, social well-being, and their adaptation strategies are not well described (Costello *et al*., 2009; McMichael *et al*., 2006). Furthermore, inadequate studies have used conceptual frameworks to illustrate how climate change and heat exposure influence workplaces and workers' productive capacity, social lives, and adaptation strategies in the context of the SDGs (Lucas *et al*., 2014; Schulte *et al*., 2016; Schulte & Chun, 2009). Not only do heat exposure effects due to changing climate relate to economic and environmental conditions, but they also impact negatively on social lives and health of people including workers (United Nations [UN], 2011; Nunfam *et al*., 2018).

Social impacts include the consequence of socioeconomic and natural events (e.g., projects, policies, heat exposure) which affect the corporeal and mental well-being of a person, socioeconomic groups, work environment and society. Social impacts often result in significant changes to at least the health and safety, environment, rights, participation in decision making, fears, culture, community, or political organisation of people (Mahmoudi *et al*., 2013; Vanclay *et al*., 2015). Heat stress social impact is exemplified in morbidity, injuries, reduced productive capacity, loss of employment, decreased income and disruption of social lives and comfort. Social impacts due to heat stress reflect those that directly affect the physical, social and emotional well-being of people including health effects, poverty and income inequality (Gasper *et al*., 2011; UN, 2011).

Workers' exposure to occupational heat stress ascribed to changing conditions of the climate viz-a-viz their social and human capital and the need to promote the SDGs is significant. Hence, the authors construct a framework to portray the conceptual pathways of climate change-related occupational heat stress, adaptation and the SDGs. The framework illustrates the conceptual dimensions and linkage between safety and health, productivity, and social well-being. It elucidates the repercussions of heat stress on SDGs based on the adequacy of workers' social protection, coping, and adaptation strategies. The paper advocates for the integration of social extents and impacts of physiological health, productivity, and social welfare ramifications of heat stress into climate change social impact assessments to enhance the SDGs. It also seeks to inform the ongoing discourse on climate change and social impact assessment as well as social protection and adaptation policies. Hence, this article reviews and synthesises salient literature on climate change, work-related heat stress, and workers' adaptation strategies. It proposes a conceptual framework depicting pathways of social extent and impacts of climate change-related occupational heat exposure and SDGs via the interconnected safety and health, productivity, and social well-being implications of work-related heat stress on workers.

Material and methods

Fundamentally, the development of this conceptual framework was informed by a previous research study that reviewed and synthesised scholarly articles in peer-reviewed journals published within the period (2007 - 2017) to provide a current perspective of the literature (Nunfam *et al*., 2018). Accordingly, keywords including 'adaptation strategies', ‘health and safety’, ‘social impact’, ‘social well-being’, ‘occupational heat stress’, ‘climate change’, ‘psychological behaviour’, ‘productivity’, and ‘workers’ were used as part of the search strategy in a variety of data repository (e.g., Google Scholar, ProQuest, PubMed, Science Direct, and Web of Science) and the references of selected relevant studies. The purpose was inter alia to identify evidence of journal articles with conceptual frameworks related to social impact of work-related heat stress and adaptation policies of workers in the context of climate change.

Overall, the procedure of database exploration culminated into 25 relevant studies out of 23,352 selected studies from which 123 findings were extracted (see Supplementary Tables 1 to 25) (Nunfam *et al*., 2018). The 25 relevant studies were selected based on an inclusion and exclusion criteria. To be included for review and synthesis, scholarly studies had to be peer-reviewed, published in the English language and related to occupational heat exposure risk and adaptation strategies. Similarly, the studies had to assess the effect of work-related heat stress on workers’ productivity, health and safety, and social welfare and/or used conceptual frameworks to describe the linkages among climate change, occupational heat exposure, worker’s safety and health, their social well-being, productivity, and adaptation strategies. However, we excluded from the review studies which: 1) were letters, editorials, reviews, comments and viewpoints; 2) assessed climate change-related precipitation, drought, increasing sea levels and rainstorms; 3) assessed the effect of heat stress on animals, crops, plants and ecosystems; and 4) were related to climate change mitigation. The included studies were presented according to author name(s), year of publication, title, study design, population and sample size, data collection methods and analysis, and author(s)’ conclusions (Table 3.1). This paper relied on the extracted findings as secondary data for the purpose of data categorisation, which were synthesised into themes and illustrated with the aid of diagrams.

Table 3.1: Summaries of findings in selected studies

#	Author, year & title	Study design	Population & sample size	Methods	Data analysis	Author(s)' conclusions
1	Balakrishnan *et al*. (2010). Case studies on heat stress related perceptions in different industrial sectors in southern India	Case study	242 manufacturing workers	Questionnaires and Wet Bulb Globe Temperature (WBGT) index	Correlation analysis	Given the potential implications of future climate change-related increases in ambient heat stress that are likely to translate into workplace exposures in developing country settings
2	Crowe *et al*. (2013). Heat exposure in Sugarcane harvesters in Costa Rica	Descriptive study design	105 harvesters	WBGT and non-participatory observation	Descriptive analysis using WBGT data, metabolic rate and Threshold limit values	Sugarcane harvesters are at risk of heat stress for the majority of the work shift. Immediate action is warranted to reduce such exposures
3	Flocks *et al*. (2013). Female Farmworkers' Perceptions of Heat-Related Illness and Pregnancy Health	CBR approach using narrative interviews	35 female farmworkers	Focus group discussion	Thematic analysis	Participants believe that heat exposure can adversely affect general, pregnancy, and fetal health, yet feel they lack control over workplace conditions and that they lack training about these specific risks
4	Crowe *et al*. (2010). Heat exposure in sugarcane workers in Costa Rica during the non-harvest season	Exploratory observational study	45 sugarcane workers	WBGT	Descriptive analysis	It is therefore important to take action to decrease current and future heat-related risks for sugarcane 45workers in both harvest and non-harvest conditions and in all sugarcane growing regions in Costa Rica. It is also necessary to improve guidelines and occupational health standards for protecting worker health and productivity in the tropics
5	Stoecklin-Marios *et al*. (2013). Heat-related illness knowledge and practices among California hired farm workers in The MICASA study	Comparative study design	467 hired farm workers	structured interviews questions	Statistical analysis using multivariate survey logistic regression	The study suggests important areas to target for heat illness prevention in farmworker population, and that gender-specific approaches may be needed for effective heat illness
6	Tawatsupa *et al*. (2013). Association between heat stress and occupational injury among Thai worker: Findings of the Thai cohort studies	Cohort studies	58495 workers	Mail out health questionnaires	Logistic regression using STATA version 12	The study provides useful evidence linking heat stress to occupational injury in tropical Thailand and identifies factors that increase heat exposure

7	Tawatsupa *et al.* (2012). Association between occupational heat stress and kidney disease among 37816 workers in the Thai cohort studies (TCS)	Cohort studies	37816 workers	Self-reported questionnaires	Logistic regression	There is an association between self- reported occupational heat stress and the self-reported doctor diagnosed kidney disease in Thailand. There is a need for occupational health interventions for heat stress among workers in tropical climates
8	Sett and Sahu (2014). Effects of occupational heat exposure on female brick workers in West Bengal, India	Evaluative study design	120 brick moulders and carriers	WBGT and questionnaires	Statistical analysis using t-test and ANOVA	High heat exposure in brickfields during summer caused physiological strain in both categories of female brickfield workers
9	Luo *et al*. (2014).Exposure to ambient heat and urolithiasis among outdoor workers in Guangzhou, China	Correlational Case-control study design	190 cases and 760 control shipbuilding workers	2003-2010 health check data	Conditional logistic regression	Significant association between exposure to ambient heat and urolithiasis among outdoor working populations
10	Langkulsen *et al*. (2010). Health impact of climate change on occupational health and productivity in Thailand	Descriptive cross-sectional study	21 workers	WBGT and questionnaires	Descriptive and trend analysis	Climate conditions in Thailand potentially affect both the health and productivity in occupational settings
11	Sahu *et al*. (2013). Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: Implications for a climate change future	Comparative study design	124 rice harvesters	WBGT and an interviewer-administered questionnaire	Trend and Statistical analysis using a t-test	High heat exposure in agriculture caused heat strain and reduced work productivity. This reduction will be exacerbated by climate change and may undermine the local economy
12	Krishnamurthy *et al*. (2017). Occupational Heat Stress Impacts on Health and Productivity in a Steel Industry in Southern India	Cross-sectional study design	84 steel worker	WBGT and structured questionnaires	Statistical analysis	High heat exposures and heavy workload adversely affect the workers' health and reduce their work capacities. Health and productivity risks in developing tropical country work settings can be aggravated by temperature rise due to climate change, without appropriate interventions
13	Tawatsupa *et al*. (2010). The association between overall health, psychological distress, and occupational heat stress among a large national cohort of 40,913 Thai workers	Cohort studies	40913 workers	Self-reported questionnaires	Descriptive statistical analysis	This association between occupational heat stress and worse health needs more public health attention and further development of occupational health interventions as climate change increases Thailand's temperatures

14	Delgado-Cortez (2009). Heat stress assessment among workers in a Nicaraguan sugarcane farm		22 sugarcane workers	data loggers and data collection sheet	Descriptive statistics and Chi-square analysis	Productivity improved with the new rehydration measures. Awareness among workers concerning heat stress prevention was increased
15	Venugopal et al. (2016b). Occupational heat stress profiles in selected workplaces in India	Experimental study design	442 workers	WBGT and questionnaires	Statistical analysis using Z-test a chi-square for bivariate	Reducing workplace heat stress benefits industries and workers via improving worker health and productivity. Adaptation and mitigation measures to tackle heat stress are imperative to protect the present and future workforce as climate change progresses
16	Dutta *et al*. (2015). Perceived heat stress and health effects on construction workers	A cross-sectional survey using mixed method approach	219 construction workers	WBGT, focus group discussion and survey questionnaires	Thematic analysis using grounded theory approach for qualitative data and descriptive statistical analysis and trend analysis	This study suggests significant health impacts on construction workers from heat stress exposure in the workplace, showed that heat stress levels were higher than those prescribed by international standards and highlights the need for revision of work practices increased protective measures, and possible development of indigenous work safety standards for heat exposure.
17	Venugopal *et al*. (2016a). The social implications of occupational heat stress on migrant workers engaged in public construction: a case study from Southern India	Both quantitative and qualitative studies	142 migrant workers	WBGT and questionnaires	Quantitative and qualitative analysis	In an increasingly warmer global climate and with increasing construction demand, stronger policies to prevent morbidity/mortality among vulnerable migrant workers in the construction sector is imperative. Better health, literacy rates, and decreased crime statistics among migrant community are potential positive implications of protective policies
18	Pradhan *et al*., (2013).Assessing climate change and heat stress response in the Tarai Region of Nepal	Case Study household survey	120 household factory workers	Data loggers, questionnaire and observation checklist	Comparative analysis of quantitative data	More quantitative measurement of workers' health effect and productivity loss will be of interest for future work
19	Xiang *et al*. (2015). Perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialists in Australia	Cross-sectional research design	180 occupational hygienists	Questionnaire	Descriptive analysis using STATA and Excel	The findings suggest a need to refine occupational heat management and prevention strategies

20	Fleischer *et al*. (2013). Public health impact of heat-related illness among migrant farmworkers	cross-sectional survey research design	405 farmworkers	in-person interview	Statistical analysis using logistic regression	Migrant farmworkers experienced high levels of HRI symptoms and faced substantial barriers to preventing. Heat-Related Illness may be reduced through appropriate training of workers on HRI prevention, as well as regular breaks in shaded areas these symptoms
21	Mirabelli *et al*. (2010). Symptoms of heat illness among Latino farm workers in North Carolina	Cross-sectional study	300 farm workers	Interviewer-administered questionnaires	Descriptive statistical analysis using log-binomial regression	These findings suggest the need to improve the understanding of working conditions for farm workers and to assess strategies to reduce agricultural workers' environmental heat exposure
22	Ayyappan *et al*. (2009). Work-related heat stress concerns in automotive industries: a case study from Chennai, India	Quantitative research design		WBGT	Descriptive statistical analysis	The study re-emphasises the need for recognising heat stress as an important occupational health risk in both formal and informal sectors in India. Making available good baseline data is critical for estimating future impacts
23	Xiang *et al*. (2016). Workers' perceptions of climate change related extreme heat exposure in South Australia: a cross-sectional survey	Cross-sectional research study	479 workers	Questionnaire survey	Bivariate and multivariate analysis	Need to strengthen workers' heat risk awareness and refine current heat prevention strategies in a warming climate. Heat education and training should focus on those undertaking physically demanding work outdoors, in particular, young and older workers with low education
24	Lao *et al*. (2016). Working smart: An exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia	A qualitative case study design	32 council male workers	focus groups	Thematic analysis and Interpretative Phenomenological Analysis	The results showed the importance of workplace management and training, and an understanding of the need for workers to be able to self-pace during hot weather
25	Mathee *et al*. (2010). Climate change impacts on working people (the HOTHAPS initiative): findings of the South African pilot study	Grounded theory	151 workers	Focus group discussion and interviews	STATA for quantitative data analysis and thematic analysis for qualitative data	People working in sun-exposed conditions in hot parts of South Africa currently experience heat-related health effect, with implications for their well-being and ability to work and that further research is warranted

Source: Reprinted from *Science of the Total Environment*, *643*, Nunfam, V. F., Adusei-Asante, K., Van Etten, E. J., Oosthuizen, J., & Frimpong, K., Social impacts of occupational heat stress and adaptation strategies of workers: A narrative synthesis of the literature, 1542-1552, (2018), with permission from Elsevier.

Results of categorising and synthesising findings

Subsequently, the findings extracted were grouped into 11 categories (see Supplementary Figures 1 - 11) and synthesised into three main themes according to comparable and divergent patterns: 1) work-related heat stress risk; 2) social impact due to work-related heat stress; and 3) work-related heat stress adaptation (Fig's 3.1-3.3). Synthesis One describes work-related heat stress risk linked to workers and the workplace environment. It emerged from findings aggregated into categories (1 - 6) (Fig. 3.1). Social impact due to work-related heat stress, which constitutes Synthesis Two, was based on combining three groupings (7 - 9) (Fig. 3.2) while categories 10 and 11 were grouped into Synthesis Three (Fig. 3.3).

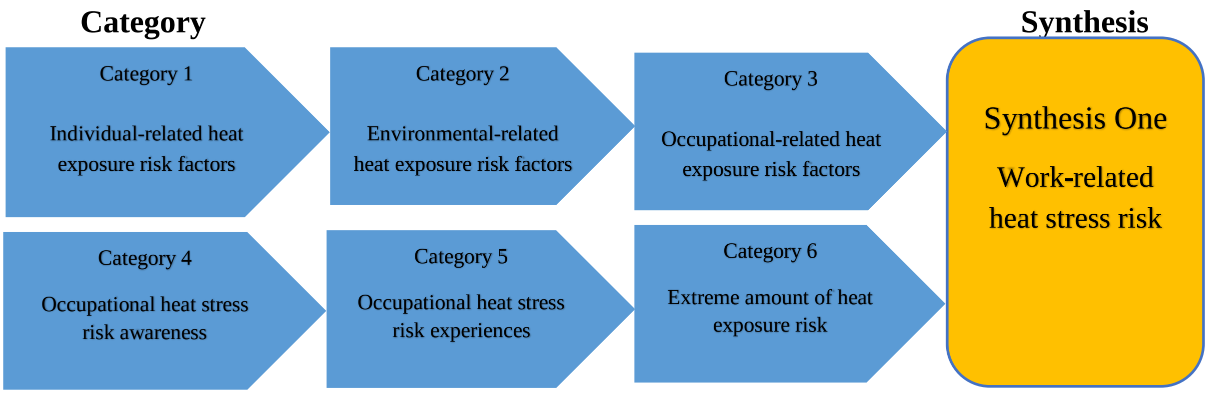


Fig. 3.1. Synthesis One: Work-related heat stress risk

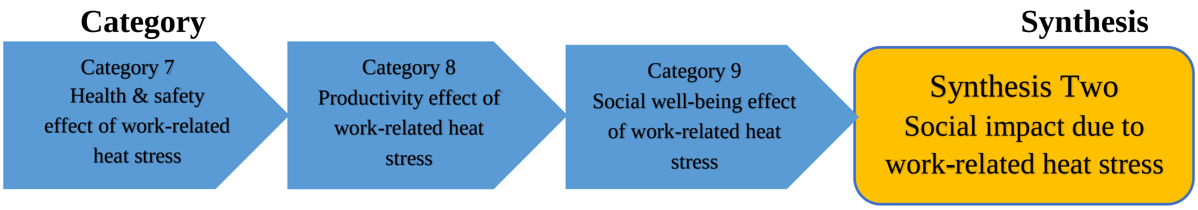


Fig. 3.2. Synthesis Two: Social impact due to work-related heat stress

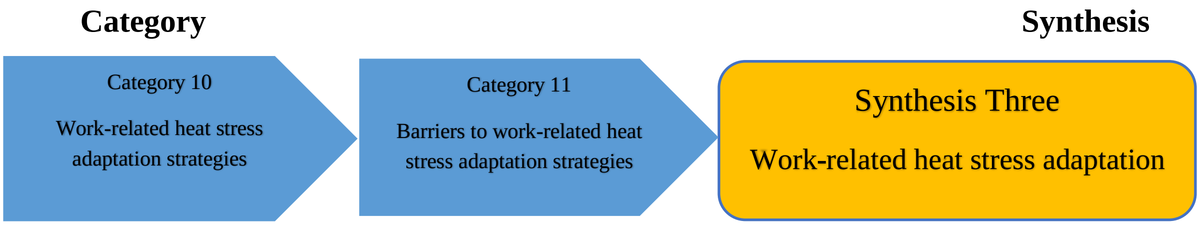


Fig. 3.3. Synthesis Three: Work-related heat stress adaptation

Conceptual perspective

The themes emanating from the synthesis served as the basis for the conceptual framework of the study. The framework provides a description and illustration of the social dimensions and impact trajectory of occupational heat exposure hazards associated with changing climate, adaptation strategies, and the SDGs (Figure 3.4). Vulnerability and risk of working populations to health hazards, loss of labour productivity and employment opportunities seem to be exacerbated by impacts of heat exposure (Ford *et al*., 2006; Lundgren *et al*., 2014). Climate change and occupational heat exposure impact poses a threat to the health, productivity and social lives of employees especially in low-and middle-income countries of tropical regions (Kjellstrom *et al*., 2011; Kjellstrom & McMichael, 2013; Kjellstrom *et al*., 2016b). These regions have inadequate adaptive capacity and inappropriate adaptation and social protection measures due to worsening poverty, insufficient resources, and lack of innovative technologies (Kjellstrom *et al*., 2016b; Lucas *et al*., 2014; Venugopal *et al*., 2016b).

The basic principle of vulnerability is that the extent of speed and severity associated with various forms of changes in climate conditions and heat exposure risks define the degree of susceptibility and risk of persons, social units, and communities. Similarly, the magnitude of coping, adaptation, and social protection strategies of climate change and occupation-related heat stressors to individual workers, social units, and communities determine the level of vulnerability (Davidson *et al*., 2003; Davies *et al*., 2009; Ford *et al*., 2006; Kelly & Adger, 2000). Furthermore, education, poverty, gender inequality, infrastructure, food and nutrition, employment, income, livelihood, health, mobility, social services and institutional response as drivers of social, economic, and traditional developments also explain the magnitude of people's exposure and resilience to variations in climate conditions and hazards emanating from work-related heat stress (Ford *et al*., 2006; UN, 2011).

There are existing conceptual pathways that stipulate the dimensions, linkages, and impacts of heat exposure and risk factors on health, economic productivity, and in limited instances, on the social well-being of workers, as well as coping, social protection, mitigation and adaptation strategies to heat exposure and global climate change impacts on people (Berry *et al*., 2010; Frimpong *et al*., 2015; Haines & Patz, 2004; Kjellstrom & McMichael, 2013; Lucas *et al*., 2014; McMichael *et al*., 2006; Schulte & Chun, 2009). Thus, the application of the underlying ideas of the vulnerability and adaptation models to assess the risks and adaptive capacity of different cohorts of working populations, ecological units and systems, and communities to impacts of heat exposure and climate variation is not new (Crowe *et al*., 2010; Ford *et al*., 2006; Hanna *et al*., 2011; Xiang *et al*., 2016). Distinctively, the conceptual perspective as illustrated in the framework provides the basis for highlighting the link between heat exposure risk factors and occupational heat stress effects and the mediation role of adaptation strategies aimed at promoting the SDGs.

The various conceptual frameworks are comprehensive and valuable in explaining the scope, routes, and impacts of climate change-related hazards to human performance, health, productivity, communities, and ecosystems. However, concerns of social dimensions, linkages, and effects of climate change and occupational heat exposure effects on the healthiness, productivity, and social lives of workers and their families and communities appear to have been underestimated and/or piecemeal in these models (Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2016b; Venugopal *et al*., 2016a). Hence, the necessity for a new conceptual framework describing the social dimensions and impacts of heat exposure, risk and effect of work-related heat stress on workers' health, productivity, social welfare, and adaptation policies in the perspective of the SDGs.

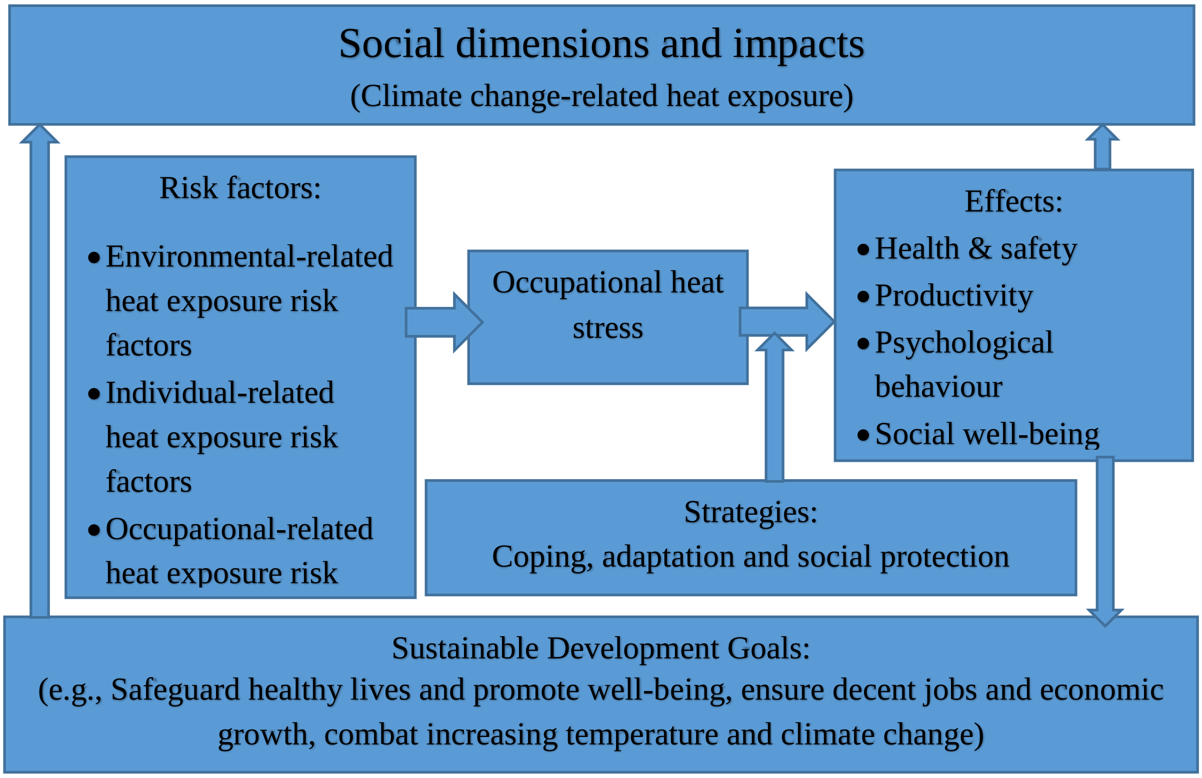


Figure 3.4: Social dimensions and impacts of climate change-related occupational heat stress and adaptation strategies: A conceptual framework

The proposed framework (Figure 3.4) operates on the assumption that the extent of work-related heat stress is linked to the intensity of heat exposure risk factors namely: (1) environmental-based heat exposure factors (e.g., temperature, air movement, humidity, and solar radiation); (2) occupational-related heat susceptibility factors (e.g., physical workload, clothing, work-break regimes, shade, cooling systems, type of work); and (3) individual-related vulnerability factors (e.g., age, sex, body size, medical condition, medication, use of drugs and alcohol, rehydration, acclimatisation level, physical fitness, metabolism rate, choice of clothing, and prior heat injury). Consequently, occupational heat stress results in social implications associated with its physiological, health, psychological, behavioural, productivity, and social well-being effects on workers. The social repercussions of occupational heat stress in the form of illness, injuries, productivity losses, inadequate social welfare of workers in connection with their family relations, co-workers, and communities are interlinked. The social impact of heat stress on workers, workplace, and communities has implications for the realisation of the SDGs (Kjellstrom *et al*., 2016b). The effects of heat exposure as a result of current intensity and predicted rising temperature, precipitations, and droughts are reflective of the nature and characteristics of the environment, infrastructure, poverty, health and well-being, hunger, and food and nutrition related to the working population. Heat stress consequences arising from heat exposure has significant ramifications for the success of the SGDs. This further impacts on the extent of occupational heat exposure aggravated by climate change without adequate control measures and the cycle continues as indicated by the arrows (Figure 3.4). However, the social effects of heat stress linked to occupations on human performance, working populations, the environment, health, productivity, and economic output can be prevented and well managed. In addition to mitigation, impacts can be managed and ameliorated through appropriately improved policies of coping, adaptation and social protection, with the positive consequence of realising the SDGs.

Social dimensions and impacts of climate change-related heat stress of workers

The scope and spectrum of work-related heat stress effects from the perspective of climate change on workers in high danger of being exposed to heat include physiological, psychological, behavioural, health and safety impact as well as social and productivity concerns (Dunne *et al*., 2013; Hanna *et al*., 2011; Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2009b; Nunfam *et al*., 2019a; Nunfam *et al*., 2019b; Venugopal *et al*., 2016a; Xiang *et al*., 2014a). Nonetheless, evidence of awareness and research accentuating the scope of social impact and the relationship between heat exposure concerns on safety, health, productivity, and adaptation policies for workers are inadequate (Kjellstrom *et al*., 2016a; Miller, 2014; UN, 2011; Venugopal *et al*., 2016a).

Recognised health impacts of morbidity and mortality linked with heat stress-related physiological disorders and its effect on people are varied (Kjellstrom *et al*., 2016a; Singh *et al*., 2013; Smith *et al*., 2014). Heat stress arises from the combined effect of intra-body heat beyond the core body temperature of 37 ^{o}C (Kjellstrom *et al*., 2016b). This results from physical workload, excessive outdoor ambient temperature, and clothing that prevents sweat evaporation and heat convection (Parsons, 2014). For instance, prolonged or short-term heat exposure coupled with inadequate dissipation of body heat results in direct heat-related illness described as heat rash, discomfort, and heat cramps (Kjellstrom & Crowe, 2011). It is also symptomatic of excessive sweating, headaches, dizziness, nausea, confusion, and weakness as a result of heat exhaustion, and heat stroke, that can be fatal. Heat is also connected to the danger of chronic illness and clinical damage to organ function including the risks of injuries and accidents (Bridger, 2003; CDCP, 2008; National Institute for Occupational Safety and Health [NIOSH], 2010). Hence, it is essential and timely to use the framework as the conceptual basis in future research and highlight evidence of the social dimensions and impacts of climate change-related health consequences on different worker cohorts.

Also, productivity impacts linked to heat stress experiences of workers have been acknowledged. Productivity hinges on temperature conditions when carrying out work which requires physical exertion (Lloyd, 1994). Thus, working under excessive ambient temperatures of above 35-37 ^{o}C creates occupational heat-related health hazards, reduces productive capacity, and loss of labour productivity (Kjellstrom *et al*., 2016b). The natural protective response mechanism of a worker's body when working in a hot environment is to slow down work. This is to decrease metabolic heat production and thus reduce core body temperature. The response consequence is reduced productive capacity and loss of labour productivity (Dunne *et al*., 2013; Kjellstrom *et al*., 2009a; Parsons, 2014). Eventually, health impairment coupled with productive losses have the potential of adversely eroding workers' family income earnings through increased medical expenses, reduced economic output, and loss of employment opportunities (Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2016b; Venugopal *et al*., 2016a). Accordingly, labour productivity impacts have been estimated to lead to output reduction in affected sectors of over 20 percent throughout the subsequent part of the 20th Century, and worldwide economic cost of decreased productivity could be over two trillion USD by 2030 (IPCC, 2013). However, the extent of social impacts of productivity losses resulting from heat stress remains unanswered among various workers, particularly about mining workers and their families and communities.

Furthermore, unregulated core temperature beyond the body's tolerable limits and dehydration has been associated with adverse behavioural and psychological conditions. For example, adverse behavioural conditions (e.g., physical fatigue, prickliness, sluggishness, diminished vigilance, impaired judgment, and focus), and diminished visual alertness undermine work competence, occupational safety, health, and productivity (Kjellstrom *et al*., 2009a; Wyon et al., 1996). Similarly, easy exhaustion and self-pacing are behavioural changes connected to heat stress, which often results in reduced capacity, productivity losses, and increased risks of accidents and injuries (Singh *et al*., 2013; Xiang *et al.*, 2014b). Psychologically, fear of accidents, injuries, increased irritation and decreased vigilance linked to heat stress also influence mental well-being and impede hands-on dexterity, and productive capacity leading to productivity losses (DeVries & Wilkerson, 2003; Lundgren *et al*., 2013). However, the extent of these social impacts and implications associated with adverse behavioural and psychological repercussions of heat stress on different workers are piecemeal and without adequate research evidence.

Finally, workers' social lives, comfort and cohesion are affected by work-based heat stress. Not only does heat-related illness and productivity loss result in income erosion and loss of occupation but it also influences the social health and cohesion of workers, their families, co-workers, and communities (Miller, 2014; Venugopal *et al*., 2016a). More so, tiredness, sickness, and workplace stress and frustration expressed in alcoholism, smoking, substance abuse, and workplace violence lead to interpersonal issues with colleagues, subordinates, and supervisors. It also results in domestic violence and disrupted family life in the form of loss of leisure, loss of family income, increased medical expenses, and increased risk to family education, health, and social cohesion and well-being at the community level because of aggravated poverty, inequality, domestic violence, and suicide (Miller, 2014; Venugopal *et al*., 2016a).

Workers' adaptation strategies to work-related heat stress driven by climate change

The social dimensions of exacerbating impacts of heat stress could potentially undermine the capacity of workers. The socioeconomic and health ramifications of occupational heat stress on working populations are substantial. Therefore, various conceptual and empirical schemes of preventive and control strategies to protect workers against heat stress hazards have been identified. The essence is to decrease exposure to heat hazard, boost resilience and adaptive capacity of workers, including their family members and social groups to ensure viable well-being. Investing and implementing strategies (e.g., social protection, adaptation and mitigation) are identified as workable in work-related heat stress prevention and control measures (Nunfam *et al*., 2019a; Venugopal *et al*., 2016a; Venugopal *et al*., 2015; Xiang *et al*., 2016). Obligations to international protocols underscore the necessity for preventive and control actions to heat stress (IPCC, 2014b; Rhodes, 2016; Rogelj *et al*., 2016). Based on these protocols, policy frameworks, programmes, and targets have been outlined to reduce vulnerability, hazards and exposure to heat as the world experiences climate change. It is also to boost workers' resilience and adaptive capability (Rhodes, 2016; World Meteorological Organisation [WMO] & World Health Organisation [WHO], 2015). Accordingly, the conceptual perspective, as highlighted in the framework, can shape future studies in providing evidence of coping, adaptation and social protection strategies aimed at informing heat stress management protocols, actions and policy decisions.

By priority, it is advocated that effects of heat stress due to increasing temperature in the context of global warming on workers should be significantly reduced through shared global regulation of human-induced GHG emissions (IPCC, 2015; Lundgren *et al*., 2013). However, at more local scales, healthy and productive adaptation and social protection strategies for working and living in warmer environments are also needed (Frimpong *et al*., 2015). Adaptation involves minimising actual workplace heat exposure, avoiding heat stress, and protecting workers from occupational heat exposure. Social protection involves collective and individualised strategies, programmes, and actions directed at averting, decreasing, and eradicating poverty, and social marginalisation. It also seeks to boost prospects and resilience by stimulating social capital of workers to ensure decent and productive employment (Cichon, 2013; Mundial, 2012; UNICEF, 2012).

The impact of heat stress related to occupations because of climate change on workers' social welfare, productivity, and health remains critical. However, the application of mitigation, coping, adaptation, and social protection policies as sustainable alternatives in preventing and controlling risks and vulnerabilities to excess poverty and socioeconomic exclusion related to climate change are not exclusive (Davies *et al*., 2009; Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2009b; Venugopal *et al*., 2016a; Venugopal *et al*., 2016b). Generally, preventive and control intervention of heat exposure comprise managerial controls, engineering designs, and continued training and education regimens. It also involves social safety mechanisms, consolidation of guidelines, changing economic systems to indoor work, and providing reparations for productivity losses of workers (Kjellstrom *et al*., 2016b; Lucas *et al*., 2014; Lundgren *et al*., 2013; UN, 2011).

Innovatively designing and regulating workers' resting and workplace environments, plants, equipment, ventilation systems and processes help in avoiding, adjusting, and reducing the impacts of heat stress exposure. Engineering controls enhance cooling and air circulations, insulations, access to adequate shade, worker rehydration, and protective clothing. However, inadequacies of engineering controls, have necessitated the use of administrative control mechanisms through worker practice and monitoring systems. These are exemplified in work-rest regimes, self-pacing, shift work schedules, hazard alerts, acclimatisation regimes, and biophysical monitoring (Kjellstrom *et al*., 2016b).

Furthermore, regular information, education, communication, and awareness campaigns, including training programmes, enhance the prevention and control of heat stress impacts. Also, improving the preventive and control intervention of climate change-related heat stress by strengthening labour organisations, regulations and workers' protective policies have implications for work-related heat stress. Similarly, it is advocated that direct effects of work-related heat stress in the form of illness, injuries, income losses, and social disruptions of workers are compensated (Kjellstrom *et al*., 2016b; Lundgren *et al*., 2013).

Besides, workers' vulnerability is reduced, and their resilience and adaptive capacity enhanced by social protection and insurance policies, programmes, and strategies (e.g., social security, superannuation, pension schemes). Also, health insurance, interventions to employment market (e.g., standards for employment, regulation to protect workers interest, minimum wage policy), and humanitarian relief and aids to workplace disasters are valuable strategies (Davies *et al*., 2009). Another measure with the possibility of indirectly preventing and controlling the impact of heat stress relates to fiscal and regulatory mechanisms of accelerating the pace of transforming the structure of economies with a focus on industries involving non-outdoor working environments such as service and industrial sectors (Frimpong *et al*., 2015; Kjellstrom *et al*., 2016b).

However, these preventive and control mechanisms are somehow inadequately and inequitably implemented without recourse to adequate global collaboration of developed and developing nations in the era of worsening and unavoidable heat exposure. It is, therefore, imperative to use the framework as the basis to investigate and highlight the social implications of coping, adaptation and social safeguard policies of workers to the impact of work-related heat stress particularly amongst worker cohorts of various industries.

Conclusions and implications for policy and research

The conceptual framework developed here based on the relevant literature shows that the social dimensions and potential effects of heat stress on occupations relate to workers' productive capacity, health and safety, psychological behaviour, and social lives and well-being. The framework also demonstrates that the risks and impacts of work-related heat stress hinge on the extent of employees' susceptibility and adaptive capacity and which has implication for the realisation of the SDGs. This is derived from the principle that a worker's exposure and sensitivity to the danger and impact of work-related heat stress is positively related to the worker's state of susceptibility and negatively related to the worker's adaptive capacity and resilience. Similarly, concerns of social dimensions and occupational heat stress impacts on workers seem to receive little attention in empirical, review and conceptual studies. It is also overlooked in social impact and climate change discourse, even though, it has implications for ecological, socioeconomic and human health.

The essence of the focus on the social dimensions of work-based heat stress and climate change is to contribute to the ongoing discourse, policy and research effort on climate change to ensure an inclusive sustainable development to overcome poverty, ensure healthy lives, combat increasing ambient temperature, and promote decent jobs. This has the possibility of facilitating environmental justice and decreasing the vulnerability of people including worker cohorts, improving their adaptive capacity and resilience as well as their productive capacity and social well-being for social and economic growth and development. The research and policy implication is that ecological, social risk, and environmental health scientists as well as governments in developing countries, for instance, would need to promote research, socially inclusive, climate resilient policies and operations to improve progress towards the SDGs. Thus, significant and sustained global collaborative effort, financial support for research and development, improved social protection and adaptation policies can reduce exposure and boost the resilience and adaptive capacity of workers to facilitate the global achievement of the SDGs.

SECTION III: METHODOLOGY

Overview

SECTION III describes and evaluates the methodology used in this thesis, as illustrated in Chapter Four. This chapter discusses the utilisation of the convergent mixed methods approach, involving both quantitative and qualitative methods to demonstrate the practical use of between-method triangulation, complementarity and combination of quantitative and qualitative results of heat exposure studies. It also shows the possibility of using MMR characterised by multiple data collection, analysis and integration to enhance our understanding of the social impacts of occupational heat stress on mining workers. This chapter is currently under review for publication with the Journal of Mixed Methods Research.

CHAPTER FOUR: MIXED METHODS STUDY INTO SOCIAL IMPACTS OF OCCUPATIONAL HEAT STRESS ON MINING WORKERS IN GHANA: A DYNAMIC RESEARCH APPROACH

Abstract

Mixed methods research has emerged as a strategy for understanding complex social phenomena. However, its utility in exploring heat exposure, particularly in the developing world, has been limited. In this paper, we employed a convergent mixed methods research design comprising 320 surveys and two focus group interviews, to assess the impact of occupational heat stress on mining workers in Ghana. We affirmed the practical application of between-method triangulation, complementarity and integration of both quantitative and qualitative results in mixed methods research. The merged quantitative and qualitative results also showed an adequate sense of corroboration and complementarity between qualitative and quantitative data. The mixed methods approach enabled us to obtain credible data that identified social impacts of occupational heat stress on mining workers as heat-related illness, injuries, anxiety, slow work pace, loss of productive capacity, and poor social well-being. The chapter shows that the mixed methods approach is a useful strategy for researching complex topics such as the social impacts of occupational heat stress.The findings of this study are relevant for policy decisions on occupational heat stress management, workplace health and safety, and adaptation strategies in the mining industry.

Keywords: Mixed methods research, social impacts, occupational heat stress, mining workers

Introduction

Globally, mixed methods research (MMR) have progressively become the third popular research methodological paradigm among researchers (Creswell, 2015; Greene, 2006; Johnson & Onwuegbuzie, 2004; Mertens, 2003; Tashakkori et al., 1998; Teddlie & Tashakkori, 2012). MMR involves the process of collecting, analysing and integrating both quantitative and qualitative strategies, data and findings to enlighten inferences drawn from one or more studies for a comprehensive understanding of a research phenomenon (Creswell, 2015; Creswell & Plano Clark, 2011; Plano Clark & Ivankova, 2016; Tashakkori & Teddlie, 2010, 2011). The basis of contemporary MMR emerged in the early 1950s with the introduction of the idea of triangulation and multiple operationalism in social science research (Boring, 1953; Campbell & Fiske, 1959). However, MMR formally began in the late 1980s and developed throughout the second half of the 20th Century (Denzin, 1978; Greene *et al*., 1989; Jick, 1979; Sieber, 1973; Webb, Campbell *et al*., 1999). The rationale for MMR is to adopt varied research philosophies, designs and sampling procedures, use multiple data sources, data collection and analysis methods, integrate and discuss the results, and draw conclusions to offset the inadequacies of one research strategy (Creswell, 2015; Hesse-Biber, 2010).

Integration is one of the distinguishing features of MMR. Integration is the process of combining results of quantitative and qualitative studies. Three common strategies of integration are identified as merging, connecting, and building (Fetters et al., 2013). Merging involves bringing together quantitative and qualitative data for the purpose of comparison to determine whether findings are either congruent or divergent or cross-tabulate themes with statistics. Connecting entails combining data by purposively selecting participants based on quantitative results for interviews, while building is the systematic use of qualitative results of a study to inform the development of a survey or instrument in another study. Integrated results of MMR may be presented using descriptive narrative or joint display to graphically enhance and characterise integration (Fetters *et al*., 2013; Guetterman *et al*., 2015). However, integration may occur at various stages of the research process comprising multiple philosophies, paradigms, designs, and methods including sampling, data collection, analysis and interpretation (Fetters et al., 2013; Greene, 2015; O'Cathain et al., 2007).

Occupational heat stress refers to heat stress conditions driven by high ambient temperatures and / or humidity, which is currently being exacerbated by climate change, combined with exhaustive physical work (Kjellstrom *et al*., 2016a). Social impacts connote the perceived or physical effect of a phenomenon on the lives, culture, cohesion, political system, environment, health and well-being, rights, and fears of people (Vanclay, 2003; Vanclay *et al*., 2015). Hence, social impacts of occupational heat stress comprise the health, safety, behavioural, mental, and social well-being consequences of heat stress on workers characterised by heat-related illness and injuries, mental and behaviour concerns, and poor social well-being. Globally, indoor and outdoor workers in occupational settings (e.g., manufacturing, oil and gas, agricultural, mining, firefighting, military and construction) are exposed to higher risk and impacts of excessive heat exposure. Occupational heat stress hazards and impacts on working populations susceptible to heat exposure include, but are not limited to, physiological health and safety concerns, socio-economic effects, productivity and mental consequences (Dunne *et al*., 2013; Kjellstrom *et al*., 2016a; Lucas *et al*., 2014; Nunfam *et al*., 2018; Venugopal *et al*., 2016a; Xiang *et al*., 2016). Significantly, the impacts of hazards associated with heat exposed workers especially in hot low-and middle-income countries of tropical regions of the world are much worse on account of intensifying global climate warming, inadequate resources, poor access to cooling systems, and the need to keep up with productivity and economic growth.

Aside from a few empirical and review studies (Miller, 2014; Nunfam *et al*., 2018; Venugopal *et al*., 2016a) related to social impacts of occupational heat stress on workers, there appears to be no mixed methods empirical studies that focus on social impacts of occupational heat stress on mining workers in Africa. For instance, out of 685 peer-reviewed studies published in library and information science journals in sub-Saharan Africa, 53% employed quantitative methods, 40% adopted qualitative strategies, while 7% used mixed methods (Ngulube, 2010). Similarly, in content analysis, only 7% out of 322 articles published from 2003-2011 were identified to have MMR philosophies and designs in the South African Journal of Economics and Management Sciences (Ngulube & Ngulube, 2015). Furthermore, in a systematic review of 25 peer-reviewed studies related to the social impacts of occupational heat stress and adaptation strategies of workers from 2007-2017, 76% were quantitative studies, 12% were qualitative studies, and 12% used mixed methods strategies (Nunfam *et al*., 2018). The inadequate proportions of articles associated with the use of MMR in Africa and studies related to social impacts of occupational heat stress and adaptation strategies of workers may be due to integration and interpretation challenges of quantitative and qualitative data and findings based on research philosophical and design incompatibility (Bryman, 2006; Denzin, 2008; Teye, 2012; Yanchar & Williams, 2006). Except for few recent studies on occupational heat stress published in content-specific journals illustrating the application of mixed methods (Dutta *et al*., 2015; Nunfam *et al*., 2019b; Nunfam *et al*., 2019a; Venugopal *et al*., 2016a) there appears to be no empirical MMR on occupation heat stress impacts on workers' health and safety, productivity and social well-being published in mixed methods-specific journals. Given the methodological significance of MMR and the need to contribute to the growing literature on mixed methods and its utility, this empirical paper seeks to show how the MMR strategy enabled us to obtain data that assessed the social impacts of occupational heat stress on mining workers in Ghana.

Conceptual and theoretical philosophies that underpin the rationale of MMR include triangulation, complementarity, initiation, development, and expansion (Bryman, 2006; Greene *et al*., 1989; Hesse-Biber, 2010). Triangulation (within-method or between-methods) involves the combination of multiple data, theories, methodologies and researchers to study the same phenomenon for convergence and corroboration of findings based on varied methods (quantitative and qualitative approach) (Denzin, 1978; Greene *et al*., 1989). Complementarity comprises the use of multiple methods to measure the overlapping and varied aspects of a research problem and to complement the inadequacies inherent in the findings of a single method study, and thus, clarify, elaborate, and illustrate a holistic understanding of the research phenomenon (Greene *et al*., 1989; Hesse-Biber, 2010). Initiation refers to the process of starting a new study based on contradictory findings of a previous study, which requires further clarification. The purpose of initiation is to discover contradictions, new contextual viewpoints, reframe questions or findings from one method with questions or results of another method (Greene *et al*., 1989; Hesse-Biber, 2010). Development is the process in which the findings of one method is used to enlighten another method (Greene *et al*., 1989). Expansion involves increasing the scope of a research inquiry based on the use of varied methods for different aspects of the research problem (Greene *et al*., 1989; Hesse-Biber, 2010).

We used between-method triangulation and complementarity as the basis for adopting a convergent mixed method approach in this research. Hence, we sought to use multiple research designs, data, and methods in complementary and corroborative ways to assess the social impacts of occupational heat stress on mining workers in Ghana and provide answers to address the following research questions: What are the perceptions and experiences of the social impacts of occupational heat stress on mining workers? Similarly, the study sought to test the hypothesis that there is no significant difference in social impacts of occupational heat stress on mining workers across the type of mining activity. The independent and yet connected nature of the specific objectives supports the use of convergent parallel design which requires the combination of quantitative and qualitative strategies, analysing and merging the findings for a thorough and richer discussion and interpretation of the social impacts of occupational heat on mining workers.

Materials and methods

Research philosophy and design

There are diverse philosophical worldviews that affect the framework, method and direction of social science research. The various theoretical paradigms include the post-positivist, social constructivist, advocacy or participatory, and pragmatist schools of thoughts (Creswell, 2013; Mertens, 2014; Neuman & Kreuger, 2003). However, this study was guided by pragmatist philosophical perspectives. Pragmatism is the underlying philosophical orientation or tool that supports methodological eclectism and mixed methods approach to a social inquiry (Biesta, 2010; Johnson & Onwuegbuzie, 2004; Teddlie & Tashakkori, 2012). Pragmatism does not exclusively rely on single methods with its associated inherent limitations but involves multiple approaches and procedures of social inquiry based on their points of congruence or dissimilarity that best meet the requirements of a study. It also underscores an eclectic blend of both quantitative and qualitative ideas involving positivism and interpretive theories to provide a holistic understanding of a research problem (Creswell, 2002, 2013; Neuman & Kreuger, 2003; Sarantakos, 2012). Positivists employ surveys, numerical data, and tests to seek robust, precise measures and 'objective' research, and test propositions by analysing numbers from the measures. However, positivism has been criticised for reducing people to numbers, and its use of theoretical laws and formulae are defined as irrelevant to actual and lived experiences of people. Interpretivists employ interviewing, participant observation and field research and this requires spending time and resources in direct personal contact with the phenomena being studied. It also involves analyses of transcripts of conversations or videotapes of behaviour in detail (Neuman & Kreuger, 2003). Therefore, this study was characterised by paradigm pluralism comprising the philosophical orientations of positivists and interpretivists.

Consistent with the pragmatists' research ideas, the convergent mixed methods research design involving both quantitative (e.g., survey research) and qualitative (e.g., interpretive phenomenological research) strategies were employed to assess the research problem (Creswell, 2013; Creswell & Plano Clark, 2017). Both quantitative and qualitative research strategies were combined for the purpose of between-methods triangulation and complementarity of multiple philosophical paradigms, research designs, data collection and analysis methods to gain a comprehensive understanding of the social impacts of occupational heat stress on mining workers in Ghana (Denzin, 1978; Greene *et al*., 1989; Hesse-Biber, 2010). The essence of triangulation is to seek convergence and corroboration of results from both strategies, while complementarity involves using quantitative and qualitative methods to measure distinct but overlapping aspects of the social impact of occupational heat stress on mining workers (Creswell, 2013; Mertens, 2015). Figure 4.1 illustrates the steps involved in the convergent parallel mixed methods design for the study.

MMR designs have proved valuable in evaluating concerns related to climate change and heat stress impacts and adaptation involving multiple interrelating systems (Birchall, Murphy, & Milne, 2016; Mertens, 2015). For instance, the mixed method research design was used in studying climate change adaptation in Zimbabwe by triangulating qualitative and quantitative data for complementarity. The study also used simple random and purposive sampling in selecting respondents while survey questionnaires, interview guide, FGDs guide and observation were employed in data collection (Tanyanyiwa & Kanyepi, 2015). Similarly, the mixed methods approach involving the use of three exclusive data sets (quantitative documents, quantitative surveys, and qualitative in-depth interviews) were employed in researching the voluntary carbon market in New Zealand. The study also used both explanatory (qualitative interviews and survey results) and convergent (data sets were examined separately and combined for analysis) techniques in data collection and analysis (Birchall et al., 2016).

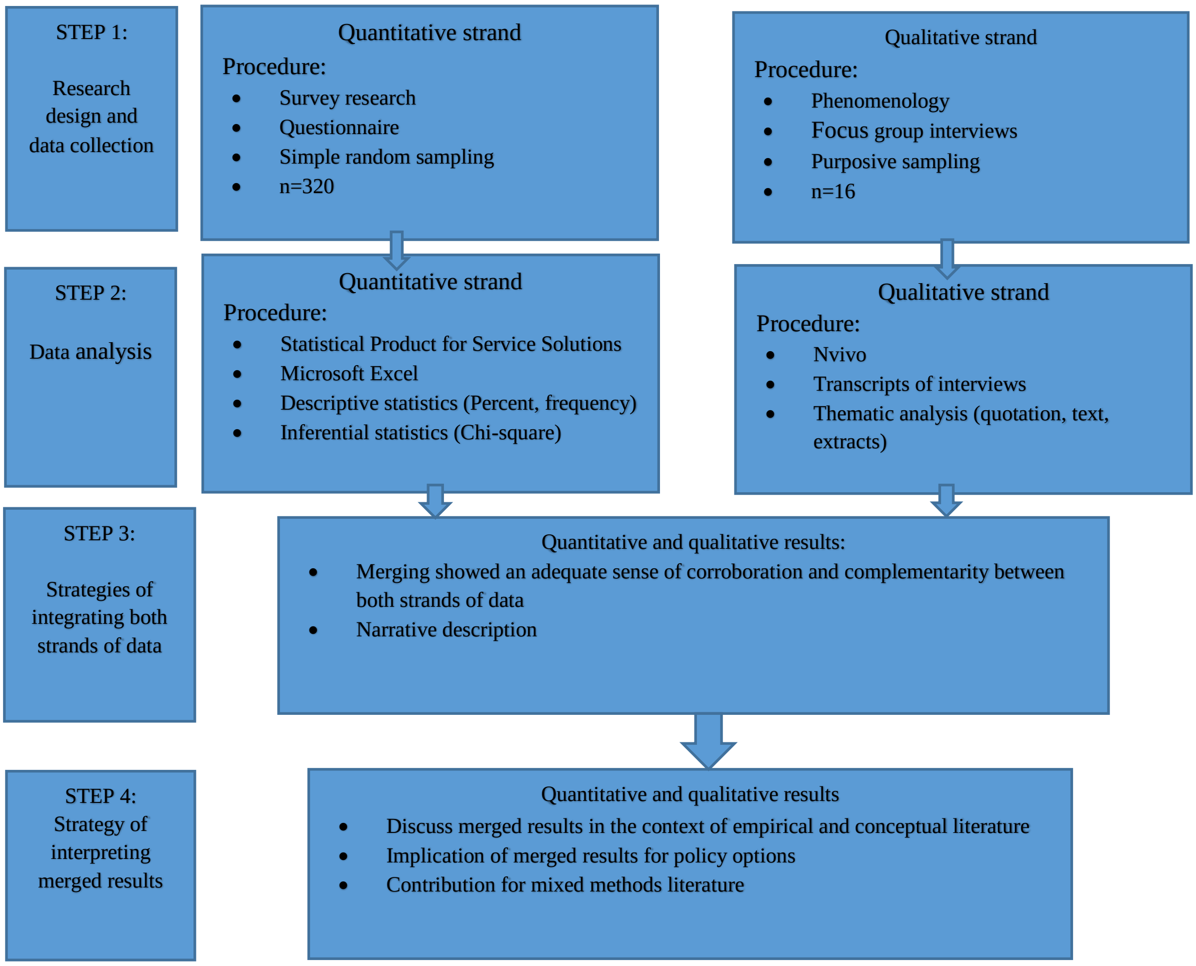


Figure 4.1: An illustration of the procedures involved in the convergent mixed methods design of the study

Source: Adapted from Creswell and Plano Clark (2011)

The qualitative approach provides a much needed strategy to gain a detailed understanding of an in-depth context of mining workers' experiences and perceptions of the social impacts of occupational heat stress on mining workers. It is also used to promote some degree of flexibility in data collection and analysis, avoid pre-determined assumption while focusing on meanings of important variations of participants' perspectives of the study. However, a pure qualitative research approach can be biased, time-consuming, expensive, and relies on a small number of participants whose results cannot be generalised. The use of a quantitative approach is to seek analysis and explanation of the relationships among respondents' demographic characteristics and to provide a broader understanding of the mining workers' view of the social impacts of occupational heat stress. This approach is relatively objective, less costly and time-consuming, uses large samples whose results can be generalised, but is limited in providing detailed perspectives of participants. Therefore, the use of mixed methods designs tends to allow complementarity in strength and weaknesses between quantitative and qualitative research strategies as compared to a single method strategy.

Study setting, population, sampling procedure and sample size

The study was conducted in Ghana, West Africa. Ghana is associated with a tropical weather condition, intensifying temperature and risk of heat exposure, inadequate technological advancement and lower heat adaptive capacity. Due to the climatic conditions, outdoor workers in the informal and small-scale mining (SSM) and the large-scale mining (LSM) sectors in Ghana are at risk of occupational heat stress. The SSM sector comprises of local people with inadequate finance and technology who use labour-intensive methods and simple equipment to semi-mechanised mining equipment in their mining activities while the LSM sector is dominated by multinationals with adequate funding who use advanced technology and expertise in their mining operations (McQuilken & Hilson, 2016). This study involved workers of five mining sites located in the Western Region of Ghana, where both SSM and LSM companies operate. Over a million mine workers constituted the study population and comprised an estimated population of a million workers in the small-scale mining sectors (McQuilken & Hilson, 2016) and 11,628 workers from 13 mining companies in the large-scale mining sector as of 2017 (Ghana Chamber of Mines[GCM], 2018). Eight out of an estimated 177 SSM companies and five from 13 LSM companies who expressed their willingness and interests in the study were purposively selected for inclusion. Subsequently, a simple random sampling procedure was used to select a sample of 320 workers (SSM: 161 and LSM: 159) who participated in the study. During the survey, purposive sampling was used to select 16 mining workers who consented and willingly participated in two focused group discussions (FGDs) consisting of eight members each for the category of SSM (FGD 1) and LSM (FGD 2) workers.

Data collection

This study relied on data collected as part of this doctoral thesis that assessed climate change and occupational heat stress and adaptation strategies of mining workers in Ghana to illustrate convergent mixed methods inquiry. The questionnaire employed to elicit quantitative data from the mining workers consisted of closed-ended Likert type question items measured on a response scale comprising Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D) and Strongly Disagree (SD). The validated instruments of High Occupational Temperature Health and Productivity Suppression (HOTHAPS) programme as well as previous empirical studies based on climate change, heat exposure impacts on health, productivity, and adaptation strategies were used as a guide to inform the design and content of the survey questionnaire. The self-reported question items focused on respondents' demographic and work background, health and safety concerns, behavioural and psychological effects, productivity issues and social well-being concerns of occupational heat stress on mining workers. Before its administration for data collection, the questionnaire was reviewed by experts from Edith Cowan University (ECU) and pretested in Ghana to assess its local suitability, reliability and validity. The guided FGD consisted of open-ended question items and were centred on respondents' background characteristics, occupational heat stress effects on workers' health, safety, behaviour, psychology, productivity and social well-being. Like the survey questionnaires, the guided FGD was reviewed by experts and pretested in Ghana to ascertain its soundness and consistency before it was used to obtain the qualitative data for the study. Also, before data collection in Ghana, ethical approval was sought from the Human Research Ethics Committee (HREC) of ECU.

Data analysis

The quantitative data was processed using IBM Statistical Product and Service Solution (SPSS) version 25 and Microsoft Excel 2016. Descriptive statistics (e.g., *frequency and percent*) and inferential statistics (e.g., *Chi-Square test*) were used to establish the variation in social impacts of occupational heat stress on mining workers across the type of mining activity at a level of significance ($p<.05$). Also, the degree of significant difference was determined by the effect size criteria (very small: 0.01, small: 0.20, medium: 0.50, large: 0.80, very large: 1.20, & huge: 2.0) (Cohen, 1988; Sawilowsky, 2009). The recorded and transcribed qualitative data were reviewed, validated and processed utilising NVivo version 11 software. The data on workers' perceptions and experiences of social impacts of occupational heat stress was subsequently thematically analysed and synthesised into themes that emerged from the texts, quotations and extract of the FGDs. The themes assisted in describing and interpreting the data based on the relationships and differences arising from the social impacts of occupational heat stress on mining workers. Based on the convergent mixed methods strategy, we integrated by merging and narratively describing the quantitative (e.g., *statistics*) and qualitative (e.g., *themes*) results simultaneously to facilitate interpretation and discussion, conclusions and implications (Fetters & Freshwater, 2015). Weaving, as a dynamic approach to narrative integration, was then used to present results theme-by-theme consisting of both the quantitative and qualitative data (Fetters & Freshwater, 2015). Tables and figures were also used to illustrate the results of the study where necessary.

Results

Descriptive summary of respondents' background information

The composition of gender showed that there were 80.9% males (SSM: 89.4% vs LSM: 72.3%), and 19.1% females (SSM: 10.6% vs LSM: 27.7%) and the variation in gender composition across the type of mining activity was statistically significant ($p<.001$) with small effect size. Also, the age categorisation consisted of 92.2% younger respondents (SSM: 93.8% vs LSM: 90.6%), and older respondents (SSM: 6.2% vs LSM: 9.4%) and the difference in age category between workers of SSM and LSM was not statistically significant (Table 4.1). Similarly, respondents (2.8%) without formal education consisted of workers of SSM (5.6%) and LSM (0%) while those with formal education composed of workers of SSM (94.4%) and LSM (100%). The disparity in education level across the type of mining activity was statistically significant ($p<.001$) with a very small effect size (Table 4.1).

Table 4.1: Results of the difference in type of mining activity across workers' demographic factors (Pearson Chi-Square test); SSM=Small scale mining; LSM=Large scale mining; n=320; n (SSM) =161; n (LSM) =159

Type of mining activity	Demographic factors					
	Sex		Age		Education	
	Male	Female	Younger (21- 49yrs)	Older (50 - 61yrs)	No formal education	Formal education
	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)
SSM	144(89.4)	17(10.6)	151(93.8)	10(6.2)	9(5.6)	152(94.4)
LSM	115(72.3)	44(27.7)	144(90.6)	15(9.4)	0(0)	159(100)
Total	259(80.9)	61(19.1)	295(92.2)	25(7.8)	9(2.8)	311(97.2)
	$\chi^2(1) = 15.186$, $p < .001$, $Phi = 0.218$		$\chi^2(1) = 1.154$, $p = 0.283$		$\chi^2(1) = 9.145$, $p < .001$, $Phi = 0.169$	

Source: Field survey, 2017

The work hours category showed that there were fewer respondents (35.3%) working under 10hrs/day (SSM: 52.2%% vs LSM: 18.8%) and more respondents (64.7%) working over 10hrs/day (SSM: 47.8% vs LSM: 81.8%). The difference in work hours across the type of mining activity was statistically significant ($p<.001$) with a small effect size. Furthermore, based on the work environment category, there were more (65.9%) indoor workers (SSM: 58.4% vs LSM: 73.6%) and less (34.1%) outdoor workers (SSM: 41.6% vs LSM: 26.45). The dissimilarity in the work environment between workers of SSM and LSM was statistically significant ($p<.001$) with a very small effect size. In terms of work efforts, respondents (18.8%) with less work effort consisted of fewer SSM (7.5%) against more LSM (30.2%) and the respondents (81.3%) with more work effort composed of more SSM (92.5%) and fewer LSM (69.8%) workers. The difference in work effort across the type of mining activity was statistically significant ($p<.001$) with a small effect size. Additionally, the majority of respondents (87.2%) who answered in the affirmative to working around heat sources consisted of more SSM workers (92.5%) and fewer LSM workers (81.8%). However, the respondents (12.8%) who answered negatively comprised fewer SSM (7.5%) and more LSM (18.2%) workers. The discrepancy in working around heat sources between workers of SSM and LSM was statistically significant ($p<.05$) with a very small effect size. Lastly, the respondents with light workload (6.6%) comprised less SSM (5.0%), and more LSM (8.2%) workers, moderate workload (30.6%) included less SSM (24.2%) and more LSM (37.1%) workers, and heavy workload (62.8%) consisted of more SSM (70.8%) and less LSM (54.8%) workers. The variation in workload across the type of mining activity was statistically significant ($p<.001$) with a small effect size (Table 4.2).

Table 4.2: Results of the difference in type of mining activity across workers' occupational factors (Pearson Chi-Square test); SSM=Small scale mining; LSM=Large scale mining; n=320; n (SSM) =161; n (LSM) =159

Type of mining activity	Occupational factors: Work hours		Work environment		Work effort		Work around heat source		Workload		
	Under 10hrs/day	Over 10hrs/day	Indoor	Outdoor	Less	More	Yes	No	Light	Moderate	Heavy
	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)	F (%)
SSM	84(52.2)	77(47.8)	94(58.4)	67(41.6)	12(7.5)	149(92.5)	149(92.5)	12(7.5)	8(5.0)	39(24.2)	114(70.8)
LSM	29(18.2)	130(81.8)	117(73.6)	42(26.4)	48(30.2)	111(69.8)	130(81.8)	29(18.2)	13(8.2)	59(37.1)	87(54.8)
Total	113(35.3)	207(64.7)	211(65.9)	109(34.1)	60(18.8)	260(81.3)	279(87.2)	419(12.8)	21(6.6)	98(30.6)	201(62.8)
	$\chi^2(1) = 40.329$, $p < .001$, *Phi*= 0.355		$\chi^2(1) = 8.229$, $p < .05$, *Phi*= -0.160		$\chi^2(1) = 27.142$, $p < .001$, *Phi*= -0.291		$\chi^2(1) = 8.331$, $p < 0.05$, *Phi*= 0.161		$\chi^2(3) = 38.936$, $p < .001$, *V*= -0.349		

Source: Field survey, 2017

Health and safety concerns

Concerns related to heat stress effects on health and safety of workers emerged from the views of mining workers contained in both the quantitative and qualitative data. The workers were conscious that workplace heat exposure posed a significant danger to their health and safety, as shown by the quantitative data. For instance, the majority of workers (SSM and LSM) agreed that intensive physical mining work in hot weather conditions resulted in excessive sweating, headaches and dizziness (over 98%), doing mining work in hot weather conditions increased the risks of tiredness, weakness, and muscle cramps or body pains (>95%), excessive sweating as a result of hot weather conditions during intensive mining work enhanced the potential for heat rashes (>79.2%), excessive sweating due to heat exposure increased the risk of extreme thirst (over 98%)(Table 4.3). However, there was a statistically significant difference between SSM and LSM workers as to whether excessive sweating as a result of hot weather conditions during intensive mining work enhanced the potential for heat rashes ($p<.001$), and excessive sweating due to heat exposure increased the risk of extreme thirst ($p<.001$) (Table 4.3). In addition, most research participants supported and complemented the results of the quantitative data based on their perceptions and experiences of heat-related illness and injuries associated with mining work. This was confirmed by a participant during the FGDs as follows:

> *I have experienced some illness working in a place where there is heat or more heat, and you need to do that job. You need to be as fast as you can to do that job by not risking yourself, but at the end of the job you will find yourself that you feel dehydrated, you are sweating and having a little bit of headache…most of our friends also get these heat illness like sweating and collapsing too.*

Similarly, the majority of workers affirmed that intensive work in hot weather conditions enhanced the risk of injuries such as heat burns from the sun or hot surfaces (>85%), fatigue, confusion and lack of concentration due to heat exposure during mining work led to heat-related injuries like skin burns, bruises and cuts (over 91%), and loss of grip and control of mining equipment due to sweaty hands resulted in heat-related injuries like skin burns, bruises and cuts (over 52%). There was evidence of statistically significant difference between SSM and LSM workers on statements that fatigue, confusion and lack of concentration due to heat exposure during mining work led to heat-related injuries like skin burns, bruises and cuts ($p<.001$) and loss of grip and control of mining equipment due to sweaty hands resulted in heat-related injuries like skin burns, bruises and cuts ($p<.001$) (Table 4.3).

Table 4.3: Results of the difference in health and safety effects of occupational heat stress on mining workers across the type of mining activity (Pearson Chi-Square test); n=320; n(SSM)=161; n(LSM)=159

Statement	SA		A		U		D		SD		Chi-Square
	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	
Intensive physical mining work in hot weather conditions results in excessive sweating, headaches, and dizziness	84.5	83.0	12.4	15.7	1.2	0.6	1.9	0.0	0.0	0.6	$\chi^2(4) = 4.936$, $p = .294$
Doing mining work in hot weather conditions increases the risks of tiredness, weakness, and muscles cramps or body pains	72.0	70.4	23.6	25.8	1.2	2.5	2.5	0.0	0.6	1.3	$\chi^2(4) = 5.172$, $p = .270$
Excessive sweating as a result hot weather conditions during intensive mining work enhances the potential for heat rashes	75.8	45.9	11.8	33.3	6.2	0.6	1.9	19.5	4.3	0.6	$\chi^2(4) = 63.281$, $p < .001$, V=0.445
Excessive sweating due to heat exposure increases the risk of extreme thirst	83.2	72.3	13.0	25.8	2.5	1.3	0.6	0.6	0.6	0.0	$\chi^2(4) = 9.556$, $p < .05$, V=.173
Intensive work in hot weather conditions enhance the risk of injuries such as heat burns from the sun or hot surfaces	37.9	44.0	52.8	45.3	3.1	5.7	5.6	3.8	0.6	1.3	$\chi^2(4) = 3.759$, $p = .440$
Fatigue, confusion and lack of concentration due to heat exposure during heavy mining work leads to heat-related injuries likes skin burns, bruises and cuts	29.2	47.8	62.1	44.0	1.9	4.4	2.5	2.5	4.3	1.3	$\chi^2(4) = 16.497$, $p <.05$, V=0.227
Loss of grip and control of mining equipment due to sweaty hands results in heat-related injuries like skin burns, bruises, and cuts	28.6	42.1	24.2	49.1	36.0	3.1	5.0	3.1	6.2	2.6	$\chi^2(4) = 64.744$, $p < .001$, V=0.450

Source: Field survey, 2017

Similar sentiments were expressed by SSM participants involved in the FGD to illustrate their perceptions and experiences related to the effects of heat stress on their health and safety, as captured in the following statement by an SSM worker:

> *With small-scale mining, illness or injury is inevitable. It is common with our work in the underground…, at times your leg will hit a stone or a rock, and you will get hurt. I got hurt both my leg and hands. It is only God that protects us from our work. Sickness is always there because of the heat and hot air that we breathe. For sickness like headache, it is always there if you work so hard carrying a heavy load on your head*.

Behavioural and psychological effects

Mining workers' actions, emotions, mental state and attitude were influenced by their exposure to workplace heat consequences. As evident in the quantitative data (in Table 4.4), the majority answered in affirmative that tiredness, weakness and muscle cramps due to high temperature slowed down the pace of mining workers (over 52%), physical fatigue and excessive sweating due to heat exposure affected the attentiveness and judgement of mining workers (>85%), thoughts of risk of accidents and injuries due to heat-related exhaustion reduced alertness and sense of understanding increased the fear and anxiety of mining workers (>79%), fatigue, weakness and lack of concentration due to intensive mining work in hot environments increased the need for work-rest hours for mine workers (over 91%), and mistakes/errors during work in hot weather conditions were due to lack of training and information on risk of heat exposure (>76%) (Table 4.4).

The stories of workers' perceptions and experiences during the FGDs showed that mining workers' actions and emotions were driven by the effects of occupational heat stress, as indicated in the following narratives:

> *I will add that sometimes when you are working in the sun or heat conditions; you shouldn't rush...work slowly because sometimes when you rush and do the work, you will start sweating or become tired early and may make mistakes or injure your body* (Participant, LSM workers).

> *Working under a hot environment will surely affect your behaviour because you get distressed and become worried when the heat affects you. In any matter, you need the patience to resolve it, but you may not have that patience because you are feeling hot and irritated. You can even give an undeserving answer to someone that you are working with, which may not be a good behaviour* (Participant, SSM workers).

Table 4.4: Results of the difference in behavioural and psychological effects of occupational heat stress on mining workers across the type of mining activity (Pearson Chi-Square test); n=320; n(SSM)=161; n(LSM)=159

	SA		A		U		D		SD		
Statement	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	Chi-Square
Tiredness, weakness and muscle cramps due to high temperature slow down the pace of mining workers	37.3	46.5	15.5	45.9	37.9	0.6	8.7	6.3	0.6	0.6	$\chi^2(4) = 83.695$, $p <.001$, $V=0.511$
Physical fatigue and excessive sweating due to heat exposure affects the attentiveness and judgement of mining workers	63.4	50.3	22.4	40.3	1.2	0.6	10.6	7.5	2.5	1.3	$\chi^2(4) = 12.485$, $p < .05$, $V=.196$
Thoughts of risk of accidents and injuries due to heat-related exhaustion reduced alertness and sense of understanding increase the fear and anxiety of mining workers	21.1	49.7	58.4	29.6	6.2	6.9	10.6	12.6	3.7	1.3	$\chi^2(4) = 35.867$, $p < .001$, $V=0.335$
Fatigue, weakness and lack of concentration due to intensive mining work in hot environment increase the need for work-rest hours for mine workers	30.4	60.4	60.9	33.3	3.1	2.5	5.0	3.8	0.6	0.0	$\chi^2(4) = 30.031$, $p < .001$, $V=0.306$
Mistakes/errors during work in hot weather conditions are due to lack of training and information on risk of heat exposure	64.0	56.6	19.3	19.5	1.9	3.1	12.4	17.6	2.5	3.1	$\chi^2(4) = 2.808$, $p = .591$

Source: Field survey, 2017

The difference in the behavioural and psychological effects of occupational heat stress on workers across the type of mining activity was assessed using Chi-square. There was evidence of statistically significant variation between SSM and LSM workers as to whether tiredness, weakness and muscle cramps due to high temperature slowed down the pace of mining workers ($p<.001$), physical fatigue and excessive sweating due to heat exposure affected the attentiveness and judgement of mining workers ($p<.001$), thoughts of risk of accidents and injuries due to heat-related exhaustion reduced alertness and sense of understanding increased the fear and anxiety of mining workers ($p<.001$), and fatigue, weakness and lack of concentration due to intensive mining work in hot environment increased the need for work-rest hours for mine workers ($p<.001$) (Table 4.4).

Productivity issues

Workers' productive capacity, effective performance and output were affected by occupational heat stress. The quantitative results indicated that the majority of workers (SSM and LSM) were of the view that tiredness, weakness and muscle cramps due to intensive mining work in hot environment reduced the productive capacity of mining workers (over 88%), lack of concentration, confusion and coordination as a result of heat exposure led to loss of productive efficiency of mining workers (over 83%), heat-related illness and injuries increased the risk of absenteeism of mining worker (>86%), absenteeism of mining workers due to heat-related illness and injuries resulted in loss of income and employment opportunities (above 83%), and work-rest regimes due to excessive heat exposure increased the risk of reducing the productivity of mining workers (>82%) (Table 4.5). Nonetheless, the difference between SSM and LSM was statistically significant in whether tiredness, weakness and muscle cramps due to intensive mining work in hot environment reduced the productive capacity of mining workers ($p<.001$), lack of concentration, confusion and coordination as a result of heat exposure led to loss of productive efficiency of mining workers ($p<.001$), absenteeism of mining workers due to heat-related illness and injuries resulted in loss of income and employment opportunities ($p<.05$), and work-rest regimes due to excessive heat exposure increased the risk of reducing productivity of mining workers ($p<.05$) (Table 4.5).

Like the quantitative data, the results of the FGDs with participants also indicated that mining work in hot environments resulted in exhaustion, slow work pace, and lack of concentration as well as the loss of productive capacity, low energy, and absenteeism which affects productivity and effective performance. This is apparent in the following quotations from both SSM and LSM workers in the FGDs:

Table 4.5: Results of the difference in productivity effects of occupational heat stress on mining workers across the type of mining activity (Pearson Chi-Square test); n=320; n(SSM)=161; n(LSM)=159

	SA		A		U		D		SD		
Statement	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	Chi-Square
Tiredness, weakness and muscle cramps due to intensive mining work in hot environment reduces productive capacity of mining workers	72.7	44.0	16.1	47.8	1.2	0.0	8.1	7.5	1.9	0.6	$\chi^2(4) = 39.352$, $p < .001$, V=0.351
Lack of concentration, confusion and coordination as result of heat exposure leads to loss of productive efficiency of mining workers	67.7	40.9	15.5	50.3	3.1	1.9	13.7	6.3	0.0	0.6	$\chi^2(4) = 45.925$, $p < .001$, V=0.375
Heat-related illness and injuries increase the risk of absenteeism of mining workers	32.3	42.1	55.9	44.7	2.5	1.9	8.7	8.8	0.6	2.5	$\chi^2(4) = 6.064$, $p = .195$
Absenteeism of mining workers due to heat-related illness and injuries result in loss of income and employment opportunities	29.2	44.0	56.5	39.7	3.7	3.1	9.9	11.3	0.7	1.9	$\chi^2(4) = 10.809$, $p < .05$, V=0.184
Work-rest regimes due to excessive heat exposure increase the risk of reducing productivity of mining workers	21.1	34.6	61.5	50.9	4.3	1.3	11.2	11.3	1.9	1.9	$\chi^2(4) = 9.521$, $p < .05$, V=0.172

Source: Field survey, 2017

> *With regard to mining work, it is hard and tiresome, so when you get tired you are not able to concentrate on anything again…when they bring the load and am tired I cannot work effectively. Sometimes my work rate is slow, and my boss becomes annoyed or when l cannot continue to work again as I'm tired* (Participant, SSM workers).

> *Yes, because we have targets that we set in the mines and if the work that I'm doing exposes me to the heat. Definitely, I'm a human being and not a machine; even machine when it works above the normal temperature the machine will cease to operate. So if I'm working in that situation and I realise I have exceeded my energy I cannot continue; definitely my output will not be enough to meet the target. So it has a great impact on productivity* (Participant, LSM workers).

Social well-being concerns

Occupational heat stress was shown to affect workers' social well-being. The majority of both SSM and LSM workers indicated in the quantitative data that heat-related illnesses and injuries had increased their medical expenses (>90%). A preponderance of the SSM and LSM workers (>75%), reported tiredness and excessive sweating due to intensive mining work in hot environment increased the risk of drinking alcohol and energy drinks as well as substance abuse while others mentioned being fatigued due to intensive mining work in hot environment and disrupted family life due to loss of leisure time (above 62%) (Table 4.6). However, unequal proportions (SSM and LSM workers) were of the view that erosion of income due to increased medical expenses as a result of heat-related illness and injuries of mining workers increased the risk of family education and cohesion. Fewer SSM (37.9%) and much more LSM (70.4%) agreed, more SSM (44.1%) were undecided, while less SSM (18.0%) and more LSM (20.7%) disagreed with the statement. Similarly, as to whether increased medical costs due to heat-related illness and injuries affected the social health and cohesion of mining workers and their family, fewer SSM (39.2%) and a greater portion of LSM (78.7%) workers disagreed, more SSM (38.5%) and very few LSM (1.3%) workers were undecided, while more SSM (22.3%) and less LSM (20.1%) workers disagreed. Furthermore, based on the claim that increased irritation, exhaustion, and lack of concentration of mining workers due to workplace heat exposure increased the risk of poor interpersonal relationship with co-workers, family and community, less SSM (36.7%) and more LSM (63.6%) workers answered in support while more SSM (58.3%) and fewer LSM (28.2%) workers answered in disapproval. In addition, the assertion that heat-related illness and loss of productivity due to workplace heat exposure influenced the social well-being and cohesion of mining workers, families and communities was supported by fewer SSM (36.1%) and much more LSM (71.7%) respondents. However, more SSM (60.8%) and few LSM (23.9%) workers did not support the statement. Finally, less

SSM (31.7%) and more LSM (62.9%) workers claimed that workplace stress and frustration due to heat-related tiredness and illness influenced alcoholism, smoking, substance abuse and workplace and domestic violence. Nonetheless, more SSM (66.5%) and less LSM (32.8%) workers disagreed with the claim.

However, the contrast between SSM and LSM workers was statistically significant in heat-related illness and injuries increased the medical expenses of mining workers and their families ($p<.001$) with a small effect size, tiredness and excessive sweating due to intensive mining work in hot environment increased the risk of drinking alcohol and energy drinks as well as substance abuse ($p<.001$) with a small effect size, and fatigue and weakness of mining workers due to intensive mining work in hot environment disrupted family life due to loss of leisure time ($p<.001$) with a small effect size, erosion of income due to increased medical expenses as a result of heat-related illness and injuries of mining workers increased the risk of family education and cohesion ($p<.001$) with a small effect size. Similar statistical significant disparity was evident in increased medical costs due to heat-related illness and injuries affected the social health and cohesion of mining workers and their family ($p<.001$) with a small effect size, increased irritation, exhaustion, and lack of concentration of mining workers due to workplace heat exposure increased the risk of poor interpersonal relationship with co-workers, family and community($p<.001$) with a small effect size, heat-related illness and loss of productivity due to workplace heat exposure influenced the social well-being and cohesion of mining workers, families and communities ($p<.001$) with a small effect size, and workplace stress and frustration due to heat-related tiredness and illness influenced alcoholism, smoking, substance abuse and workplace and domestic violence ($p<.001$) with a small effect size (Table 4.6). The workers indicated that their experiences of heat stress affected the rate of interaction with their family and colleagues and fruitful coexistence. An example of the social well-being concerns of heat stress as expressed by a participant of the FGD with the LSM, which supports the quantitative data is as follows:

> *Yes, it can affect them (family and colleagues) because when I fall sick or injured at work, it will affect my duties and other workers work. When I come home and am supposed to do some work or do some rounds with my family, because of the sickness, I may not get the time or energy to do what am supposed to do. Even with your wife, once you have been to work for long like two weeks she may expect you to do something, and if you are not able to do it I think it will also maybe bring some quarrelling or she may not be happy with you and that will also affect your social life.*

Table 4.6: Results of the difference in social well-being effects of occupational heat stress on mining workers across the type of mining activity (Pearson Chi-Square test); n=320; n(SSM)=161; n(LSM)=159

Statement	SA		A		U		D		SD		Chi-Square
	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	
Heat-related illness and injuries increases the medical expenses of mining workers and their families	75.8	43.4	14.3	48.4	1.9	0.6	3.1	6.3	5.0	1.3	$\chi^2(4) = 50.123$, $p <.001$, V=.396
Tiredness and excessive sweating due to intensive mining work in hot environment increase the risk of drinking alcohol and energy drinks as well as substance abuse	32.3	43.4	49.7	32.1	3.7	1.3	6.2	11.3	8.1	11.9	$\chi^2(4) = 14.207$, $p < .001$, V=.211
Fatigue and weakness of mining workers due to intensive mining work in hot environment disrupts family life due to loss of leisure time	19.9	25.8	57.8	37.1	4.3	6.9	13.0	27.7	5.0	2.5	$\chi^2(4) = 19.064$, $p < .001$,V=.244
Erosion of income due to increased medical expense as a result of heat-related illness and injuries of mining workers increase the risk of family education, health and cohesion	21.1	22.0	16.8	48.4	44.1	8.8	11.8	18.2	6.2	2.5	$\chi^2(4) = 66.921$, $p < .001$, V=.457
Increased medical costs due to heat-related illness and injuries affect the social health and cohesion of mining workers and their family	19.3	34.0	19.9	44.7	38.5	1.3	18.0	18.2	4.3	1.8	$\chi^2(4) = 78.831$, $p < .001$, V=.498
Increase irritation, exhaustion, and lack of concentration of mining workers due to workplace heat exposure increase the risk of poor interpersonal relationship with co-worker, family and community	19.9	34.0	16.8	29.6	5.0	8.2	46.6	19.5	11.7	8.7	$\chi^2(4) = 31.234$, $p < .001$, V=.312
Heat-related illness and loss of productivity due to workplace heat exposure influence the social well-being and cohesion of mining workers, their families, co-workers, and communities	16.8	32.7	19.3	39.0	3.1	4.4	50.9	15.1	9.9	8.8	$\chi^2(4) = 50.437$, $p < .001$, V=.397
Workplace stress and frustration due to heat-related tiredness and illness influence alcoholism, smoking, substance abuse, and workplace and domestic violence	21.1	22.0	10.6	40.9	1.9	4.4	46.6	16.4	19.8	16.3	$\chi^2(4) = 54.095$, $p < .001$, V=.411

Source: Field survey, 2017

Similarly, the concerns of occupational heat stress on the social lives of mining workers as expressed by a discussant of the SSM FGD is illustrated in the following text:

> *In the mining work, there is tiredness because of the hot weather? After a hard day's job under the sun or underground when you come home you want to rest but your family may ask you to do something like your children school's problems or their homework with these matters if you are tired you will may be lazy or weak to do your responsibility…this does not bring fruitful coexistence.*

Discussion

This empirical MMR is the first known study to employ a convergent mixed methods design to concurrently assess the social impacts of occupational heat stress on mining workers in Ghana. In this study, we relied on the quantitative (self-reported survey) and qualitative (FGDs) data from mining workers (SSM and LSM) and complemented with relevant literature (e.g., reports, conceptual and empirical studies) on occupational heat stress impacts and mixed methods to provide an enhanced understanding of the social impacts of occupational heat stress on mining workers to inform policy decisions and contribute to MMR.

Accordingly, as evident in multiple studies (Dunne *et al*., 2013; Hanna *et al*., 2011; Kjellstrom *et al*., 2009; Nunfam *et al*., 2018; Smith *et al*., 2014; Venugopal *et al*., 2016a; Xiang *et al*., 2014a; 2014b), the mixed method approach yielded key themes (e.g., health and safety concerns, psychological and behavioural effects, productivity issues, and social well-being concerns) illustrating the social impacts of occupational heat stress on mining workers. Based on the use of between-method triangulation and complementarity, we found convergence, corroboration and complementary occurrence between the quantitative and qualitative results on health and safety concerns of heat stress on the workers (Denzin, 1978; Greene et al., 1989). For example, although the majority of workers as substantiated by the participants' lived experiences (e.g., heat-related illness and injuries) were concerned about heat stress health and safety consequences, there was a statistically significant difference across the type of mining activity. Based on the conceptual relationship between occupational heat stress and health and safety (Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2016b; Parsons, 2014), our findings resonate with several empirical studies which underscores the physiological health and safety repercussion of heat stress on heat exposed workers in hot and humid workplace environments (Acharya *et al*., 2018; Arbury *et al*., 2014; Flocks *et al*., 2013; Nunfam *et al*., 2018; Tawatsupa *et al*., 2012; Xiang *et al*., 2014a; 2014b; 2014c).

The corroborated and complementary findings on mining workers' psychological and behavioural concerns of heat stress on account of merging the quantitative and qualitative results re-echoes results of other studies (Lundgren *et al*., 2013; Singh *et al*., 2015; Xiang *et al*., 2014b). For instance, as shown by the workers' lived experiences in the FGDs and majority of workers views in the survey, we found that occupational heat stress has serious implications for workers' actions, mindset and emotional conditions when working in hot and humid workplaces. However, the quantitative data revealed a statistically significant difference in psychological and behavioural concerns between SSM and LSM workers. Unlike MMR, a single method study may have exhibited inherent inadequacies in providing the breadth, length and depth of understanding the psychological and behavioural heat stress effect on mining workers (Creswell, 2015; Greene *et al*., 1989; Hesse-Biber, 2010).

Furthermore, heat stress effect on workers' productivity as indicated by the quantitative results, validated and complemented the qualitative findings. For instance, the participants' views provided insights into their experiences of productivity effect of heat stress while the survey revealed a significant difference in productivity effect of heat stress between the SSM and LSM workers, even though, most workers (SSM and LSM) affirmed its consequences on productivity. The extent of holistic knowledge of how heat stress affects workers' productivity may not have been comprehensively understood in a single methods study, as illustrated in this MMR. Similarly, several studies (Delgado-Cortez, 2009; Krishnamurthy *et al*., 2017; Langkulsen *et al*., 2010; Lao *et al*., 2016; Mathee *et al*., 2010; Sahu *et al*., 2013; Venugopal *et al*., 2016a) have demonstrated that occupational heat stress effects on workers' productivity as this study highlights include reduced productive capacity, ineffective performance, decreased output, low energy, slow work pace, absenteeism and lack of concentration on account of heat-related illness and injuries.

Also, on account of incorporating the quantitative and qualitative results, we found that the discussants' perceived and actual experiences of occupational heat stress consequences on workers' social well-being were confirmed and complemented by the majority of both SSM and LSM workers' views in the survey. Nonetheless, there was a statistically significant difference in the social well-being effects of heat stress across the type of mining activity as illustrated by the quantitative analysis. Thus, the use of MMR other than single method research yielded an enhanced understanding of occupational heat stress effect on the social lives of the workers (SSM and LSM) (Creswell, 2015; Greene *et al*., 1989; Hesse-Biber, 2010). Considerably, our findings were consistent with various studies in which the effects of occupational heat stress on workers' social lives and welfare were associated with inadequate time for household tasks and family breakdown due to heat-related fatigue, domestic violence and interpersonal conflicts. Social well-being concerns of heat stress were also related to family income reduction, production losses and loss of employment opportunities due to heat-related illness, fatigue, absenteeism and inadequate productive capacity (Nunfam *et al*., 2018; Venugopal *et al*., 2016a).

It is significant to incorporate the health and safety, psychological behaviour, productivity, and social well-being concerns of occupational heat stress of the workers into workplace and national health and safety policies. The implementation of these policies creates the desired conducive work environments to reduce workers' vulnerability and enhance their adaptive capacity and resilience to heat stress-related health and safety consequences (Nunfam *et al*., 2019a). In the context of rising temperature and climate change, it also enriches the capacity of national institutions working on climate-related health and safety issues in low-and middle-income countries to avert more health burdens (Ebi *et al*., 2017).

Implication and contribution to MMR

We demonstrate the feasibility of adopting contemporary characteristics of MMR including methodological eclecticism, paradigm heterogeneity, diverse research designs, analytical techniques and integration approach in assessing the social impacts of occupational heat stress on mining workers in Ghana (Teddlie & Tashakkori, 2012). The use of a variety of methodologies that straddle between quantitative and qualitative research strategies provided the opportunity to thoroughly investigate and gain an in-depth understanding of the social impacts of occupational heat on mining workers (Tashakkori & Teddlie, 2011; Teddlie & Tashakkori, 2012). It also helped to overcome the inadequacies inherently associated with a single methodological (quantitative or qualitative) research approach (Creswell, 2015). Thus, despite the concerns that eclectic blend of methodologies is unworkable, this study supports the rejection of the inappropriateness and incompatibility proposition of combining quantitative and qualitative methods in a single or series of studies (Denzin, 2008; Yanchar & Williams, 2006).

Furthermore, the study contributes to MMR by combining two philosophical paradigms (e.g., post-positivism and phenomenological research) to illustrate the practicability of paradigm heterogeneity which is typically associated with MMR (Teddlie & Tashakkori, 2012). Hence, we used multiple paradigms to assess and accentuate the qualitative (e.g., depth of lived experiences and perceptions) and quantitative (e.g., breadth and differences) results on social impacts of occupational heat stress on mining workers which may not have been revealed by a single paradigm approach.

As consistent with the tenets of convergent mixed methods, we illustrated the appropriateness of employing multiple data collection methods (e.g., survey questionnaires and FGD guide) and integrated through merging the confirmatory results of the quantitative and qualitative data. The merging process provided the opportunity to compare and illustrate convergent, corroborative and complementary aspects of the study between the quantitative statistical results and qualitative excerpts from the FGDs.

Finally, we demonstrated the possibility of applying multiple methods in this study as evident in the high degree of data integration and congruence between the quantitative and qualitative findings (Fetters *et al*., 2013). The observed concordance in the workers' health and safety concerns, psychological and behavioural effects, productivity issues, and social well-being concerns that emerged from the qualitative and quantitative data mirror a high degree of credibility in the convergent MMR design and philosophy. Also, the congruence and adequate sense of complementarity in the quantitative and qualitative results enhanced and provided confidence in the research findings and conclusions (Hesse-Biber, 2010; Luyt, 2012).

Conclusions and implications for policy decisions

The use of MMR characterised by methodological eclecticism, paradigm heterogeneity, and multiple research designs and methods including data collection, analysis and integration are feasible in occupational heat exposure studies. Multiple data collection, analysis and integration enhanced our understanding of the social impacts of occupational heat stress on mining workers in Ghana. Based on the evidence of integration of quantitative and qualitative strategies and data by merging, the study affirmed the practical application of between-method triangulation, convergence, corroboration, complementarity and weaving in MMR. The high degree of corroboration and complementarity on account of merging the quantitative and qualitative findings resulted in key themes such as health and safety concerns, psychological and behavioural effects, productivity issues and social well-being concerns as social impacts of occupational heat stress on mining workers. The observed social impacts of occupational heat stress and the associated significant difference across the type of mining activity should inform national and workplace policy agenda on heat stress management, workplace health and safety, and adaptation strategies in the mining industry. A concerted effort including workers, employers, and other stakeholders in any occupational heat stress management and adaptation policy decisions related to planning, formulation and implementation has the potential of reducing vulnerability to heat stress and boost workers adaptive capacity and resilience.

SECTION IV: RESEARCH RESULTS

Overview

SECTION IV focuses on the research results exemplified in Chapters Five, Six, Seven and Eight. Chapter Five describes the perspectives of supervisors and other stakeholders on climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. Concurrent mixed methods were used to elicit data, which was interpreted with descriptive statistics and thematic analysis. Supervisors' climate change risks perception was adequate, workplace heat exposure risks concerns were moderate, and their views of workers' heat stress experiences were heat-related illness and minor injuries. The differences in supervisors' climate change risk perceptions and occupational heat stress risk experiences across job experience and adaptation strategies across educational status were significant ($p<0.05$). Chapter Five was published in Environmental Research on November 5, 2018.The published paper is the same as the content of this chapter except for variations in layout to maintain consistency in the thesis.

Chapter Six gives an account of the perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. The mixed methods research, including 320 surveys and two focus groups were used in data collection and analysed with both quantitative and qualitative methods. The findings indicated that workers' concerns about climate change effects and workplace heat exposure risks; heat-related morbidities experienced by workers; and their use of heat stress prevention measures significantly differed between SSM and LSM ($p<0.001$). Chapter Six was published with the Science of the Total Environmental on December 5, 2018. The details of this chapter and the published paper are the same but the layout are not.

Chapter Seven outlines the risk and magnitude of heat exposure on mining workers in Ghana. Questionnaires and temperature data loggers were used to assess the risk and extent of heat exposure in the working and living environments of Ghanaian miners. The quantitative analysis revealed that the disparity in heat exposure risk factors across workers' gender, education level, workload, work hours, physical work exertion, and proximity to heat sources was significant (p<0.05). The extent of Wet Bulb Globe Temperatures in the work and living settings showed that workers were exposed to rather high heat conditions that raise their heat stress risk. This chapter is under review with Science of the Total Environmental. There are no material difference in the content of this chapter and the paper under review with this journal.

Chapter Eight highlights the barriers to occupational heat stress adaptation of mining workers in Ghana. Guided by the mixed methods approach, questionnaires and focus group discussion were adopted in data collection and analysed statistically and thematically. The results showed that workers' adaptation strategies, social protection measures, and barriers to adaptation strategies differed significantly across the type of mining activity ($p<0.001$). This chapter is under review with International Journal of Biometeorology. The details of this chapter are the same as that contained in the paper under review with the International Journal of Biometeorology.

CHAPTER FIVE: CLIMATE CHANGE AND OCCUPATIONAL HEAT STRESS RISKS AND ADAPTATION STRATEGIES OF MINING WORKERS: PERSPECTIVES OF SUPERVISORS AND OTHER STAKEHOLDERS IN GHANA

Abstract

Increasing air temperatures as a result of climate change are worsening the impact of heat exposure on working populations, including mining workers, who are at risk of suffering heat-related illnesses, injury and death. However, inadequate awareness of climate change-related occupational heat stress risks and adaptation strategies have been shown to render occupational heat stress management ineffective. A concurrent mixed-methods approach was used to assess the perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers among supervisory personnel and other stakeholders in Ghana. Questionnaires and interviews were used to elicit data from 19 respondents. Data were processed and interpreted using descriptive statistics, chi-square and Fisher's exact tests, and thematic analysis. Supervisors' climate change risks perception was adequate, and their concern about workplace heat exposure risks was moderate. Mining workers' occupational heat stress risks experiences were linked to heat-related illness and minor injuries. Mining workers' adaptation strategies included water intake, use of cooling mechanisms, work-break practices, and clothing use. The related differences in job experience in the distribution of climate change risk perception and occupational heat stress risk experiences, and the difference in educational attainment in the distribution of adaptation strategies of occupational heat stress were significant ($p<0.05$). Hence, an effective workplace heat management policy requires adequate understanding of occupational heat stress risks and adaptation policies and continued education and training for mining workers.

Keywords: adaptation policies, climate change risks, heat stress experiences, mining workers, perceptions, supervisors

Introduction

Occupational heat exposure due to rising temperature and climate change has emerged as a threat to the health and safety, productivity, and social well-being of diverse working population in the world (Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2016b; United Nations [UN], 2009). For this reason, the essence of the 2030 Sustainable Development Goals (SDGs) is to guarantee healthy lives, promote well-being, ensure decent jobs and work capacity, and to combat intensifying temperature and climate change impacts (Leal *et al*., 2018; Xue *et al*., 2018; UN, 2015).

In Ghana, direct signs of climate change impacts are associated with increasing temperature, rainfall variability, extreme weather events (e.g., storms and floods) and sea level rise. For instance, in four decades (1960-2000), Ghana has broadly experienced an increase in mean temperature of around $1^{o}C$ since 1960 at an average rate $0.21\,^{o}C$ per decade (Government of Ghana, 2013, 2015). The average temperature is expected to rise by further $0.6\,^{o}C$, $2.0\,^{o}C$, and $3.9\,^{o}C$ in 2020, 2050, and 2080 respectively (Government of Ghana, 2013, 2015). Similarly, while rainfall levels have been reducing and becoming increasingly erratic, sea levels have risen by 2.1 mm per year over the four decades. Consequently, sea levels are projected to increase by 5.8 cm, 16.5 cm, and 34.5 cm in 2030, 2050, and 2080 respectively. Also, Ghana's total net Greenhouse Gas (GHG) emissions including Agriculture, Forestry and other Land Use (AFOLU) has increased from 14.22 million tons (Mt) CO_2-equivalent (CO_2e) in 1990 to 33.66 $MtCO_2e$ in 2012 (Government of Ghana, 2013, 2015). Like most countries in the tropical and sub-tropical regions of the world, climate change is worsening the impact of excessive heat exposure on workplace environments and puts outdoor physical workers including, but are not limited to, mining workers in Ghana at risks of heat stress (Frimpong et al., 2017; Xiang et al., 2016). Working in hot weather conditions without adequate mitigation, adaptation and social protection may significantly result in increases in heat-related illness and injuries, absenteeism, slow work pace, loss of productive capacity, and poor social well-being (Kjellstrom *et al*., 2016a; Nunfam *et al*., 2018).

Impacts of occupational heat stress (e.g., heat-related illness and injuries) are avoidable and controllable. Adequate awareness, knowledge and understanding of risks associated with climate change and occupational heat stress is a substantial part of heat stress management strategies (e.g., mitigation, adaptation and social protection policies). However, ineffective and unsustained heat stress management strategies due to weak and uncoordinated effort among stakeholders (e.g., government agencies, occupation health and safety service providers, employers, employees, and worker unions) are noticeable (Xiang *et al*., 2015b). Part of the gap relates to less concerns, varying knowledge and inadequate awareness of climate change-related occupational heat stress risks and adaptation strategies among workers, their supervisors and regulatory authorities (Balakrishnan *et al.*, 2010; Crowe *et al.,* 2010; Mathee *et al*., 2010; Stoecklin-Marois *et al*., 2013). Also, perception of temperature and climate change concerns, and the distress about its occurrence are positively associated (Li *et al*., 2015; Searle & Gow, 2010). But links between climate change concerns and heat stress, and perception of temperature and heat stress are less understood (Zander *et al*., 2017).

In particular, significant stakeholders (e.g., occupational health and safety managers, unionised interest groups, and regulatory authorities) at the forefront of occupational health and safety in Ghana's mining industry are significant actors in protecting and safeguarding workers' health, safety, productive capacity and social well-being. Not only do such stakeholders have the mandate of identifying, evaluating and controlling environmental and workplace-related hazards, but they are also responsible for monitoring, training and educating, prescribing important guidelines on heat stress management to workers. Perspectives of supervisors and other stakeholders on occupational heat stress risks and adaptation strategies of mining workers in the context of climate change in Ghana's mining industry is therefore valuable and timely. Hence, we sought to determine what are the perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers among these supervisory personnel and other stakeholders? We also sought to test the hypothesis that there are no significant differences in the distribution of climate change risks perceptions, occupational heat stress risks, and adaptation strategies among background characteristics of the supervisory personnel.

Materials and methods

In cognisance of the pragmatist methodological viewpoint, the concurrent mixed methods research strategy involving a descriptive cross-sectional survey was employed to provide a holistic understanding of the research problem (Creswell, 2002, 2013; Neuman & Kreuger, 2003; Neuman & Robson, 2012; Sarantakos, 2012). The mixed method was deemed appropriate to provide a complementary and corroborative analysis and understanding of multiple data (both quantitative and qualitative) on climate change risk perceptions, occupational heat stress risks, and adaptation strategies of mining workers among supervisors and stakeholders. The sample size (19) respondents consisted of 16 supervisory personnel (e.g., workplace hygienists; health, safety, and environmental officers) and three officials of the other (external) stakeholders (Ghana Chamber of Mines[GCM]; Inspectorate Division of the Minerals Commission [IDMC]; and Ghana National Association of Small Scale Miners [GNASSM]) of Artisanal Small Scale and Large Scale Mining Companies in Ghana). Purposive sampling was used to identify and select the participants with the knowledge and experience of the phenomenon of interest, after expressing their willingness to participate in the study based on informed consent (Bernard, 2017; Creswell & Clark, 2017). The participants were selected because they were directly responsible for overseeing and regulating the activities of mining workers and companies to ensure a decent, healthy and safe working environment. Participants also had the requisite professional competence, knowledge and experience beside the required depth of information related to issues of occupational health and safety, environmental hazards, and adaptation strategies of workers in the mining industry in the context of climate change.

Questionnaires and in-depth interviews were used in accessing data from the supervisory personnel and other stakeholders respectively on their perspectives of climate change risks, experiences of occupational heat exposure risks, and adaptation strategies of mining workers. The questionnaires were deemed suitable for the supervisory personnel because they were literate. In-depth interviews were used for the other stakeholders because of the need for detailed information. The content and design of the instruments was guided and adapted from the validated instruments used in the High Occupational Temperature Health and Productivity Suppression (HOTHAPS) programme and other studies related to peoples' perception of climate change, heat stress vulnerability, and its impacts on health, productivity, social lives, and adaptive capacity of workers (Kjellstrom, 2012; Kjellstrom *et al*., 2009a; Sheridan, 2007; Xiang *et al*., 2015b). The questions focused on perceptions and experiences of climate change and heat exposure risks, workplace health and safety policies and regulations governing working in hot environments, heat stress and climate change adaptation policies. The feasibility of the modified instruments (both open-ended and closed-ended question items) was pretested for clarity in Ghana after it was reviewed by experts from Edith Cowan University (ECU) to ascertain further validity and reliability. The fieldwork was conducted from October 2017 to December 2017. Most aspects of the data were collected during the 2017 National Inter-Mines First Aid and Safety Competition in Ghana, held from 12/11/2017 to 18/11/2017 under the theme: 'Safe and Responsible Mining! Our Heritage'. The fieldwork was preceded by the acquisition of ethical clearance from the Human Research Ethics Committee of ECU (Project Number 17487).

The qualitative data was organised with NVivo version 11 while the quantitative data were processed with the use of Microsoft Excel 2016 and IBM Statistical Product and Service Solutions (SPSS) version 24 to facilitate data analysis. Thematic analysis was employed to summarise the qualitative aspect of the data in the form of text, quotes and extracts based on emerging themes (Ritchie *et al*., 2013). The themes ensured easy description and interpretation based on relationships and differences in perceptions of climate change risks, experiences of occupational heat exposure risks, and adaptation policies. The quantitative data were analysed using descriptive statistics (e.g., minimum, maximum, frequency and percent), tables and charts. The Chi-square (χ^2) and Fisher's Exact tests were employed to test the hypothesis at the level of significance ($p < 0.05$). In social science research, the χ^2 and Fisher's Exact test are commonly used in statistical analyses to assess the probability of difference or association or independence between categorical variables (Franke *et al*., 2012; McHugh, 2013). The Yates' Continuity Correction, Likelihood Ratio, and Fisher's Exact test results were reported where assumptions of the χ^2 test were violated (Agresti, 1996; Fisher, 1935; McHugh, 2013; Pallant, 2010; Yates, 1934).

Results and discussion

Based on the mixed methods approach, results of the survey on the supervisory personnel were complemented by views of the other stakeholders. The results were also related to the relevant literature (e.g., reports, conceptual and empirical data) to provide comprehensive information and understanding of the perceptions of climate change and heat exposure risk concerns for adequate adaptation policy decisions in the mining industry.

Background characteristics

Table 5.1 shows the respondents' background characteristics. The results of the study revealed that 56.2% of the supervisory personnel were from large-scale mining companies, 93.7% were males, and the majority (62.4%) were within the ages of 31-40 years old. Also, 56.2% had graduate degrees, and 81.2% had over ten years of working experience in occupational health and safety (OH&S).

Pseudonyms (KS1, KS2 & KS3) were used to de-identify and report the views of the three stakeholders to ensure confidentiality. Officials who represented the three stakeholders in the in-depth interviews consisted of a research and analysis officer (KS1), director of operations (KS2) and a principal mine inspector (KS3). KS1 was responsible for health and safety policy advocacy and had a postgraduate degree and four years of working experience. KS2 was responsible for overseeing and coordinating the activities of SSM companies and had an undergraduate degree and five years of working experience and KS3 was responsible for enforcing mining laws, regulations and standards and had a first degree in mining and 10 years of working experience in the mining industry.

Table 5.1. Background characteristics of respondents (n=16)

Background characteristics	F	%
Type of mining:		
Small-scale mining	7	43.8
Large-scale mining	9	56.2
Sex:		
Male	15	93.7
Female	1	6.3
Age:		
31-40	10	62.4
41-50	5	31.3
51+	1	6.3
Education:		
Undergraduates	7	43.8
Graduate	9	56.2
Years of OH&S working experience:		
0-4	2	12.5
5-9	1	6.3
10+	13	81.2

Source: Field survey, 2017

Perceptions of climate change risks

Comparatively, the findings on varying and adequate awareness identified from this survey were reasonably similar to the views expressed during the in-depth interviews in similar studies found in the literature (e.g., Baptiste, 2017; Brechin & Bhandari, 2011; Lee *et al*., 2015; Pugliese & Ray, 2009;Thomas & Benjamin, 2018). The results of this study on the perceptions of climate change risks showed that all the supervisory personnel (Table 5.2) and the other stakeholders were adequately aware of the changes in patterns of climate conditions over the last three decades. For instance, one of the other stakeholders said:

> *Yes, we are all very much conversant with the issue of climate change, but we need to contextualise the change in weather pattern based on the location of the mines ... they are also experiencing some variations of the weather pattern (KS1).*

Another stakeholder commented that:

> *I have heard of weather changes, yes of course from the media, and other sources. Yes, I know that there have been changes, ocean levels are rising. I also know of the ozone*

layer depletion in certain parts of the world. In Ghana, for example, I know our weather system have shifted somehow (KS2).

Table 5.2. Perceptions of climate change risks based on the frequency of responses (n=16).

Awareness and concerns	F	%
Awareness of climate change:		
Yes	16	100
No	0	0
Signs of climate change (n=61):*		
Increase in temperature and hot environment	12	19.7
Irregular rainfall and storms	16	26.2
Frequent floods	7	11.5
Prolong drought	3	4.9
Rising sea level	12	19.7
No response	11	18
Mining workers at risk of workplace heat exposure due to climate change:		
Yes	12	75
No	4	25
Environmental factors influencing workplace heat exposure (n=45)*:		
How hot the air is around the workplace	12	26.8
The amount of air moisture in outdoor setting/workplace	11	24.4
Heat radiation from the sun and other sources around the workplace	11	24.4
No response	11	24.4
Work-related factors influencing heat exposure(n=77):*		
Type of physical workload	14	18.2
Duration of working hours	11	14.3
Type of protective clothing	11	14.3
Access to cooling systems (e.g., air conditions & fans)	9	11.7
Duration of break/rest hours	6	9.0
Access to shade	4	5.2
Access to drinking water	8	10.4
Type of clothing	2	2.6
No response	11	14.3
Extent of concern about workplace heat exposure:		
Not at all concerned	1	6.3
A little concerned	3	18.8
Moderately concerned	8	56.3
Very much concerned	3	18.8

*Multiple responses

Source: Field survey, 2017

Lower levels of climate change awareness were reported in Asia, the Middle East, North African and Sub-Saharan African regions (Pugliese & Ray, 2009). However, the findings related to climate change awareness in this study are more in line with the higher levels of climate change awareness and risk perception reported in regions of Europe, Japan and North America as well as other studies (Brechin & Bhandari, 2011; Lee *et al*., 2015; Neely, 2012; Pugliese & Ray, 2009). Adequate and sustained adaptation policies to climate change depend on workers' perceived and actual knowledge, awareness and understanding of climate change and heat exposure risks (Ford *et al*., 2010; Kjellstrom *et al*., 2016b; Tripathi & Mishra, 2017).

The opinions identified from the survey was primarily informed by increases in temperature and hot environment (19.7%), irregular rainfall and storms (26.2%), and rising sea levels (19.7%) (Table 5.2) as observed signs of climate change risk. Similarly, rising temperatures, humid and sunny weather conditions, unpredictable rainfall and rising ocean levels emerged as signs of climate change during the in-depth interviews with the other stakeholders. For example, a stakeholder observed that: 'the signs you see is the humid conditions, the sunny and the hot weather conditions' (KS3). Another stakeholder was of the view that:

> *In the past, we had a very defined period for our rainy seasons and the dry seasons, which are the two main seasons within the country, but now you cannot predict with certainty. You have rains during the dry seasons, and even in the rainy seasons, the rains may not come as expected. So it has made us revise our weather patterns (KS1).*

The findings related to signs of climate change risk reiterates similar results of various studies in which increasing temperatures, changes in precipitation patterns, changing humidity, sea level rise, and storm surges were identified as anthropogenic climate change risks (Evadzi *et al*., 2018; Hoogendoorn & Fitchett, 2018; van Oldenborgh *et al*., 2018). Similarly, in most tropical regions like Ghana, climate change risk is epitomised by variations in average temperature, precipitation, and wind conditions ascribed to increases in GHG (e.g., CO_2 and methane) emissions due to human activities (Government of Ghana, 2013, 2015). The perceptible variability of natural climate or extreme weather events (e.g., heat waves, high temperatures, erratic rainfall, drought, relative humidity, and sea levels) usually occur over a decade (United Nation Framework Convention on Climate Change [UNFCCC], 2010). These weather-related conditions are regarded as immediate factors of social vulnerability and risks of climate change (UNFCCC, 2010; UN, 2011).

Also, 75% of the respondents were of the view that due to climate change mining workers were at risk of workplace heat exposure. Similar views expressed by the stakeholders showed that mining workers were at risk of workplace heat exposure. For instance, one stakeholder indicated that:

> *The mining workers are at risk of heat exposure when they remain in that condition for a longer period. That is, in that humid or hot weather conditions for longer period.… so we have to get some mitigation measures to put in place to avoid* this heat stress and then exhaustion and the rest (KS3).

It was also observed by another stakeholder that:

> *If there is a large amount of rain, it slows down the mining activities. The dry season is very good for mining.…, but it's not good for the individuals [workers] because it leads to the rapid dehydration of the individual and it can lead to the potential of people collapsing and fainting or even getting exhausted very quickly because of the dry, humid and hot weather condition (KS1).*

The workplace heat exposure was attributed to environmental factors such as the extent of hot air around workplaces (26.8%), the amount of air moisture in outdoor setting or workplaces (24.4%) and heat radiation from the sun and other sources around the environment (24.4%). Work-related conditions such as the type of physical workload (18.2%), duration of work (14.3%), type of protective gear (14.3%), access to cooling systems (e.g., fans & air conditions), and drinking water were also perceived as contributory factors to heat exposure (Table 5.2).

The findings of the study that ascribed workplace heat exposure risk to environmental and work-related factors were supported by the view that heat exposure risk is associated with exposure factors such as environmental, personal, and occupational-related heat risks. Factors related to the environment are influenced by a combination of higher ambient temperatures, radiant heat and relative humidity, often accompanied by calm days with reduced air flow (Kjellstrom *et al*., 2009b; Schulte & Chun, 2009). The occupational-related heat exposure factors include clothing type, physical activity, cooling system, work-rest regimes, break hours, access to shade and drinking water, and the personal related factors include age, sex, body size, pre-existing disease, acclimatization, type of work, lifestyle, medication, drugs, and alcohol (Haines & Patz, 2004; Kjellstrom *et al*., 2016a; McMichael *et al*., 2006; Parsons, 2014).

Given the extent of climate change risks awareness, 56.3% of respondents were moderately concerned about heat stress-related morbidity and mortality associated with workplace heat exposure conditions in the mining sector (Table 5.2). In a similar study of perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialist in Australia, most respondents (90%) were at least moderately concerned about extreme heat exposure (Xiang *et al*., 2015b). Also, a survey of mining sector practitioners in Canada found that the respondents were somewhat concerned about future climate change impacts (Ford et al., 2010).

Considerably, individual and social awareness of climate change and perception of its risk constitute an essential part of informing policy decisions and improving climate change risk information and communication (Aswani *et al*., 2015; Carlton & Jacobson, 2013; Hagen *et al*., 2016). Hence, the awareness and understanding of the supervisory personnel and stakeholders' perceptions about climate change risk are important for policymaking, risk communication and critical to any strategic response to combating climate change impacts (Carlton & Jacobson, 2013; Lorenzoni & Pidgeon, 2006).

The results of the χ^2 test for differences in the proportion of perceptions of climate change risks among background characteristics of the supervisory personnel are illustrated in Table 5.3. The differences in distribution of climate change risks perceptions based on the signs of climate change ($\chi^2(3)=0.290$, $p=0.962$), workers at risks of workplace heat exposure ($\chi^2(1)=0.085$, $p=0.585$), environmental factors ($\chi^2(2)=0.796$, $p=0.672$), work-related factors ($\chi^2(4)=8.885$, $p=0.064$), and concerns about workplace heat exposure ($\chi^2(1)=0.017$, $p=0.438$) between categories of type of mining were not significant at alpha level of 0.05 (Supplementary Tables 1-5). Also, the differences in proportion of climate change risks perceptions based on the signs of climate change ($\chi^2(3)=1.337$, $p=0.720$), workers at risks of workplace heat exposure ($\chi^2(1)=0.085$, $p=0.585$), environmental factors ($\chi^2(2)=3.971$, $p=0.137$), work-related factors ($\chi^2(4)=5.974$, $p=0.201$), and concerns about workplace heat exposure ($\chi^2(1)=0.017$, $p=0.438$) between categories of level of education were not significant at alpha level of 0.05 (Supplementary Tables 6-10).

However, the differences in distribution of climate change risks perceptions based on the signs of climate change ($\chi^2(3)=10.944$, $p=0.012$), workers at risks of workplace heat exposure ($\chi^2(1)=6.701$, $p=0.007$), environmental factors ($\chi^2(2)=10.944$, $p=0.004$), and work-related factors ($\chi^2(4)=11.623$, $p=0.020$) except concerns about workplace heat exposure ($\chi^2(1)=0.000$, p=1.000) between the categories of years of OHS work experience were statistically significant at alpha level of 0.05 (Supplementary Tables 11-15). Thus, while the differences in the distribution of climate change risks perceptions between the categories (type of mining and level of education) were not significant, the differences in the distribution of climate change risk perceptions between the categories of years of OHS work experience were significant at the level ($p<0.05$).

Table 5.3. The difference in the distribution of climate change risks perception among background characteristics of supervisory personnel of mining workers (Chi-square test)

Background characteristics	Perceptions of climate change risks									
	Signs of climate change		workers at risk of workplace heat exposure		Environmental factors influencing workplace heat exposure risk		Work-related factors influencing workplace heat exposure risk		Concerns about workplace heat exposure/heat stress risk	
	n (%)	*p*-value	n (%)	*p*-value	n (%)	*p*-value	n (%)	*p*-value	n (%)	*p*-value
Type of mining:										
SSM	7(43.8)	0.962	7(43.8)	0.585	7(43.8)	0.672	7(43.8)	0.064	7(43.8)	0.438
LSM	9(56.2)		9(56.2)		9(56.2)		9(56.2)		9(56.2)	
Years of OHS work experience:										
Under 10 years	3(18.8)	0.012*	3(18.8)	0.007*	3(18.8)	0.004*	3(18.8)	0.020*	3(18.8)	1.000
10 years and over	13(81.2)		13(81.2)		13(81.2)		13(81.2)		13(81.2)	
Level of education:										
Undergraduate	7(43.8)	0.720	7(43.8)	0.585	7(43.8)	0.137	7(43.8)	0.201	7(43.8)	0.438
Graduates	9(56.2)		9(56.2)		9(56.2)		9(56.2)		9(56.2)	

Source: Authors, 2017

Experiences of occupational heat stress risk

We found that workers' experiences of heat-related illnesses and injuries were associated with workplace heat exposure as shown in the literature (Balakrishnan *et al*., 2010; Stoecklin-Marois *et al*., 2013; Xiang *et al*., 2015a, 2016). Table 5.4 presents the experiences of occupational heat stress risks of mining workers as described by supervisors of the respondents involved in this research. Eighty-seven percent of supervisory personnel were of the view that, in their respective working experience, mining workers had expressed concern about workplace heat exposure during hot weather conditions. Hence, heat-related illness concerns most frequently expressed by mining workers included excessive sweating (25.5%). This was followed by headaches (17.6%), heat rash (15.7%), fainting (13.7%), and heat exhaustion or tiredness (5.9%).

Similarly, empirical evidence (e.g., in Australia, Southern India, California, and South Africa) confirms the view that mining workers were concerned about workplace heat exposure and its associated illness and injury conditions (Singh *et al*., 2015; Stoecklin-Marois *et al.*, 2013; Xiang *et al*., 2016). Specific studies related to mining workers also substantiates comparable experiences of heat-related illness concerns among surface and underground mining workers in US and Australia (Donoghue, 2004; Donoghue *et al*., 2000; Hunt, 2011).

Furthermore, views akin to heat tiredness, fainting, excessive sweating and dehydration were expressed by other stakeholder interviewees as heat-related illness concerns of mining workers as exemplified in the following statements:

> *What is quite popular is the exhaustion, of course, it may lead to the person fainting, collapsing etc. So there is a risk that you [worker] may be dehydrated. So water has been provided at point A, B or C to make sure you [worker] drink water from time to time on a regular basis. If for some reasons you [worker] think you are dehydrated and need a break (KS1).*

> *That is why we ensure that where you [workers] are working you don't have poor ventilation. If you experience excessive sweating, you have to report to the supervisor. What is guiding the regulation is that at first, we were experiencing these heat stress and heat strokes, so the regulations seek to address all these challenges so that they don't encounter such situation again (KS3).*

> *Yes, excessive sweating. There have been some experiences of headaches, but may be not to the extent of dehydration because the workers drink a lot of water when on site compared to when they are in the house (KS2).*

Table 5.4. Experiences of occupational heat stress risk (n=16)

Experience of occupational heat stress	F	%
Workers concerns about heat exposure at workplace:		
Yes	14	87.5
No	2	12.5
Heat-related illness concerns (n=51):*		
Excessive sweating	13	25.5
Headaches	9	17.6
Heat exhaustion/tiredness	3	5.9
Heat rash	8	15.7
Heat syncope(fainting)	7	13.7
No response	11	21.6
Heat-related injury concerns:		
Yes	9	56.3
No	7	43.8
Extent of injury:		
Minor	5	55.6
Moderate	4	44.5
Type injury concerns (n=23):*		
Burns from hot objects/surfaces	5	21.7
Falls, trips, and slips due to dizziness, fainting and fatigue	5	21.7
Being hit by objects	2	8.8
No response	11	47.8
Witnessed heat-related injury to mining workers:		
Yes	6	37.5
No	10	62.5
Type of injury witnessed (n=18):*		
Burns from hot objects/surfaces	3	16.7
Falls, trips, and slips due to dizziness, fainting and fatigue	2	11.1
Loss of grip and controls due to sweaty hands	1	5.6
Being hit by objects	1	5.6
No response	11	61.1

*Multiple response
Source: Field survey, 2017

In addition, 56.3% of the supervisory personnel indicated that mining workers had some form of heat-related injury concerns in their workplaces or workplaces where they had consulted during hot weather conditions. However, unlike studies in Thailand and Southern Australia (e.g., Tawatsupa *et al*., 2013; Xiang *et al*., 2016), the magnitude of occupational heat-related injuries was described by 55.6% of the respondents as minor injury conditions other than moderate, serious, severe, or critical injury conditions. Also, falls, trips, and slips due to dizziness, fainting and fatigue were indicated by 21.7% of the respondents as the common cause of the injuries aside from burns (21.7%) and being hit by objects (8.8%). As substantiated in other studies, the findings based on occupational heat-related injury concerns have been linked to workplace heat stress due to extreme heat exposure. For instance, heat stress is associated with occupational injury concerns in tropical Thailand and Southern Australia under extreme heat exposure (Tawatsupa *et al*., 2013; Xiang *et al*., 2016). As to whether the supervisory personnel had ever witnessed any form of heat-related injury to mining workers, 37.5% answered in the affirmative. Moreover, 16.7% associated such injuries to burns from hot surfaces and objects and 11.1% linked the injuries to falls, trips, and slips due to dizziness, fainting and fatigue (Table 5.4).

The knowledge and experiences of occupational heat stress risk concerns of mining workers, as corroborated by climate change reports in Ghana and other studies, highlights the growing impact of heat exposure as a result of rising temperature and climate change, extreme weather events, GHG emissions and loss of carbon sinks (GoG, 2013, 2015; Xiang *et al*., 2016). Occupational heat stress risks and impacts possess the tendency of affecting workers' health and safety, productive capacity, efficient performance, and social well-being (Kjellstrom *et al*., 2016b; Nunfam *et al*., 2018; Venugopal *et al*., 2016). It is important to incorporate the identified occupational heat stress risk concerns into national and workplace health and safety policies and adaptation strategies. Moreover, enforcing such policies promotes suitable job environments by reducing worker's vulnerability and enhancing their adaptive capacity and resilience to heat stress-related health and safety effects. It also enhances capacity of institutions working on climate-related health issues in low- and middle-income countries to prevent further health burdens in the context of climate change (Ebi *et al*., 2017).

The outcome of the χ^2 test for differences in the distribution of occupational heat stress risks experiences among background characteristics of the supervisory personnel is presented in Table 5.5. The disparities in the proportion of occupational heat stress risks experiences signified by workers concern about heat exposure ($\chi^2(1)=0.000$, $p=1.000$), heat-related illness concerns ($\chi^2(4)=0.429$, $p=0.980$), experience of heat-related injury ($\chi^2(1)=0.000$, $p=1.000$), magnitude of heat-related injury ($\chi^2(2)$ =0.000, p=1.000), worker's injury concerns ($\chi^2(2)$ =0.912, p=0.634), heat-related injury ever witnessed ($\chi^2(1)$ =0.000, p=1.000), and workers heat-related concerns witnessed ($\chi^2(2)$ =1.740, p=0. 419) between categories of type of mining were not significant at 0.05 (Supplementary Tables 16-22). Also, the disparities in the distribution of occupational heat stress risks experiences characterised by workers concern about heat exposure ($\chi^2(1)$ =0.327, p=0.475), heat-related illness concerns ($\chi^2(4)$ =6.341, p=0.174), experience of heat-related injury ($\chi^2(1)$ =2.520, p=0.060), magnitude of heat-related injury ($\chi^2(1)$ =0.056, p=0.524), worker's injury concerns ($\chi^2(2)$ =4.731, p=0.094), heat-related injury ever witnessed ($\chi^2(1)$ =0.830, p=0.302), and workers heat-related concerns witnessed ($\chi^2(2)$ =2.983, p=0.225) between categories of level of education were not significant at 0.05 (Supplementary Tables 23-29).

However, the disparities in the distribution of occupational heat stress risks experiences indicated by workers concern about heat exposure ($\chi^2(1)$ =4.747, p=0.025) and heat-related illness concerns ($\chi^2(4)$ =12.670, p=0.013) aside from the experience of heat-related injury ($\chi^2(1)$ =0.059, p=0.550), magnitude of heat-related injury ($\chi^2(1)$ =0.000, p=1.000), worker's injury concerns ($\chi^2(2)$ =1.660, p=0.436), heat-related injury ever witnessed ($\chi^2(1)$ =0.000, p=1.000), and workers heat-related concerns witnessed ($\chi^2(2)$ =5.434, p=0.066) between categories of years of OHS work experience were significant at 0.05 (Supplementary Tables 30-36). Thus, whereas the differences in the distribution of occupational heat stress risks experiences between the categories (type of mines and level of education) were not significant, the differences in the distribution of occupational heat stress risks experiences based on workers' concern about heat exposure and heat-related illness concerns between the categories of years of OHS work experience were statistically significant at the level ($p<0.05$).

Table 5.5. The difference in the distribution of occupational heat stress risks among background characteristics of supervisory personnel of mining workers (Chi-square test)

Background characteristics	Experiences of occupational heat stress risks													
	Workers concern about heat exposure		Heat-related illness concerns		Experience of heat-related injury		Description of injury extent		Workers injury concerns		Witnessed any form of heat-related injury		Type of heat-related injury witnessed	
	n (%)	*p*-value	n (%)	*p*-value	n (%)	*p*-value	n (%)	*p*-value	n (%)	*p*-value	n (%)	*p*-value	n (%)	*p*-value
Type of mining:		1.000		0.980		1.000		1.000		0.634		1.000		0.419
SSM	7(43.8)		7(43.8)		7(43.8)		4(44.4)		4(44.4)		7(43.8)		7(43.8)	
LSM	9(56.2)		9(56.2)		9(56.2)		5(55.6)		5(55.6)		9(56.2)		9(56.2)	
Years of OHS work experience:		0.025*		0.013*		0.550		1.000		0.436		1.000		0.066
Under 10 years	3(18.8)		3(18.8)		3(18.8)		3(18.8)		3(18.8)		3(18.8)		3(18.8)	
10 years and over	13(81.2)		13(81.2)		13(81.2)		13(81.2)		13(81.2)		13(81.2)		13(81.2)	
Level of education:		0.475		0.175		0.060		0.524		0.094		0.302		0.225
Undergraduate	7(43.8)		7(43.8)		7(43.8)		6(66.7)		7(43.8)		7(43.8)		7(43.8)	
Graduate	9(56.2)		9(56.2)		9(56.2)		3(33.3)		9(56.2)		9(56.2)		9(56.2)	

Source: Authors, 2017

Preventive and control measures of occupational heat stress due to climate change

Sustainable measures directed at avoiding and adjusting to the risks and worsening impacts of occupational heat stress due to climate change include, but are not limited to, the awareness and implementation of mitigation, adaptation and social protection strategies (Kjellstrom *et al*., 2016b; Nunfam *et al*., 2018). Significantly, all the respondents affirmed their awareness of the preventive and control measures of occupational heat stress due to climate change. As a result, drinking adequate water was identified by most (25.8%) of the respondents as a key measure for averting and adjusting to occupational heat stress. This was complemented by the use of air conditions and fans (22.6%), taking work breaks and resting in the shade (22.6%), and wearing loose and light-coloured clothing (7%) (Figure 5.1).

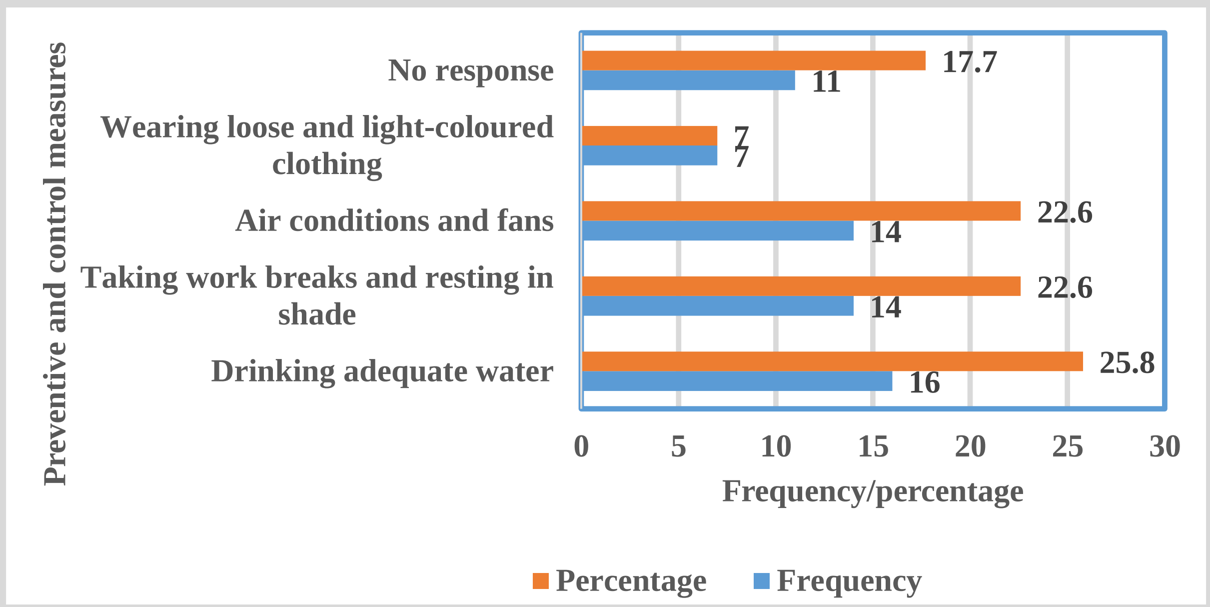


Figure 5.1: Preventive and control measures of occupational heat stress due to climate change

Source: Field survey, 2017

Similarly, data from the in-depth interviews among the other stakeholders indicated the awareness and use of schedule work breaks and rest regimens, cooling systems, cold water, and structural designs to ensure airflow to prevent and control occupational heat stress among workers. Hence, the following extracts highlight the expressions of stakeholders during the interviews:

> *Yes. We also look at the temperatures where you [worker] are working. The surface temperature should not exceed 32.5 degrees, that is, the wet bulb. It should also not exceed 27 degrees, the wet bulb temperature in the mines underground. Where it exceeds 27 degrees, you have to make provisions for breaks and long resting time, so that they*

can take some water. All these happen in the underground environment. The wet bulb should not exceed 32.5 degrees Celsius at all in the mine (KS3).

We have some breaks. Between 11.30 and 12.30pm is when they take breaks for their lunch and have rest under shades. And in the offices, we have some fans and offices are built such that we have some tress and shelter around. They [workers] come to work at 7.30 am have their breakfast, by 8.00am work resumes and between 11.30 am and 12.30pm they have their break and lunch, and by 4.30 pm we are done (KS2).

So this is where the occupational hygiene becomes very critical or fundamental. They design their own process if they will to allow more ventilation or more aeration in their offices, they design their structures to reflect that. If for one reason their structures do not have it and they have to put in an air condition they will do that. If for one reason they will have to supply a lot of tea for the workers or they have to provide more liquids, they will (KS1).

Findings from the survey and in-depth interviews as substantiated in analogous studies re-echoes the significance of workers' awareness and use of adaptation strategies (e.g., structural designs, cooling systems, drinking water, rest regimens, clothing type) in managing the risk and impact of occupational heat stress (e.g., Flocks *et al*., 2013; Lao *et al*., 2016; Pradhan *et al*., 2013). Aside from mitigation, the knowledge, awareness and enforcement of occupational heat stress adaptation strategies among cohorts of workplace managers and other stakeholders is substantial in improving and reinforcing policy decisions required in combating the effects of rising temperature and climate change (Stoecklin-Marois *et al*., 2013; Xiang *et al*., 2015b, 2016).

Table 5.6 shows results of the χ^2 tests for difference in the distribution of perceived preventive and control measures of occupational heat stress due to climate change among background characteristics of supervisory personnel. There were more proportions of supervisory personnel within the SSM companies who identified taking work breaks and resting in shades (57.1%), as compared to more proportions of supervisory personnel within the LSM who identified wearing loose and light-coloured clothing (71.4%) as measures of preventing and controlling heat stress due to climate change among mining workers (Table 5.6). The difference in the distribution of preventive and control measures of heat stress due to climate change among mining workers within the type of mining was not significant ($\chi^2(2) =1.221$, p=0.543) (Supplementary Table 37).

Similarly, there were more proportions of supervisory personnel with undergraduate degrees who identified drinking adequate water (100%) and taking work breaks and resting in shade (57.1%) as compared to more supervisory personnel with graduate degrees who identified wearing loose and light-coloured clothing (85.7%) as measures of preventing and controlling heat stress due to climate change among mining workers. In this scenario, there was evidence that the difference in the distribution of preventive and control measures of heat stress due to climate change among mining workers within the level of education was significant ($\chi^2(2)$ =6.628, p=0.036) (Supplementary Table 38).

Table 5.6. The difference in the distribution of perceptions of preventive and control measures of occupational heat stress due to climate change among background characteristics of supervisory personnel (Chi-square test)

Background characteristics	Preventive and control measures							
	Drinking adequate water		Taking work breaks and resting in shades		Wearing loose and light-coloured clothing		Total	
	n	%	n	%	n	%	n	%
Type of mining:								
SSM	1	50	4	57.1	2	28.6	7	43.8
LSM	1	50	3	42.9	5	71.4	8	56.2
Total	2	100	7	100	7	100	16	100
Level of education:								
Undergraduate	2	100	4	57.1	1	14.3	7	43.8
Graduate	0	0	3	42.9	6	85.7	8	56.2
Total	2	100	7	100	7	100	16	100
Years of OHS work experience:								
Under 10 years	1	50	0	0	2	28.6	3	18.8
10 years and over	1	50	7	100	5	71.4	13	81.2
Total	2	100	7	100	7	100	16	100

Source: Authors, 2017

In addition, there were more proportion of supervisory personnel with 10 years or more OHS work experience as compared to those with under 10 years who identified taking work breaks and resting in shades (100%) and wearing loose and light-coloured clothing (74.1%) as measures of preventing and controlling heat stress due to climate change among mining workers. But, the difference in the distribution of preventive and control measures of heat stress due to climate change among mining workers within the years of OHS work experience was not significant ($\chi^2(2)$ =4.294, p=0.117) (Supplementary Table 39). Therefore, there is no evidence that the difference in the distribution of perceptions of preventive and control measures of occupational heat stress due to climate change among background characteristics, except the level of education of supervisory personnel was statistically significant at the level (p<0.05).

Conclusions and implications for policy decisions

Work supervisors and other stakeholders are significant actors in the mining industry with the responsibility of directly supervising and regulating the activities of mining workers and companies in Ghana. This study provides insights into climate change and occupational heat stress risks and adaptation strategies of mining workers from the perspectives of their supervisors and other stakeholders, who play a vital role in leadership and policy to reduce risks and impacts on workers. Compared to other studies in developing regions (e.g., Asia, the Middle East, and Sub-Saharan Africa) (Pugliese & Ray, 2009), we found higher levels of climate change awareness and risk as reported in more developed countries. Although the supervisors and stakeholders were adequately aware of climate change risk and like other studies (e.g., Xiang *et al*., 2015b), their concern about workplace heat exposure due to climate change risk was moderate. The experiences of occupational heat stress risks of mining workers were associated with heat-related illnesses and minor injuries. Mining workers' awareness and use of adaptation strategies as observed by the supervisors and stakeholders included drinking adequate water, use of cooling systems, taking work breaks and rest, and wearing loose and light-coloured clothing.

Climate change risk perception and occupational heat stress risk experiences (based on workers' concern about heat exposure and heat-related illness) were associated with years of OHS work experience. Preventive and control measures of occupational heat stress due to climate change risk perception was associated with educational level. Educational attainment has been associated with climate change awareness as the single strongest predictor (Lee *et al*., 2015). The differences within years of OHS working experience and education level suggest that job experience and educational attainment are essential to any effective climate change risk perception and adaptation strategies to occupational heat stress due to climate change. An understanding of climate change risk perception, occupational heat stress risk experiences, and adaptation strategies of mining workers among supervisors and stakeholders are important for policymaking, risk communication and combating climate change impacts (Carlton & Jacobson, 2013; Lorenzoni & Pidgeon, 2006). It is also suitable for informing heat exposure education and training and heat stress management among mining workers to guarantee healthy lives, promote well-being, ensure decent jobs and work capacity. Consequently, this will help reduce vulnerability to the incidence of heat-related illness, injuries and possible death, and improve the adaptive capacity of mining workers.

CHAPTER SIX: PERCEPTIONS OF CLIMATE CHANGE AND OCCUPATIONAL HEAT STRESS RISKS AND ADAPTATION STRATEGIES OF MINING WORKERS IN GHANA

Abstract

Heavy physical workload for long hours coupled with increasing workplace heat exposure due to rising temperatures stemming from climate change, especially where there are inadequate prevention and control policies, adversely affect workers' health and safety, productive capacity and social well-being. However, variations in workers' concerns and awareness of occupational heat stress and climate change risks impede the effectiveness of heat stress management. A mixed method approach was used to assess climate change perceptions and occupational heat stress risks and adaptation strategies of Ghanaian mining workers. Questionnaires and focus group discussions were used to collect data from 320 respondents. Quantitative and qualitative approaches were used for data analysis. Workers' climate change risk perception, as confirmed by trends in climate data, was reasonable, but concerns about climate change effects and workplace heat exposure risks varied significantly across types of mining activity ($p < 0.001$). Workers experienced heat-related morbidities, but the variation in heat-related morbidity experiences across the type of mining activity was not significant. However, the type of heat-related morbidities experienced by workers differed across the type of mining activity ($p < 0.001$). Workers' awareness of occupational heat stress prevention and control was adequate. The disparities in workers' awareness and use of the prevention and control measures significantly differed across the type of mining activity ($p < 0.001$). Occupational heat stress prevention activities should focus on workers, and a concerted effort must be made to promote workers' adaptive capacity and inform policy decisions.

Keywords: adaptation measures, climate change risk, Ghana, heat stress experience, mining workers, perception

Introduction

Key components of the global development agenda to improve people's lives and livelihoods, as envisioned in the 2030 Sustainable Development Goals (SDGs), are to ensure healthy lives and promote well-being (SDGs 3), guarantee decent jobs and economic growth (SDGs 8), and combat increasing temperature and other climate change impacts (SDGs 13) (Leal Filho *et al*., 2018; United Nations [UN], 2015). These SDGs are reasonably informed by climate change and heat waves, which negatively impact on workers' health and safety, productivity, and social well-being due to heat exposure (Kjellstrom *et al*., 2016a; 2016b).

Evidence of global climate change risks due to increased human-induced Greenhouse Gas (GHG) emissions includes increasing temperature and humidity, more erratic precipitation, and rising sea levels over medium to long timeframes. It also includes more extreme weather events (e.g., storms, prolonged drought, floods and heatwaves) (United Nation Framework Convention on Climate Change [UNFCCC], 2010). Intergovernmental Panel on Climate Change (IPCC) reports have shown that global CO_2 concentrations have increased around 290 ppm since 1880 to 405 ppm in 2016 and 406.55 ppm as of August 2018 (IPCC, 2014b; Scripps Institution of Oceanography, 2018). Without effective climate change mitigation, CO_2 concentrations are likely to increase to somewhere between 540 - 1300 ppm in the period 2030 to 2100. The global mean temperature increase since the 1850s (currently 0.6 ± 0.2 ^{o}C) is estimated to increase by between 1.4 ^{o}C and 5.8 ^{o}C in 2100 (IPCC, 2014c). Although continental precipitation has increased by 5 - 10% in the Northern Hemisphere over recent decades, it has decreased in other regions (e.g., West and North Africa, and parts of the Mediterranean). Global mean annual precipitation is estimated to increase in the 21st Century but with regional-scale variations projected at 5 - 20%. Global mean sea levels have risen since 1890. Sea levels are currently rising at a rate of about 3.2 mm per year, and may increase by up to 2 m by 2100 (NASA, 2018a; 2018b).

Climate change data in Africa have shown an increase in temperature (~0.7 °C) over the continent, a decrease in rainfall in parts of the Sahel region, and an increase in rainfall in East and Central Africa during the 20th Century (IPCC, 2001). During the 21st Century, the temperature is expected to increase in Africa faster than the global average increase, whereas mean annual precipitation is projected to decrease in outer regions (Mediterranean, Northern, and Southern Africa), increase in Central and Eastern Africa, and vary in West Africa (IPCC, 2014a).

Ghana's mean temperature increased by 1 ^{o}C at an average rate (0.21 ^{o}C) per decade (1960-2000) and is projected to increase by between 1.0 ^{o}C-3.0 ^{o}C in 2060 and 1.5 ^{o}C-5.2 ^{o}C in the 2090s (Government of Ghana[GoG], 2013, 2015). Trend and variability analysis have showed that rainfall was unpredictable but reduced in amount in recent decades. Sea levels rose by 2.1 mm per year over the period (1960-2000) and are projected to increase by 5.8 cm and 16.5 cm in 2020 and 2050 respectively (GoG, 2013, 2015).

The predicted rise and intensity of temperature and humidity levels in tropical developing countries like Ghana driven by climate change aggravate the impacts of excessive work-related heat exposure on varied workplace environments (e.g. indoor/outdoor) and industries including the mining sector. Thus, the study of mining workers as both beneficiaries of the socioeconomic development of mining and victims of climate change-related occupational heat stress risks due to working outdoors for long hours (as compared to other industries) is deemed worthwhile. The mining sector plays a key role in the Ghanaian economy involving direct foreign and local investments, foreign exchange earnings, employment, income and revenue generation (Ghana Statistical Service (GSS), 2015; McMahon & Moreira, 2014).

The interrelated concerns of industries including mining operations and climate change-related heat exposure can have substantial adverse effects on workers' occupational health and safety, productive capacity, and productivity of industries including mining companies. For instance, in the US, 423 cases of death were recorded among all workers including 68 crop production workers because of heat exposure from 1992 to 2006 (CDC, 2008). Also, an aggregate of 20 cases of heat-related morbidity and mortality that occurred among workers were reported by the Occupational Safety and Health Administration (OSHA) during an analysis of federal cases of heat exposure in 2012-2013 (Arbury *et al*., 2014). In South Korea, a study of workers' compensation data (2010-2014) revealed 47 incidents of illness among outdoor workers due to environmental-related heat exposure (Park *et al*., 2017). Furthermore, nonattendance and decreased work execution because of heat resulted in an economic loss of US$655 per individual and an overall financial burden of US$6.2 billion in Australia (Dunne et al., 2013). Worldwide modelling of labour efficiency losses predicts a reduction in work capacity in the most humid month of the year by 37% and 20% based on climate change projections RCP8.5 and RCP 4.5, respectively (Zander *et al*., 2015).

Despite predictions of increased heat-related impacts on workers in a warming climate, the relationship between increasing temperatures and heat stress perceptions by workers are not well understood (Zander *et al*., 2017). Small-scale mining (SSM) and large-scale mining (LSM) activities (e.g., surface and underground mines) in hot and humid weather conditions without adequate mitigation, coping, adaptation and social protection increases mining workers risk to heat-related morbidities which result in absenteeism, loss of productive capacity, slow work pace, and poor social well-being (Kjellstrom *et al*., 2016b; Nunfam *et al*., 2018). SSM operations are informal mining practices by individuals, groups or cooperations with inadequate technology, whereas LSM operations are carried out by multinational companies with advanced technology. There may be differences in the impact of occupational heat stress between these two types of mining.

Climate change-related occupational heat stress management strategies are available, but its effective management depends on workers' and supervisors' awareness of heat stress impacts as well as prevention and control strategies. As such, multiple studies have explored perceptions and experiences of heat exposure and climate change impacts, and adaptation strategies of worker cohorts (Balakrishnan *et al*., 2010; Flocks *et al*., 2013; Xiang *et al*., 2015, 2016). However, there generally appears to be less concern and inadequate awareness of occupational heat stress risks of working in hot settings among workers despite the growing anxiety among researchers about the impacts of excessive heat exposure on workers (Crowe *et al*., 2009). Similar studies also confirmed inconsistencies with concerns and knowledge of heat exposure risks, and adaptation strategies among workers, supervisors, and other stakeholders (Xiang *et al*., 2015). Unlike the construction, manufacturing, and agricultural industries (Balakrishnan *et al*., 2010; Jacklitsch, 2017; Xiang *et al*., 2016), there is inadequate research into climate change perceptions and occupational heat stress risks and adaptation strategies among SSM and LSM workers in Africa. Therefore, an investigation into the trend and variability of climate change, climate change perceptions and occupational heat stress risks, and adaptation strategies of mining workers in Ghana is appropriate. This study also assessed the difference in demographic and work characteristics, climate change risks perception, occupational heat stress risks, and adaptation strategies between the two types of mining workers (SSM and LSM).

Materials and methods

Philosophical perspective and study design

Based on the pragmatist philosophical perspective, this study employed the concurrent mixed methods and descriptive cross-sectional survey approaches to provide an assessment of the research problem (Creswell, 2013; Creswell & Plano Clark, 2017). The study combined quantitative and qualitative strategies to seek complementary and corroborative assessment, description and understanding of mining workers' climate change perception, occupational heat stress risks, and adaptation strategies at a point in time in Ghana as a case study (Creswell, 2013; Mertens, 2015).

Study setting, population, sampling procedure and sample size

Ghana is situated in the West African sub-region. Ghana was chosen for the study because it has a tropical climate couple with being a hub of mining activities susceptible to the risks and impacts of heat exposure. Mining activities in Ghana are characterised by inadequate technology, low adaptive capacity and the high intensity of mining workers, particularly in the informal sector. There is also an absence of studies on the impact of climate change and occupational heat stress and adaptation in Ghana's large mining industry (GoG, 2015; GSS, 2013). This study was conducted among mining workers at five mining sites within the Western Region of Ghana (Figure 6.1). In Ghana, mining is commonly operated by accredited Artisanal and Small-Scale Mining (ASSM) and LSM operators, which are mostly multinational mining companies.

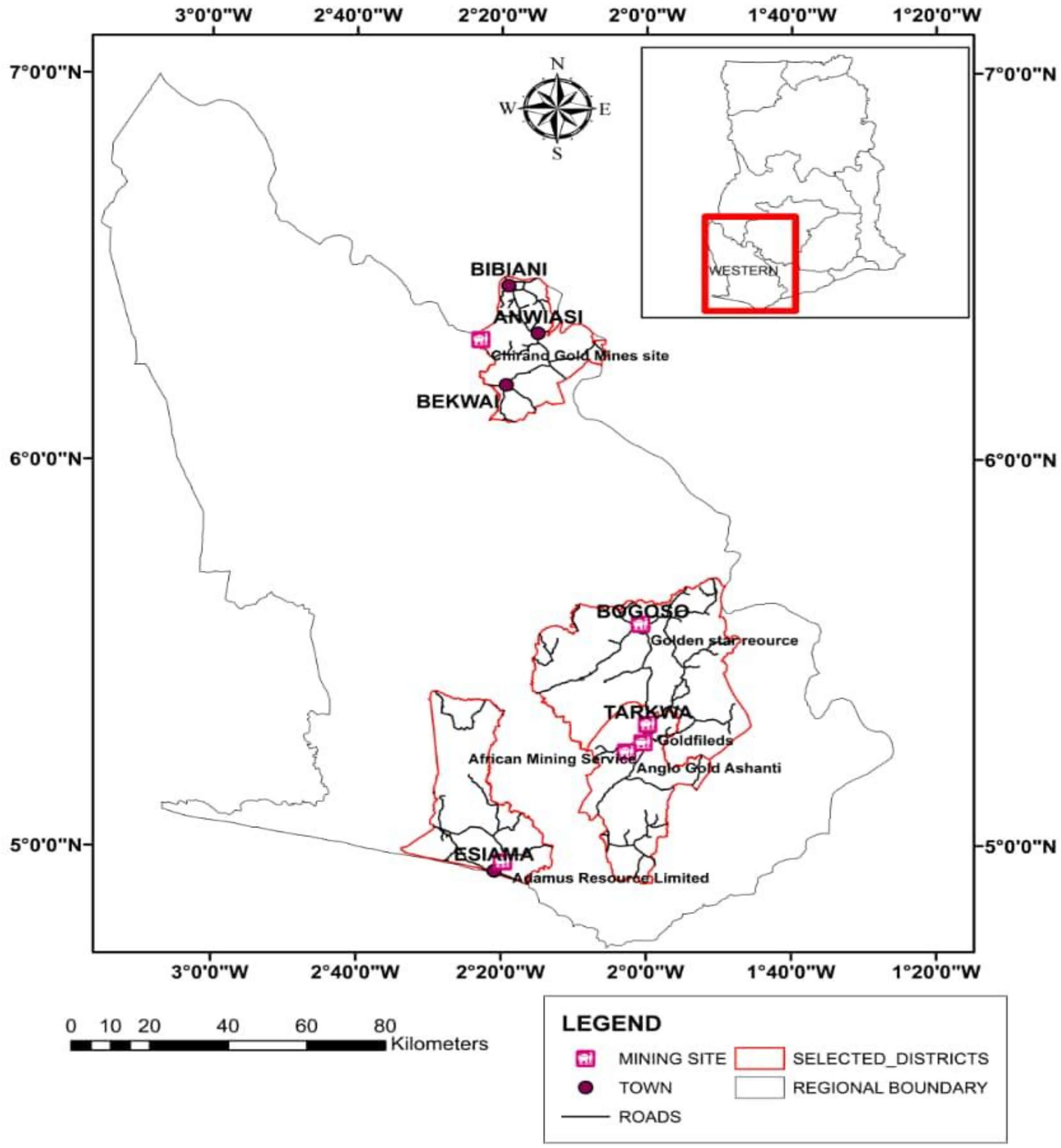


Figure 6.1: A map showing five mining sites located in the Western Region of Ghana

Source: Department of Geography and Regional Planning, University of Cape Coast, 2018

The study population is over one million mining workers and consisted of approximately a million people directly engaged in ASSM (McQuilken & Hilson, 2016), and some 9,939 employees engaged by the 13 LSM companies operating in the country as of 2015 (as compared to 12,382 in 2014; Ghana Chamber of Mines [GCM], 2015). Purposive sampling was employed to select eight out of the estimated over 177 registered ASSM companies, and five out the 13 LSM companies who willingly participated in the study with informed consent (Bernard, 2017). Simple random sampling was then employed in selecting 320 respondents consisting of individual mining workers of SSM companies (161) and LSM companies (159) who expressed their willingness to participate in the study based on informed consent.

Data sources and collection methods

The study relied on both primary and secondary data. Questionnaires and Focus Group Discussions (FGD) guide were employed to elicit self-reported perception and experiences of climate change and occupational heat stress risks and adaptation strategies of mining workers. The questionnaire was guided by the validated instruments adopted in the High Occupational Temperature Health and Productivity Suppression (HOTHAPS) programme and other empirical studies related to climate change perceptions and heat exposure impact on health, productivity and adaptation policies (Kjellstrom *et al*., 2009; Sheridan, 2007; Xiang *et al*., 2015). The modified instrument (both closed-ended and open-ended question items) focused on respondents' background characteristics, climate change risks perception, occupational heat stress experiences and adaptation strategies. The instruments were reviewed by experts and pretested in Ghana to ensure validity and reliability. The two FGDs each consisted of eight members with one group comprising individual workers of licensed SSM (FGD1) and LSM (FGD2) respectively. The primary data that emanated from the questionnaires and FGDs were complemented and validated by secondary data. Also, the average annual regional meteorological data (e.g., monthly temperature, humidity and rainfall) from two functional weather stations (Sehwi Bekwai and Tarkwa) of 50 years (1967-2017) within the study setting were obtained from the Ghana Meteorological Agency.

Data analysis

IBM Statistical Product and Service Solutions (SPSS) version 24, Microsoft Excel 2016 and XLSTAT 2018 were used to analyse the quantitative data, whereas Nvivo version 11 was used to process the qualitative data. Based on thematic analysis, the qualitative data was synthesised into themes from the text, quotes and extracts of the FGDs (Maguire & Delahunt, 2017; Ritchie *et al*., 2013). The themes facilitated data description and interpretation based on differences and relationships of the variables. Descriptive statistics (e.g., *M*, *SD*) and inferential statistics (e.g., Chi-Square) were employed to assess the difference in background characteristics, climate change risks perception, occupational heat stress experiences, and adaptation strategies between SSM and LSM at a significance level of $p < 0.05$. The significant difference was assessed based on the effect size criteria (very small: 0.01, small: 0.20, medium: 0.50, large: 0.80, very large: 1.20, & huge: 2.0 (Cohen, 1988; Sawilowsky, 2009). A moving average was used to handle instances of missing monthly weather data, and years with grossly incomplete data were excluded. Monthly climate data was used to calculate annual means of minimum and maximum temperatures, humidity and rainfall, with trend analysis performed using linear regression, Mann-Kendall (MK) and Sen's slope tests in XLSTAT. The MK test is widely used to assess the increasing or decreasing trend of time series data and its statistical significance, and for meteorological data characterised by outliers and missing cases (Kiros *et al*., 2016; Tabari *et al*., 2015).

Results

Background characteristics

The study gender composition of the study sample was 80.9% male (SSM: 55.6% vs LSM: 44.4%), 19.1% female (SSM: 27.9% vs LSM: 72.1%). The difference in the gender proportion distributed between SSM and LSM was significant ($p < 0.001$), with a small effect size. The workers' age ranged from 21 to 61 years, with a mean age of 35.1 years ($SD = 8.20$). Most (43.8%) workers were within the age group (25-34) years, followed by workers within 35-44 years (34.1%). More SSM workers (72%) were within 25-34 years compared to LSM (68%). Most (91.9%) workers were under the age of 50 (Table 6.1). The difference in age distribution between SSM and LSM was not significant. Also, the variation between younger and older workers was not significant (χ^2 (1) = 1.165, $p = 0.304$). Most (37.8%) workers had a secondary education, which consisted of SSM (43.0%) and LSM (57.0%) workers. More workers of LSM (76.4%) compared to SSM (23.6%) had a tertiary education. All workers of SSM and none from LSM had no formal education. The difference in workers' education level between SSM and LSM was statistically significant ($p < 0.001$), with small effect size (Table 6.1). Furthermore, the study showed that fewer (2.6%) workers were uneducated while most (97.4%) had at least a basic education. The disparity between the uneducated and educated workers was significant (Pearson Chi-Square: (χ^2 (1) = 11.196, $p = 0.007$).

Table 6.1. Results of the difference in mining workers' demographic and work characteristics across the type of mining activity (Chi-Square test) (n=320). Numbers in the columns refer to the number of respondents with % of respondents in parentheses

Characteristics	Type of mining activity SSM F(%)	 LSM F(%)	 Total F(%)
Sex			
Male	144(55.6)	115(44.4)	259(80.9)
Female	17(27.9)	44(72.1)	61(19.1)
Pearson Chi-Square: (χ^2(1)= 15.186, p< 0.001, Cramer's V= 0.218)			
Age group (M= 35.1; SD= 8.20)			
< 25	16(59.3)	11(40.7)	27(8.4)
25-34	72(51.4)	68(48.6)	140(43.8)
35-44	52(47.7)	57(52.3)	109(34.1)
45-54	18(51.4)	17(48.6)	35(10.9)
55+	3(33.3)	6(66.7)	9(2.8)
Pearson Chi-Square: (χ^2(1)= 2.286, p= 0.683)			
Level of education			
No formal education	9(100.0)	0(0.0)	9(2.8)
Basic education	79(78.2)	22(21.8)	101(31.6)
Secondary education	52(43.0)	69(57.0)	121(37.8)
Tertiary education	21(23.6)	68(76.4)	89(27.8)
Pearson Chi-Square: (χ^2(3)= 68.367, p= 0.001, Cramer's V= 0.462)			
Years of working experience (M= 7.71; SD= 4.434)			
<5	67(50.0)	67(50.0)	134(41.8)
5-9	44(43.6)	57(56.4)	101(31.6)
10+	50(58.8)	35(41.2)	85(26.6)
Pearson Chi-Square: (χ^2(2)= 4.308, p= 0.116)			
Workload			
Light	8(38.1)	13(61.9)	21(6.6)
Medium	39(39.8)	59(60.2)	98(30.6)
Heavy	49(40.8)	71(59.2)	120(37.5)
Very heavy	65(80.2)	16(19.8)	81(25.3)
Pearson Chi-Square: (χ^2(3)= 38.936, p= 0.001, Cramer's V= 0.349)			
Working hours			
8-10	124(79.5)	32(20.5)	156(48.8)
11-13	34(21.1)	127(78.9)	161(50.3)
14-16	3(100.0)	0(0.0)	3(0.9)
Pearson Chi-Square: (χ^2(2)= 110.969, p= 0.001, Cramer's V= 0.589)			
Workplace environment			
Completely outdoor	37(34.3)	71(65.7)	108(33.8)
Mostly outdoor	57(55.3)	46(44.7)	103(32.1)
Completely indoor	53(76.8)	16(23.2)	69(21.6)
Mostly indoor	14(35.0)	26(65.0)	40(12.5)
Pearson Chi-Square: (χ^2(3)= 35.308, p= 0.001, Cramer's V= 0.332)			
Job physically demanding			
Not at all	12(20.0)	48(80.0)	60(18.7)
Very little	16(31.4)	35(68.6)	51(15.9)
Moderate	36(42.9)	48(57.1)	84(26.3)
Very much	97(77.6)	28(22.4)	125(39.1)
Pearson Chi-Square: (χ^2(3)= 68.471, p= 0.001, Cramer's V= 0.463)			
Working around heat sources			
Yes	149(53.4)	130(46.6)	279(87.2)
No	12(29.3)	29(70.7)	41(12.8)
Pearson Chi-Square: (χ^2(1)= 8.331, p= 0.004, Phi= 0.161)			
Frequency of work around heat sources			
Never	5(62.5)	3(37.5)	8(2.5)
Not often	9(19.1)	38(80.9)	47(14.7)
Sometimes	26(34.7)	49(65.3)	75(23.4)
Often	75(79.8)	19(20.2)	94(29.4)
Always	34(59.6)	23(40.4)	57(17.8)
No response	12(30.8)	27(69.2)	39(12.2)
Pearson Chi-Square: (χ^2(5)= 66.691, p= 0.001, Cramer's V= 0.457)			

Source: Field survey, 2017

Years of working experience ranged from 1 to 21 years with a mean of 7.71 (*SD* = 4.43) years. Most (41.8%) respondents who had less than five years of working experience comprised equal proportions of workers from SSM (50%) and LSM (50%). While most (58.8%) SSM workers had over 10 years working experience, fewer (56.4%) LSM workers had 5-9 years working experience. The difference in years of working experience was not significant. The study also showed that most (37.5%) respondents who described their workload as heavy included SSM (40.8%) and LSM (59.2%) workers. Most workers of SSM (80.2%) and LSM (60.2%) described their workload as very heavy and medium respectively. The difference in workload between workers (SSM and LSM) was statistically significant ($p < 0.001$), with small effect size. The majority (50.3%) of respondents who worked for 11 to 13 hours comprised fewer SSM workers (21.1%) compared to LSM workers (78.9%). Workers (SSM: 79.5% vs LSM: 20.5%) worked for 8 to 10 hours. There was evidence of statistically significant ($p < 0.001$) difference in working hours between SSM and LSM with a moderate effect size (Table 6.1).

Furthermore, most (65.9%) respondents, comprising workers who worked completely outdoors (34.3%) and mostly outdoors (32.1%), described their work environment as ‘outdoor’. Workers whose workplace environment was completely outdoor comprised (SSM: 34.3% vs LSM: 65.7%) and completely indoor comprised (SSM: 76.8% vs LSM: 23.2%). The difference in workplace environment between SSM and LSM was statistically significant ($p < 0.001$) with a small effect size (Table 6.1). Thirty-nine percent of respondents described their job as very physically demanding (SSM: 77.6% vs LSM: 22.2%). However, 20.0% of SSM and 80.0% of LSM workers described their job as not at all physically demanding. The difference in job physical demands between workers (SSM and LSM) was statistically significant ($p < 0.001$) with a small effect size (Table 6.1). The study further revealed that most (87.2%) respondents who worked around heat sources comprised slightly more SSM (53.4%) workers than LSM workers (46.6%). The difference in working around heat sources between SSM and LSM was statistically significant ($p < 0.05$) with a very small effect size. The 29.4% of respondents who often worked around heat sources included more (79.8%) SSM workers as compared to fewer (20.2%) LSM workers; whereas the 14.7% of respondents who did not often work around heat sources comprised fewer (19.1%) SSM workers and more (80.9%) LSM workers. The difference in frequency of working around heat sources between SSM and LSM was statistically significant ($p < 0.001$) with a small effect size (Table 6.1).

Trend and variability of climate change indices

Descriptive statistics, trends and variability in temperature, humidity and rainfall data (1967-2017) showed evidence of climate change in the study setting (Figure's 6.2 – 6.5 & Table 6.2). Minimum and maximum temperatures over the period showed an increasing trend in mean values and variability. There was a significant rise in annual mean minimum and maximum temperatures of 0.027 °C and 0.038 °C per year respectively (Figure's 6.2 & 6.3). The MK and Sen's slope tests showed that the increasing trend in mean annual minimum and maximum temperatures were statistically significant ($p < 0.0001$) (Table 6.2).

Table 6.2: Results of descriptive statistics and trend analysis of annual climate data (1967 – 2017)

Variables	Min	Max	*M*	*SD*	MK's tau	Sen's slope	*p*-value	Confidence interval
T Min	21.5	23.9	22.5	0.551	0.511	0.027	<0.0001*	0.025-0.028
T Max	31.1	33.2	32.4	0.647	0.679	0.038	<0.0001*	0.036-0.040
Humidity	91.0	97.9	93.6	1.597	-0.358	-0.053	0.000*	-0.061-0.044
Rainfall	88.1	238	121	21.8	-0.042	-0.050	0.667	-0.128-0.012

*Two-tailed test at significance level ($p < 0.05$)

Source: Authors, 2017

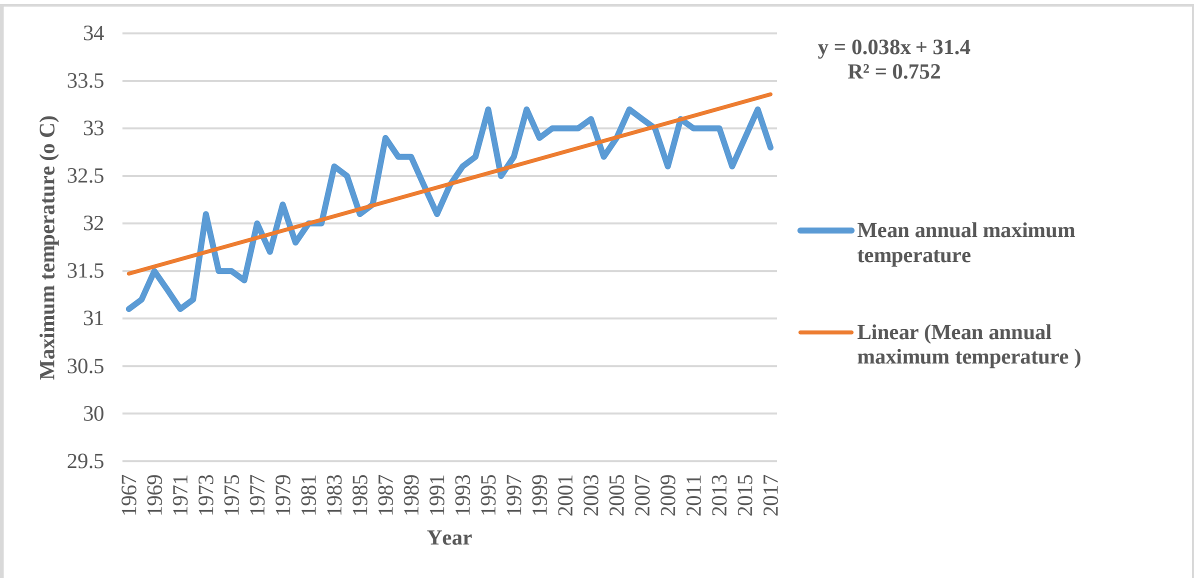


Figure 6.2: Trend and variations in mean maximum temperature of Western Region

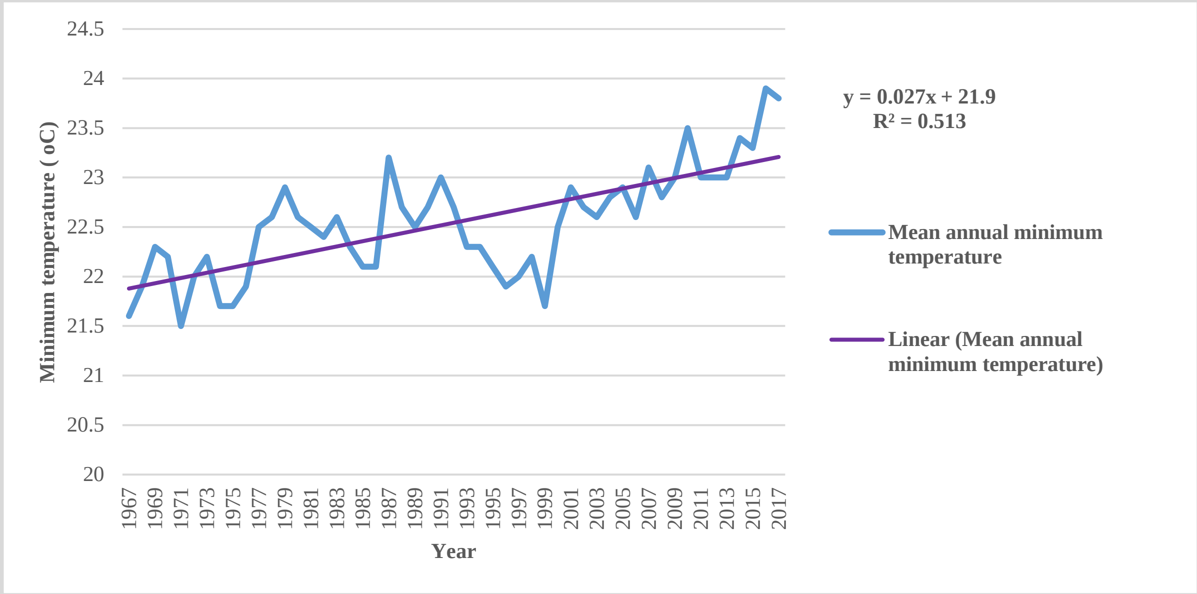


Figure 6.3: Trend and variations in mean minimum temperature of Western Region

The data on mean annual humidity and rainfall showed a decreasing trend and decreased variability over the period (1967-2017). There was a significant reduction in annual mean humidity (-0.063) per year (Figure 6.4). The MK and Sen's slope tests showed that the decreasing trend in mean humidity was statistically significant (p < 0.001) (Table 6.2). The pattern of mean annual rainfall within the study area was erratic with a decreasing trend (-0.26mm) per year (Figure 6.5). The results of the MK and Sen's slope tests indicated that the decreasing trend in mean rainfall was not statistically significant (Table 6.2).

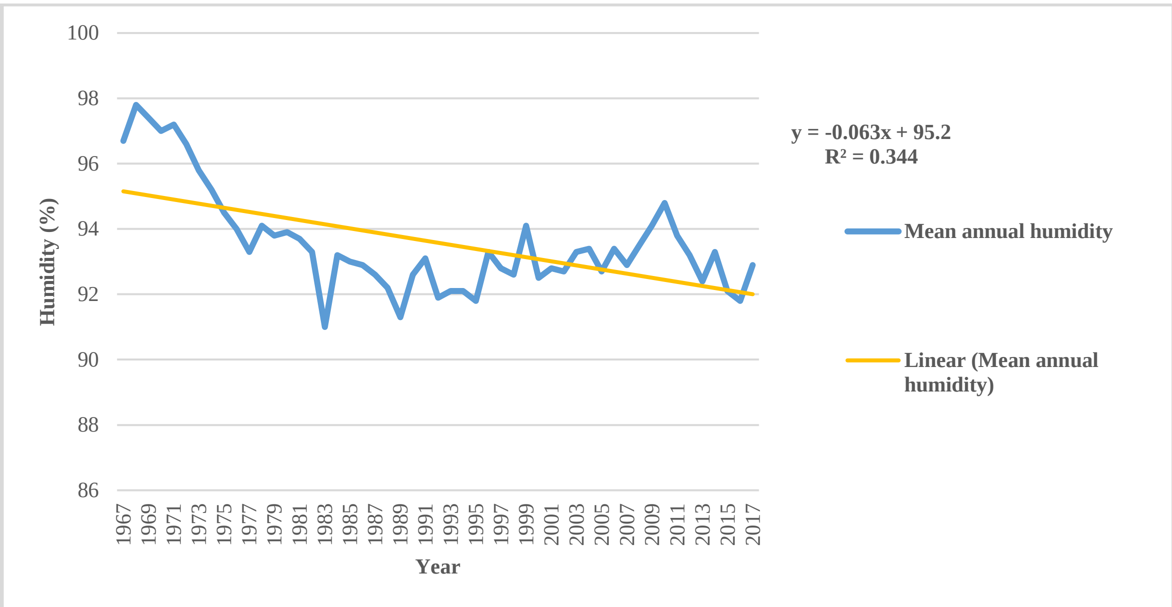


Figure 6.4: Trend and variations in mean annual humidity of Western Region

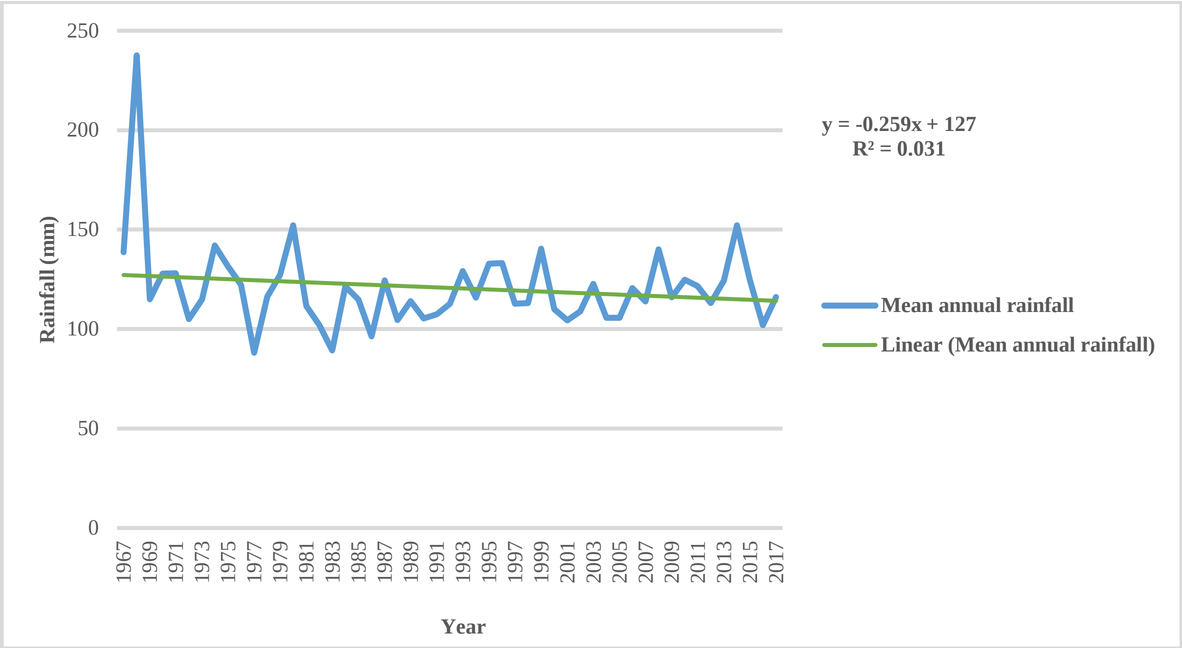


Figure 6.5: Trend and variations in mean annual rainfall of Western Region

Perceptions of climate change risks

The study showed that 96.6% of the respondents who were aware of climate change comprised more (50.2%) SSM workers as compared to less (49.8%) LSM workers. The disparity in climate change awareness between SSM and LSM was not significant. Nearly 77.0% of the respondents were concerned about climate change risk effect. More respondents of SSM (87.8%) and fewer LSM (12.2%) were not at all concerned about climate change risk effect while fewer respondents of SSM (33.6%) and more LSM (66.4%) were moderately concerned about climate change risk effect. The difference in proportions of respondents with concerns about climate change risk effect between SSM and LSM was statistically significant ($p < 0.001$) with a small effect size (Table 6.3).

The study found that respondents' climate change awareness and associated signs and risks was informed by the occurrence of increases in temperature and hot environment (45.3%), irregular rainfall and storms (36.9%), frequent floods (6.5%) and rising sea levels (6.5%). Greater proportions of SSM workers (64.9% and 62.2%) compared to LSM (35.1% and 37.8%) identified irregular rainfall and storms, and frequent floods, as signs and effect of climate change respectively. A slightly greater proportion of LSM (51.4%) compared to SSM (48.6%) identified rising sea levels as a sign of climate change. The difference in climate change signs and effects as identified by respondents between SSM and LSM was statistically significant ($p < 0.001$), with a moderate effect size (Table 6.3).

The views expressed during the FGDs on climate change awareness, signs and effects over the last 30 years were similar to the findings from the questionnaire and trends in the climate data. Participants of the FGDs showed that they were aware of climate change and its associated signs and effect. A participant of the SSM workers characterised this by the following statement:

> *The climate has changed. When we look at the years gone by there were days the rain had its seasons. March was considered as the start of the raining seasons when it falls without any failure but this time it is not like that even in December it rains, but at certain times it changes, and at times you cannot even get the rains and the weather becomes hot.*

Another respondent reiterated this sentiment with the remark:

> *Yes, am very much aware of climate change and the way our environment has been polluted because of the depletion of the ozone layer. Since we in Ghana lie in the tropics, the sun heat is very high, and we have a hot environment. The depleting of the ozone layer is having a negative effect on us especially the mining workers as most of our activities are outdoors and not indoors.*

We asked respondents to share their thoughts on mining workers being at risk of workplace heat exposure driven by climate change. The majority (91.9%) of respondents who answered positively included workers (SSM: 50.3% vs LSM: 49.7%) (Table 6.3). The study showed that respondents associated workplace heat exposure with environmental factors including heat radiation from the sun and other sources around the workplace (37.3%), how hot the air is around the workplace (32.5%), and airspeed/movement around the workplace (17.3%). A greater proportion of workers of SSM (63.6% and 83.0%) compared to LSM (36.4% and 17.0%) identified hotness of the air around the workplace and airspeed/movement around the workplace respectively. More proportions of LSM (51.2%) compared to SSM (48.8%) respondents identified the amount of air moisture in the outdoor settings or workplaces. The difference in respondents with regards to environmental factors that influence the risk of workplace heat exposure was statistically significant ($p < 0.001$), with a moderate effect size (Table 6.3).

Table 6.3: Results of the difference in mining workers' perceptions of climate change risks across the type of mining activity (Chi-Square test) (*n* = 320).

Perception of climate change risk	Total F (%)	Type of mining activity SSM F (%)	LSM F (%)
Aware of climate change			
Yes	309(96.6)	155(50.2)	154(49.8)
No	11(3.4)	6(54.5)	5(45.5)
Pearson Chi-Square: (χ^2(1)= 0.082, *p*= 0.775)			
Concerns about climate change risk effect			
Not at all concerned	74(23.1)	65(87.8)	9(12.2)
A little concerned	64(20.0)	30(46.9.4)	34(53.1)
Moderately concerned	119(37.2)	40(33.6)	79(66.4)
Very much concerned	63(19.7)	26(41.3)	37(58.7)
Pearson Chi-Square: (χ^2(3)= 57.320, *p*= .001, Cramer's *V*= 0.423)			
Signs and effect of climate change (n=572*)			
Increase in temperature and hot environment	259(45.3)	147(56.8)	112(43.2)
Irregular rainfall and storms	211(36.9)	137(64.9)	74(35.1)
Frequent floods	37(6.5)	23(62.2)	14(37.8)
Prolong drought	17(3.0)	9(52.9)	8(47.1)
Rising sea levels	37(6.5)	18(48.6)	19(51.4)
No response	11(1.9)	6(54.5)	5(45.5)
Pearson Chi-Square: (χ^2(5)= 84.977, *p*= 0.001, Cramer's *V*= 0.515)			
Mining workers at risk of workplace heat exposure due to climate change			
Yes	294(91.9)	148(50.3)	146(49.7)
No	26(8.1)	13(50.0)	13(50.0)
Pearson Chi-Square: (χ^2(1)= 0.001, *p*= 0.973)			
Environmental factors that influence risk of workplace heat exposure (n=542*)			
How hot the air is around the workplace	176(32.5)	112(63.6)	64(36.4)
The amount of air moisture in the outdoor settings or workplaces	43(7.9)	21(48.8)	22(51.2)
Air speed/movement around the workplace	94(17.3)	78(83.0)	16(17.0)
Heat radiation from the sun and other sources around the workplace	203(37.3)	120(59.1)	83(40.9)
No response	26(4.8)	13(50.0)	13(50.0)
Pearson Chi-Square: (χ^2(4)= 91.528, *p*= 0.001, Cramer's *V*= 0.535)			
Work-related factors that influence risk of workplace heat exposure (n=738)*			
Type of physical workload	167(22.6)	72(43.1)	95(56.9)
The duration of working hours	150(20.3)	108(72.0)	42(28.0)
Type of protective clothing, e.g. overall	67(9.1)	26(38.8)	41(61.2)
Access to the cooling system, e.g., air condition and fans	64(8.7)	37(57.8)	27(42.2)
Duration of break/rest hours	95(12.9)	77(81.1)	18(18.9)
Access to shade	82(11.1)	64(78.0)	18(22.0)
Access to drinking water	85(11.5)	71(83.5)	14(16.5)
Type of clothing	19(2.6)	9(47.4)	10(52.6)
No response	9(1.2)	6(66.3)	3(33.3)
Pearson Chi-Square: (χ^2(8)= 69.493, *p*= 0.001, Cramer's *V*= 0.466)			
Extent of concern about workplace heat exposure			
Not at all concerned	15(4.7)	11(73.3)	4(26.7)
Very little concerned	31(9.7)	14(45.2)	17(54.8)
Moderately concerned	53(16.6)	10(18.9)	43(81.1)
Very much concerned	221(69.0)	126(57.0)	95(43.0)
Pearson Chi-Square: (χ^2(3)= 28.441, *p*= 0.001, Cramer's *V*= 0.298)			

Source: Field survey, 2017

Comparatively, participants of the FGDs corroborated the questionnaire results on the risk of workplace heat exposure to mining workers because of weather-related factors. An SSM worker who participated in the FGD illustrated the workers' risks to heat exposure due to environmental-related factors as follows:

> *As mining workers, we are exposed to the risk of heat if we do heavy work under the sun for a long time and when the wind blows occasionally, or it ceases then you feel the heat. We then drink a lot of water when we feel thirsty or take a break.*

Another FGD participant with the LSM workers summed it up in these words:

> *Mining workers are surely at risk of heat exposure especially working with the machines and also working in the sun. It produces more heat for us, and some of us who work underground we face a lot of heat. The deeper you go, the more heat you meet because the ventilation doesn't get* down there to the main deep line.

Work-related conditions based on type of physical workload (22.6%), the duration of working hours (20.3%), duration of break/rest hours (12.9%), access to drinking water (11.5%), and access to shade (11.1%) were also mentioned as factors that influence workplace heat exposure risk. There were discrepancies in proportions of respondents who identified access to drinking water (SSM: 83.5% vs LSM: 16.5%), type of protective clothing (SSM: 38.8% vs LSM: 61.2%), duration of break/rest hours (SSM: 81.1% vs LSM: 18.9%), and type of physical workload (SSM: 43.1% vs LSM: 56.9%) (Table 6.3). The difference in respondents who identified work-related factors that influence workplace heat exposure risk between SSM and LSM was statistically significant ($p < 0.001$) with small effect size.

Similar comments made by the discussants in the FGDs of the SSM and LSM workers showed that the risk of workers to heat exposure was associated with work-related factors (e.g., access to cooling systems, drinking water, shade, and workload). Workers' heat exposure risk due to work-related factors was explained during the FGD, as exemplified in the following vignettes:

> *We do heavy work under the scorching sun. Here, you will begin to sweat but if you are working under air condition or fan for hours, you will not sweat and will not feel the heat. In the open space where no tree or shade will protect you and bring you fresh air, there will be heat, and you will sweat and need to drink more water or go for a break (Participant, SSM workers).*

> *I do agree. The nature of our work contributes to the risk of heat exposure. Like when you are working in a hot environment where you are exposed to a lot of heat, let say, the welders most at times you see them welding, and then they have provided a fan to reduce*

the heat that they may be exposed to, and it helps a lot. Without the fan, I don't think that they will have enough energy to complete the task assigned (Participant, LSM workers).

Considering the extent of workers' risks associated with heat exposure and climate change, respondents (69.0%) who were very much concerned about workplace heat exposure and heat stress comprised (SSM:57.0% vs LSM:43.0%). A relatively large proportion of SSM (73.3%) respondents, as compared to LSM (26.7%) were not at all concerned about workplace heat exposure. However, there were more LSM (81.1%) respondents, compared to SSM (18.9%) who were moderately concerned about workplace heat exposure. The difference in the extent of concern about workplace heat exposure and heat stress between SSM and LSM was statistically significant ($p < 0.001$) with a small effect size (Table 6.3).

Experiences of occupational heat stress risks

The respondents (81.3%) who had ever experienced heat-related illness comprised (SSM: 51.2% vs LSM: 48.8%). The difference in heat-related illness experience of respondents was not significant. Heat-related illness most frequently experienced by the workers were excessive sweating (25.1%), headaches (20.6%), heat exhaustion/tiredness (19.5%), and heat rash (14.3%). There was variation in the proportion of respondents who identified excessive sweating (SSM: 68.0% vs LSM: 32.0%), headache (SSM: 76.0% vs LSM: 35.0%), heat cramps (SSM: 43.9% vs LSM: 56.1%), and heat rash (SSM: 83.2% vs LSM: 16.8%). The difference in the proportion of respondents who identified workers' heat-related illness experience between SSM and LSM was statistically significant ($p < 0.001$) with a moderate effect size (Table 6.4).

Views of the discussants in the FGDs (SSM and LSM) workers on heat-related illness experiences of mining workers were headache, tiredness, excess sweat, and collapsing. For example, one discussant of SSM workers summed up their concerns of heat-related morbidity as:

Yeah, we sweat a lot even if you are with the 'chamfan' or if you are in the machine room. If you are exposed to heat, or you are working under the sun, you get tired easily, and if you get tired, you usually become confused and because you are tired you can get injured or hurt yourself.

Table 6.4: Results of the difference in mining workers' experiences of occupational heat stress risks across the type of mining activity (Chi-Square test) (*n* = 320).

Experiences of occupational heat stress risks	Total F (%)	Type of mining activity SSM F (%)	LSM F (%)
Heat-related illness experience			
Yes	260(81.3)	133(51.2)	127(48.8)
No	60(18.8)	28(46.7)	32(53.3)
Pearson Chi-Square: (χ^2(1)= 0.393, p= 0.531)			
Type of heat-related illness experience (n=708*)			
Excessive sweating	178(25.1)	121(68.0)	57(32.0)
Headaches	146(20.6)	111(76.0)	35(24.0)
Heat exhaustion/tiredness	138(19.5)	98(71.0)	40(29.0)
Heat cramps (pains)	57(8.1)	25(43.9)	32(56.1)
Heat rash	101(14.3)	84(83.2)	17(16.8)
Heat syncope (fainting)	25(3.5)	20(80.0)	5(20.0)
Admitted to the hospital due to heat stroke	3(0.4)	2(66.7)	1(33.3)
No response	60(8.5)	29(48.3)	31(51.7)
Pearson Chi-Square: (χ^2(7)= 121.738, p= 0.001, Cramer's V= 0.617)			
Heat-related injury experience			
Yes	227(70.9)	119(52.4)	108(47.6)
No	93(29.1)	42(45.2)	51(54.8)
Pearson Chi-Square: (χ^2(1)= 1.392, p= 0.238)			
Extent of heat-related injury			
Minor	94(29.4)	30(31.9)	64(68.1)
Moderate	58(18.1)	24(41.4)	34(58.6)
Serious	64(20.1)	59(92.2)	5(7.8)
Severe	6(1.9)	2(33.3)	4(66.7)
Critical	5(1.6)	4(80.0)	1(20.0)
No response	93(29.1)	42(45.2)	51(54.8)
Pearson Chi-Square: (χ^2(5)= 62.912, p= 0.001, Cramer's V= 0.443)			
Type of heat-related injury experience (n=443)*			
Burns from the sun	41(9.3)	14(34.1)	27(65.9)
Burns from hot objects/surfaces	49(11.0)	21(42.9)	28(57.1)
Falls, trips, and slips due to dizziness, fainting and fatigue	52(11.7)	32(61.5)	20(38.5)
Loss of grip and controls due to sweaty hands	41(9.3)	24(58.5)	17(41.5)
Being hit by objects	86(19.4)	76(88.4)	10(11.6)
Hitting objects	81(18.3)	62(76.5)	19(23.5)
No response	93(21.0)	41(44.1)	52(55.9)
Pearson Chi-Square: (χ^2(6)= 81.215, p= 0.001, Cramer's V= 0.504)			
Heat-related injury witnessed			
Yes	265(82.8)	140(52.8)	125(47.2)
No	55(17.2)	21(38.2)	34(61.8)
Pearson Chi-Square: (χ^2(1)= 3.909, p= 0.048, Phi= 0.111)			
Type of heat-related injury experience (n=474)*			
Burns from the sun	39(8.2)	17(43.6)	22(56.4)
Burns from hot objects/surfaces	62(13.1)	22(35.5)	40(64.5)
Falls, trips, and slips due to dizziness, fainting and fatigue	86(18.1)	54(62.8)	32(37.2)
Loss of grip and controls due to sweaty hands	32(6.8)	21(65.6)	11(34.4)
Being hit by objects	104(21.9)	87(83.7)	17(16.3)
Hitting objects	95(20.0)	68(71.6)	27(28.4)
No response	56(11.8)	21(37.5)	35(62.5)
Pearson Chi-Square: (χ^2(6)= 85.223, p= 0.001, Cramer's V= 0.516)			

Source: Field survey, 2017

A participant of the FGD with the LSM workers explained the heat-related illness of mining workers in the following statement:

> *Yes! I have experienced some before. Like working in a place where there is heat... at the end of the job you will find yourself that you're feeling dehydrated and tired, having a little bit of headache and sweating. Most of our friends too, get involved in those dangers like sweating and even collapsing*.

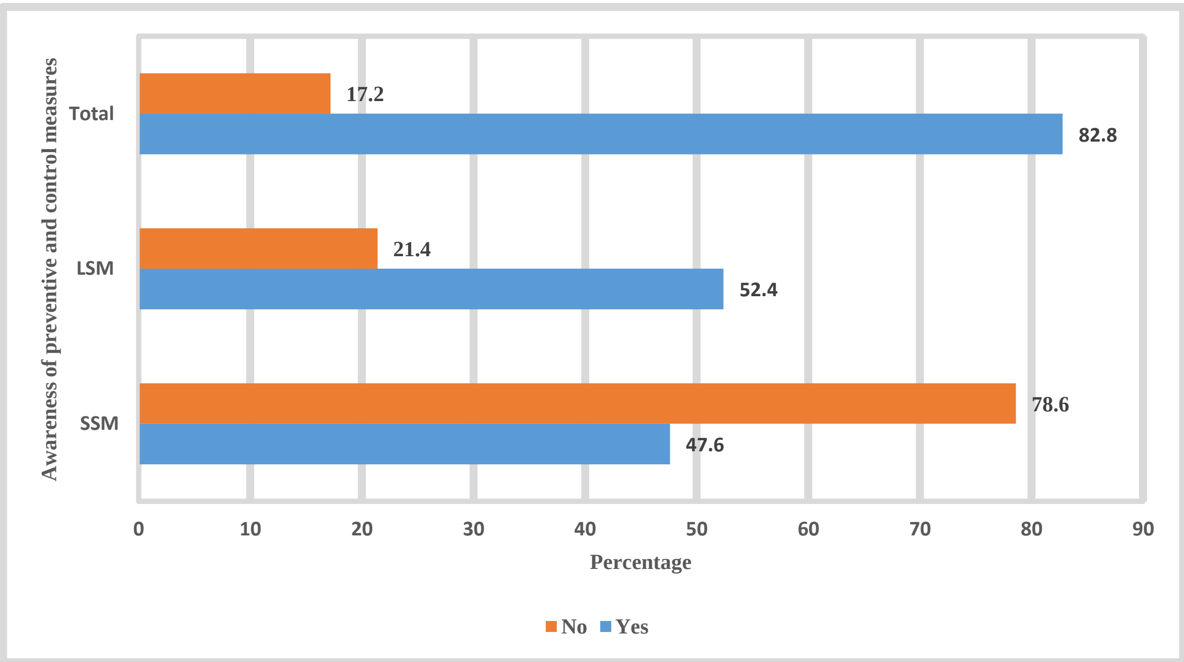
The study also revealed that respondents (70.9%) who had experienced heat-related injuries involved (SSM: 52.4% vs LSM: 47.6%). The variations in heat-related injury experience of workers between SSM and LSM were not statistically significant. The degree of heat-related injury mostly experienced by workers was described as minor (29.4%), moderate (18.1%) and serious (20.1%). There was a difference in the proportion of respondents between SSM and LSM who indicated minor (SSM: 31.9% vs LSM: 47.6%), moderate (SSM: 41.4% vs LSM: 58.6%) and serious (SSM: 92.2% vs LSM: 7.8%). The difference in the proportion of respondents who identified workers' heat-related injury experience between SSM and LSM was statistically significant ($p < 0.001$) with small effect size (Table 6.4).

Furthermore, the respondents specified the type of heat-related injuries of workers as being hit by objects (19.4%), hitting objects (18.3%), fall, trips, and slips due to dizziness, fainting, and fatigue (11.7%) and burns from hot objects/surfaces (11.0%). The instances of variation in proportion of respondents who stated being hit by objects (SSM: 88.4% vs LSM: 11.6%), hitting objects (SSM: 76.5% vs LSM: 23.5%), fall, trips, and slips due to dizziness, fainting, and fatigue (SSM: 61.5% vs LSM: 38.5%), and burns from hot objects (SSM: 42.9% vs LSM: 57.1%) was statistically significant ($p < 0.001$) with a moderate effect size.

Respondents were asked if they had witnessed any form of heat-related injury to another mining worker; 82.8% comprising (SSM: 52.8% vs LSM: 47.3%) answered in the affirmative. The difference in the proportion of respondents who witnessed a heat-related injury to another mining worker between SSM and LSM was statistically significant ($p < 0.05$) with very small effect size. The respondents stated the type of heat-related injuries witnessed to mining workers as being hit by objects (21.9%), hitting objects (20.0%), fall, trips, and slips due to dizziness, fainting, and fatigue (18.1%) and burns from hot objects/surfaces (13.1%). The variation in proportion of respondents who stated being hit by objects (SSM:83.7% vs LSM:16.3%), hitting objects (SSM:71.6% vs LSM:28.4%), fall, trips, and slips due to dizziness, fainting, and fatigue (SSM:62.8% vs LSM:37.2%), and burns from hot objects (SSM:35.5% vs LSM:64.5%) as the type of heat-related injury witnessed was statistically significant ($p < 0.001$) with a moderate effect size.

Preventive and control measures of occupational heat stress due to climate change

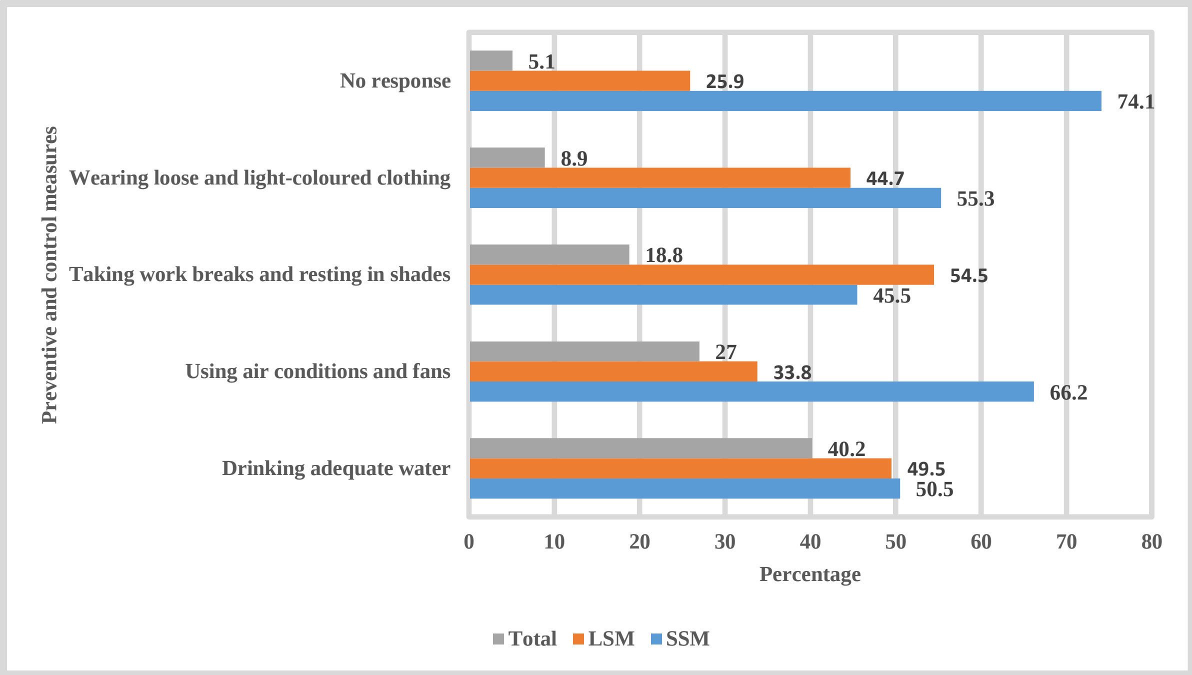
Figure 6.6 illustrates the preventive and control measures of occupational heat stress due to climate change among mining workers. The study showed that the respondents (82.8%) who were aware of preventive and control measures comprised (SSM: 47.6% vs LSM: 52.4%). The difference in the proportion of respondents who were aware of preventive and control measures of occupational heat stress due to climate change between SSM and LSM was statistically significant ($p < 0.05$) with very small effect size. The preventive and control measures of occupational heat stress mostly used by workers included drinking adequate water (40.2%), using air conditioners and fans (27.0%), and taking work breaks and resting in the shade (18.8%). The variation in proportion of respondents across the type of mining activity who stated drinking adequate water (SSM: 50.5% vs. LSM: 49.5%), using air conditioners and fans (SSM: 66.2% vs. LSM: 33.8%), and taking work breaks and resting in shade (SSM: 45.5% vs. LSM: 54.5%) was statistically significant ($p < 0.05$) with a small effect size (Figure 6.7).



n=320, Pearson Chi-Square: (χ^2 (1) = 9.802, p= 0.002, *Phi*= 0.175)

Figure 6.6: Results of the difference in mining workers' awareness of preventive and control measures of occupational heat stress due to climate change across the type of mining activity

Source: Field survey, 2017



n=527*, Pearson Chi-Square: (χ^2 (4) = 51.853, p= 0.001, Cramer's V= 0.403)
Figure 6.7: Results of the difference in mining workers' preventive and control measures of occupational heat stress due to climate change across the type of mining activity
Source: Field survey, 2017

Similarly, evidence from the FGDs re-echoed workers' awareness and use of cooling systems, drinking water, rest-break regimes, and clothing to prevent and control occupational heat stress due to climate change. This is evident in the following extracts from the FGDs with SSM and LSM workers.

> *When we are going down [underground], we use the blower to blow air into it for a about thirty minutes to one hour. To protect us from injury and heat while working, you wear shirts that are light that will allow air to penetrate it to help you not to feel the heat. If you are working underground, you frequently drink water (Participant, SSM workers).*

> *We work on the surface in the sun or underground, the strategy is that we break for a while like an hour and cool ourselves in the offices where we do the paperwork. The things we do to protect ourselves are the water we drink, the air conditions and go to cool place to have fresh air for a while before we continue the work (Participant, LSM workers).*

Discussion

This study is the first to apply a mixed method approach to assess the perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. The study relies on the results of a self-reported survey and FGDs among the workers (SSM and LSM), complemented by trends and variability of meteorological data in the study setting. The results were related to conceptual and empirical studies to provide a comprehensive understanding of mining workers' demographic and work characteristics, climate change risks perceptions, occupational heat stress risks, and adaptation strategies to inform policy decisions in the mining industry.

Demographic and work characteristics

Differences in the demographics of workers (e.g., gender and education level) between SSM and LSM that were significant should be considered in climate change and heat stress risk management policy deliberations. Though younger males with secondary school qualification dominated the mining sector, more males worked in SSM compared to LSM. Gender inequality in the mining sector is due to its typical male dominance *(Abrahamsson et al*., 2014; ABS, 2016; Bowers *et al*., 2018). More SSM workers had no formal education whereas more LSM workers had tertiary education. Younger workers with less sense of vulnerability as compared to older colleagues tend to work more hours for higher pay without recourse to the risk of heat-related illness, reduced productive capacity and disrupted social well-being (Jia et al., 2016; Xiang et al., 2014). The educated and younger workers' behaviour and attitude should inform occupational health and safety policies to promote workers' adaptive capacity and resilience.

The significant differences in work characteristics (e.g., workload, working hours, physical demands of jobs, working around heat sources and frequency of working around heat sources) between SSM and LSM workers has implications for sustainable and strategic utilisation of workers in the context of intensifying temperature and climate change. The significant variations between SSM and LSM in demographic and work factors should mirror workplace strategies meant to reduce the magnitude of heat exposure and promote workers' adaptive capacity. The policies should include a reduction in workload, working hours on hot days, physically exerting jobs, the frequency of working close to heat sources, and continued education, information and training of workers on heat exposure and adaptation.

Perceptions of climate change risks

Overall, the workers were reasonably aware of climate change and had serious anxieties about its risks and effects. Similar studies substantiate adequate knowledge and awareness of climate change and concerns of its risk among people and workers in various regions around the world (e.g., Baptiste, 2017; Brechin & Bhandari, 2011; Frimpong *et al*., 2015; Pugliese

&Ray, 2009; Thomas & Benjamin, 2018). The evidence of significant variation found in workers' concerns about climate change risk effect is likely due to differences in the educational attainment of workers and should be valuable for policy decisions in reducing climate change risk as most of the workers are educated and younger. Educational attainment has been found to be a good predictor of climate change awareness and concerns of people (Ajuang *et al*., 2016; Knight, 2016; Lee *et al*., 2015; Mattah *et al*., 2018).

The workers' high level of awareness of climate change was explained by observed markers including increase in temperature, hot environment, erratic rainfall, frequent floods, and rising sea levels. The workers' assertions were supported by the significant increasing trend in mean annual temperature, decreasing trend in mean annual humidity, and an erratic and slightly decreasing trend in rainfall pattern recorded in the study area over the last 50 years. The findings on significant disparity in the signs and effect of climate change between SSM and LSM are noteworthy in policy consideration at reducing climate change risk. The workers' awareness of climate change markers corroborates recent studies in which increasing temperature, humidity, irregular rainfall, rising sea levels, and prolonged droughts and storms were given as examples of climate change (Evadzi *et al*., 2018; Hoogendoorn & Fitchett, 2018; van Oldenborgh *et al*., 2018).

Workers' risk of workplace heat exposure is due to environmental, personal, and occupational-related heat exposure risks factors (Kjellstrom *et al*., 2016a; Parsons, 2014; Schulte & Chun, 2009). The important difference in environmental factors (e.g., heat radiation from the sun and other sources, hot air, and airspeed/movement) which influenced workers' risk of workplace heat exposure are essential for strategic options aimed at adaptation or reducing the magnitude of outdoor heat exposure of workers. Similarly, intensifying ambient temperature, radiant heat, relative humidity, and reduced air movement are notable weather-related factors that influence work-related heat exposure (Kjellstrom *et al*., 2009; Parsons, 2014; Schulte & Chun, 2009). Furthermore, the significant variations between SSM and LSM in work-related conditions (e.g., type of physical workload, duration of working hours, duration of break/rest hours, access to drinking water, and shades) which influenced workers' risk of workplace heat exposure should be used to shape different climate change adaptation and workplace heat management policies for these two groups of workers. Multiple studies found break hours, work-rest regimes, access to shade, physical activity, cooling system, clothing type, and drinking water as factors that influence heat exposure (Haines & Patz, 2004; Kjellstrom *et al*., 2016a; McMichael *et al*., 2006). Similarly, the significant difference in the extent of concern about workplace heat exposure between SSM and LSM are worthy of consideration for an effective workplace heat management policy as majority of the workers are educated.

Thus, effective and sustained policies to climate change risk hinge on workers' perceived and actual knowledge of climate change and heat exposure risks (Ford *et al*., 2010; Kjellstrom *et al*., 2016a; Tripathi & Mishra, 2017). Workers' awareness of climate change risk, information and communication are important for policy making and implementation, particularly to any strategic response to combating climate change impacts (Aswani *et al*., 2015; Carlton & Jacobson, 2013; Hagen *et al*., 2016).

Occupational heat stress risk experience

Many workers experienced heat-related morbidity. However, the difference in workers' heat-related morbidity experiences between SSM and LSM was not significant. The type of heat-related illness experienced by workers were commonly reported in similar studies in different work environments (Krishnamurthy *et al*., 2017; Lao *et al*., 2016; Stoecklin-Marois *et al*., 2013). The significant variations in the type of personal or witnessed heat-related injury experiences of workers (e.g., being hit by objects, hitting objects, falls, trips, and slips due to dizziness, fainting, and fatigue, and burns from hot objects/surfaces) between SSM and LSM are important factors to be taken into account when framing policy to protect workers against heat stress hazards. As with studies among mining supervisors in Ghana (Nunfam *et al*., 2018), the degree of heat-related injury experience of most workers was described as minor. The variation in the extent of injury experience of workers between SSM and LSM was significant as more workers of LSM experienced minor to moderate injuries while more SSM workers experienced serious injuries. However, other studies (Tawatsupa *et al*., 2013; Xiang *et al*., 2016) described the extent of workers' heat-related injuries as moderate to serious.

Comparable findings on the type of injury experienced by workers due to heat exposure were recounted in other studies (Tawatsupa *et al*., 2013; Varghese *et al*., 2018; Xiang *et al*., 2016). The evidence of significant variations in the workers' experiences of heat-related injuries, the magnitude of injuries, and the type of personal or witnessed injuries was likely due to variations in workload, length of working hours, work environment conditions, work physical demands, and frequency of working around heat sources across the type of mining activity. The extent of workers' awareness of occupation heat stress, as corroborated by other studies, and the variation in heat-related morbidity experiences across the type of mining activity illustrates the extent of heat exposure risk due to rising temperature and climate change (Government of Ghana, 2013, 2015; Xiang *et al*., 2016). Therefore, workplace policies and procedures aimed at ensuring workers' health, safety and effective performance need to incorporate the identified occupational heat stress risk concerns of workers to promote appropriate workload, working hours, and work environments devoid of heat stress risk.

Preventive and control strategies of occupational heat stress due to climate change

Occupational heat stress is manageable with awareness and enforcement of standards for assessing and monitoring occupational heat-related hazards among workers (NIOSH, 2016; Parsons, 2013). Most workers were aware and often used measures (such as drinking adequate water, air conditioners and fans, taking work breaks and resting in shades) to manage occupational heat stress. However, more workers of SSM than LSM experienced the use of loose and light-coloured clothing, taking work breaks and resting in shades. The significant difference in workers' awareness and use of preventive and control measures of occupational heat stress due to climate change between SSM and LSM are important indicators for heat adaptation strategies. The results of the study as reiterated in several studies corroborate the usefulness of workers' knowledge and effective use of coping and adaptation policies (e.g., housing designs, drinking water, break/rest regimes, use of cooling systems, and type of clothing) (Lao *et al*., 2016; Pradhan *et al*., 2013; Xiang *et al*., 2015). Mitigation and adaptation policies of climate change-related heat stress mainly include engineering solutions, administrative controls, education and training regimes, compensation, and social protection of workers (Davies *et al*., 2009; Kjellstrom *et al*., 2016b; NIOSH, 2016). Enhancing awareness and implementing heat stress management strategies among workers has the significant implication of boosting adaptive capacity and resilience and improving policy decisions for combating heat stress due to rising temperature and climate change impacts.

Conclusions and implications for policy decisions

Workers of both SSM and LSM were reasonably aware of climate change and its effects, and their views agreed with the measured trend and variability of climate data in the study setting. The utilisation of preventive and control measures to reduce occupational heat stress due to high temperature and climate change was based on workers' experiences and concerns of heat-related morbidity. Workers' concerns about climate change and workplace heat exposure risks, experiences of the type of heat-related morbidities, and awareness and use of adaptation strategies differed significantly between SSM and LSM. The observed differences between the type of mining activity include workers' gender, educational attainment, workload, working hours, physical job exertion, and working near heat sources. Similar disparities include workers' exposure to heat radiation, hot air, and air speed as well as work-related factors such as break/rest hours, access to drinking water, and type of protective clothing. Other variations are the type of heat-related injury experiences, use of clothing, drinking sufficient water, use of cooling systems, and resting in shade. Workplace policies on health and safety, heat stress management, and workers' adaptive capacity in the mining sector should be informed by these inconsistencies. Mining workers and other stakeholders should be part of the main focus of occupational heat stress and climate change adaptation intervention and planning to manage the risk climate change poses to their lives and livelihood. Hence, a concerted effort among stakeholders is required to promote mining workers' health and safety, productive capacity, and effective performance and to enhance their adaptive capacity and inform policy decisions and enforcement in the mining industry.

CHAPTER SEVEN: THE RISK AND MAGNITUDE OF HEAT EXPOSURE ON MINING WORKERS IN GHANA

Abstract

Many occupational settings located outdoors in direct sun, such as open cut mining, pose a health, safety, and productivity risk to workers because of their increased exposure to heat. This issue is being exacerbated by climate change effects, the nature of work, and the requirement to wear protective clothing and extended shifts, which is becoming a global industry standard. Though Ghana has a rapidly expanding mining sector with a large workforce, no study has assessed the risk and magnitude of heat exposure on mining workers and its potential impact on this workforce. Questionnaires and temperature data loggers were used to assess the risk and extent of heat exposure in the working and living environments of Ghanaian miners. The variation in heat exposure risk factors across workers' gender, education level, workload, work hours, physical work exertion, and proximity to heat sources were significant ($p<0.05$). Mean Wet Bulb Globe Temperatures (WBGT) in the working environment (24 hr, daytime, daily maximum & nighttime) were 27.1^{o}C, 28.2^{o}C, 29.6^{o}C and 26.5^{o}C (indoor) and 27.5^{o}C, 28.2^{o}C, 29.2^{o}C and 26.9^{o}C (outdoor), respectively. In miner's homes, the mean WBGTs (24 hr, daytime, daily maximum, and nighttime) were 26.7^{o}C, 28.1^{o}C, 29.7^{o}C and 25.4^{o}C (indoor), and 27.0^{o}C, 27.0^{o}C, 27.3^{o}C and 27.0^{o}C (outdoor), respectively. Mining workers are exposed to relatively high heat at work and home, thus raising their heat stress risk. Adequate adaptation policies and heat exposure management for workers are imperative to reduce heat stress risk, improve productive capacity and the social health of mining workers.

Keywords: Ghana, Heat exposure, Mining workers, Adaptation strategies

Introduction

In general, excessive heat exposure risks have been identified in many occupational settings, including agriculture, oil and gas, construction, manufacturing, firefighting, military and mining (Dutta *et al*., 2015; Xiang *et al*., 2014). The health, safety, productivity and social well-being of various workers in these occupational environments are increasingly under serious threat due to extreme heat exposure. The impact of heat-related illnesses, injuries, and reduced productivity among workers due to workplace heat exposure is being aggravated by the current episode of rising temperature and humidity in Ghana, which is attributed to global warming and climate change (Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2016b) related to anthropogenic-induced increases in greenhouse gas (GHG) emissions (United Nation Framework Convention on Climate Change [UNFCCC], 2010). Under conditions of GHG-based global warming, intensifying temperature and relative humidity (RH) exposes outdoor workers, in particular, to excessive heat events, especially during the hot season. The quest to combat excessive heat exposure as a global risk phenomenon to environmental well-being and human subsistence, including workers, has been unequivocally expressed in the 2030 Sustainable Development Goals (SDGs) (Leal Filho *et al*., 2018; United Nations [UN], 2015).

The global climate is increasingly experiencing hotter and more humid conditions, especially in the tropical and sub-tropical regions of the world. Notably, since the 1850s, average global temperature has increased by 0.6 ± 0.2 °C and is anticipated to further escalate by between 1.4 °C and 5.8 °C in 2100 (IPCC, 2014b). Furthermore, on the continent of Africa, the average temperature has increased by approximately 0.7 °C since 1850s and is estimated to increase more rapidly during the remainder of the 21st Century (IPCC, 2014a). Similarly, Ghana has high temperatures with the average annual temperature variation ranging between 24°C to 30°C and yet temperatures can be as low as 18°C and high as 40°C in the southernmost and northernmost parts of Ghana, respectively (Asante & Amuakwa-Mensah, 2015). Following the 1960s, Ghana has experienced an average increase in temperature of 1.0 °C, which is expected to intensify by 2.0 °C by 2050 (Government of Ghana, 2013, 2015). Changes in temperature and humidity are critical variables in assessing the extent of human heat exposure risk and its implications for human comfort, safety, health, productivity, and social well-being (Kjellstrom *et al*., 2016b; Steadman, 1984). Working and living environments with low (<30%) or high (>60%) relative humidity and core body temperature above 37 °C have the potential for dire heat exposure consequences on outdoor workers' health and performance in various industries in the world, including the mining industry in Ghana (Arundel *et al*., 1986; Epstein & Moran, 2019; Parsons, 2014). Conditions of extreme humidity and temperature does not effectively allow heat generated by the body to be lost via evaporation of sweat to maintain core body temperature and yet excessive sweating creates dehydration risks (Kjellstrom et al., 2018).

Globally, the mining industry has significantly contributed to socioeconomic growth and development. Specifically, the sector has increasingly served as a key source of internal revenue, foreign exchange and employment in Ghana. For instance, gold exports increased by 20% from 3.84 million ounces to 4.61 million ounces between 2016 and 2017 (Bank of Ghana, 2018) and this, in turn, contributed to an increase in corporate tax revenue for the government of 39%, rising from Ghc 696.9 million in 2016 to Ghc 969.6 million in 2017 (Ghana Revenue

Authority, 2018). The large-scale mining (LSM) sector, which is dominated by multinational organisations recorded increased employment from 10,503 workers in 2016 to 11,628 in 2017 (Ghana Chamber of Mines, 2018). The small-scale mining (SSM) sector is commonly operated informally by local people with inadequate technology. The SSM sector directly employs an estimated one million people and provided indirect support for nearly 4.5 million people (McQuilken & Hilson, 2016). Within the period (1989-2010), it produced 851000 ounces of gold valued at US$467 million, that is, 11.68% of total gold export in Ghana. The value of gold production in the sector also increased from US$1.8billion (2011-2012) to US$2.5billion in 2014 (Adjaye & Ampofo, 2017).

Considering the importance of the mining industry to socioeconomic development, the risk of occupational heat exposure to workers as temperature and humidity levels at workplace intensifies due to global climate change should not be marginalised. In particular, mining activities are commonly characterised by heavy physical work while wearing restrictive protective clothing for long durations of work in hot and humid work environments either under the sun, close to heat radiating operational equipment or underground. Under hot and humid conditions in both the working and living environments, as well as dwindling resources and inadequate prevention strategies, mining workers in tropical developing countries like Ghana are more vulnerable to excessive heat exposure. The consequences of this include, but are not limited to, heat-related illnesses, injuries, mental impairment, reduced productive capacity and social ill-health. Similarly, empirical studies have shown that intensive physical workload in hot environments increases core body temperature, reduces physical work capacity, diminishes mental concentration and ability to work, escalates the risk of accidents and injuries, and heightens the risk of heat illness such as heat exhaustion and heat stroke (Bridger, 2003; Ramsey, 1995; Richards & Hales, 1987).

However, in the context of Ghana, only few local studies have focused on investigating the trend and impact of heat exposure risk on outdoor workers in a given locality (although an exception is the study of farmers in Bawku East of Northern Ghana by Frimpong *et al*., 2017). Notably, indigenous knowledge of the risk and magnitude of heat exposure in the working and living environment on mining workers in Ghana seem to be ignored, marginalised and not available. Moreover, the extent of heat exposure risk and impact may vary according to the type of workers and their background characteristics (Nunfam *et al*., 2019a; Nunfam *et al*., 2019b). The consequence of this is inadequate execution of suitable and significant heat exposure policies in occupational settings (Parsons, 2009). Occupational heat exposure risk is expected to increase as global temperature, and climate change intensifies (Kjellstrom *et al*., 2009). Therefore, studies of this kind that seek to incorporate local perspectives of heat exposure risk and magnitude due to high temperature and humidity into the climate change discourse are worthwhile (Alexander *et al*., 2011; Klein *et al*., 2014; Orlove *et al*., 2010; Riedlinger & Berkes, 2001).

Hence, scientific, ethical and practical justifications are provided for considerable use of indigenous knowledge. Scientifically, local knowledge of heat exposure risk contribute to our understanding of the patterns and variability in such risks across the globe and help fill gaps in critical observational data needed for climate change analysis (Roth, 2004; Turnbull, 2002; Wilbanks, 2002). From an ethical viewpoint, personal experiences of heat exposure risk at the local level are a significant source of data for discourse on and evaluation of climate change impacts (Brace & Geoghegan, 2011; Burningham & Obrien, 1994). Understanding people's perceptions of climate change based on heat exposure risk and magnitude from a practical perspective is relevant in providing suitable and locally based social protection, adaptation and mitigation strategies (Becken *et al*., 2013; Yaro, 2013). Consequently, the study sought to assess the risk and magnitude of heat exposure in the working and living environments on mining workers in the Western Region of Ghana. The study also aimed to test the hypotheses that there is no significant difference in heat exposure risk factors among background characteristics of small-scale and large-scale mining workers.

Materials and methods

Philosophy and study design

In the context of the post-positivist research paradigm, the descriptive cross-sectional survey research approach was deemed suitable in this study to assess the research problem. Hence, complementary data from several sources, including survey and self-reported responses from workers, and measurement of heat exposure via weather data loggers, were used to describe the magnitude of heat exposure and its attendant risk on mining workers in Ghana at a point in time (Creswell & Plano Clark, 2017; Mertens, 2015).

Study setting, population, sampling procedure and sample size

The study was conducted in the Western Region of Ghana, which is popular for small- and large-scale mining operations. Mining provides significant socioeconomic benefits for both local, national and multinational investors in Ghana. An estimated population of over one million mining workers were used as the basis to randomly select 320 respondents from five mining sites in the Western Region of Ghana (Nunfam *et al*., 2019a). Also, two out of the five mine sites, including four mining workers, were conveniently selected to measure the extent of heat exposure risks in the working and living environments of the mining workers.

Sources and methods of data collection

Both primary and secondary heat exposure data were used in the assessment of heat stress risk of mining workers in this study. Primary data comprised mining workers' background characteristics, heat exposure risk factors and estimated Wet Bulb Globe Temperature (WBGT) values based on hourly temperature and RH data (October 2017 - September 2018) in the Western Region of Ghana. Secondary data included average annual temperature and RH data (1967 - 2017) from two serviceable meteorological stations of Sefwi Bekwai and Tarkwa in the Western Region of Ghana (Nunfam *et al*., 2019a) and relevant literature.

A questionnaire was used to elicit from the 320 respondents, their background characteristics and heat exposure risk factors. The validated instruments of the High Occupational Temperature Health and Productivity Suppression (HOTHAPS) programme and analogous research studies on heat exposure assessment served as a guide in the design of the questionnaire (Kjellstrom *et al*., 2009a; Kjellstrom *et al*., 2009b; Nunfam *et al*., 2019a; Xiang *et al*., 2015). The self-reported question items centred on respondents' demographics (e.g., age, sex and education), work characteristics (e.g., workload, hours of work, work environment, physical work exertion, and work around heat sources), workplace heat exposure risk, environmental risk factors, work-related risk factors and concerns about workplace heat exposure risk.

The extent of heat stress risk is inextricably linked to the intensity of workers' exposure to environmental-related heat exposure factors (e.g., temperature and humidity), occupational-related heat susceptibility factors (e.g., workload and working hours) and individual-related vulnerability factors (e.g., age and sex). Considering the hazards of heat exposure to working people, different indices (e.g., Wet Bulb Globe Temperature (WBGT) index, the Universal Thermal Climate Index (UTCI), Heat Stress Index (HSI), and simple temperature/humidity averages) have been developed for its measurement and validation (Bernard & Pourmoghani, 1999; Brode *et al*., 2012; Kjellstrom *et al*., 2009a; Lemke & Kjellstrom, 2012; Liljegren *et al*., 2008). These indices have been used in previous studies to measure the magnitude of outdoor and indoor heat exposure on various cohorts of high risks workers in both temperate and tropical regions of the world (Adam-Poupart et al., 2013; Dutta *et al*., 2015; Frimpong *et al*., 2017; Lundgren *et al*., 2014; Venugopal *et al*., 2015).

Lascar EL-USB-2-LCD data loggers were used to capture daily records of hourly ambient temperature and RH, and these were used to estimate hourly WBGT indices over a 12-month duration. The WBGT is a widely used index to measure heat stress risk of workers. The Lascar instrument is a battery-powered device equipped with sensors and microprocessors to accurately monitor and record temperature, RH and dew point. It has a long-life lithium battery which permits logging for 12 months with the capacity to record and store many thousands of measurements in the range 0-100% for RH and -35 to +80°C (-31 to +176^{o}F) for temperatures (ClimateChip, 2016). Four Lascar EL-USB-2-LCD data loggers were used to measure temperature and humidity levels in the working and living environments of mining workers for the period (October 2017 to September 2018). The Lascar sensors were relatively easy to set up and did not need any maintenance over the period of usage in the selected remote mine sites or an external power supply. The Lascar data loggers were calibrated to measure ambient temperature and RH every hour for 12 months. Under the trust, monitoring and supervisory care of four selected workers, each Lascar was attached strategically to a convenient but representative setting either indoors (within homes or resting places for workers with cooling systems) and/or in full shade outdoors (e.g., strapped underneath a suitable tree branch or shaded construction) within the working environment (mine site) without exposure to direct sunshine (Byass *et al*., 2010).

The WBGT index uses four climate-related heat exposure variables (temperature, humidity, air velocity, and radiant heat) based on measures of air temperature (Ta), natural wet bulb Temperature (Tnwb) and globe temperature (Tg). Unlike the other indices, the WBGT is relatively simple, flexible and usable to measure heat exposure conditions. It is also an International Organisation for Standardisation (ISO)'s approved index suitable for measuring workplace heat stress (ISO, 1989; Parsons, 2013). Previous heat exposure studies among various workers in Thailand, India, Ghana, Zimbabwe, Nicaragua and Nepal have used Lascar measurements to effectively approximate WBGT values (Frimpong *et al*., 2017; Krishnamurthy *et al*., 2017; Ngwenya *et al*., 2018: Pradhan *et al*., 2013). As exemplified in an empirical study of heat exposure on farmers in Ghana, the Lascar was validated and found to have a strong correlation (r = 0.988) with the QuesTemp 34 heat stress monitor for the WBGT index (Frimpong *et al*., 2017). QuesTemp 34 is a standard instrument for accurately measuring WBGT including radiant heat but is very expensive and cumbersome as compared to the Lascar dataloggers which were preferred in this study. However, the magnitude of heat exposure is influenced by variables such as differences in individual work environment (e.g., indoor, in the shade, or outdoor), exposure duration, extent and type of activity, type of clothing and acclimatisation. It also depends on other factors (e.g., age, sex, obesity, and pre-existing health status) of the worker.

Data processing and analysis

Computer software including Microsoft Excel 2016 and IBM Statistical Product and Service Solutions (SPSS) version 25 were used in data processing and analysis. Descriptive statistics (e.g., mean, standard deviation, frequency and percent) and inferential statistics (e.g., Chi-Square) were used to assess the risk and magnitude of heat exposure on mining workers. The hypothesis related to the difference in heat exposure risk factors among workers with different background characteristics was assessed through Chi-Square tests at a significance level of ($p < 0.05$). The criteria (very small: 0.01, small: 0.20, medium: 0.50, large: 0.80, very large: 1.20, & huge: 2.0) was employed to determine the effect size of significant differences (Cohen, 1988; Sawilowsky, 2009). In situations where assumptions of Chi-Square were not met, results based on Yates' continuity correction and likelihood ratio results were reported (Fisher, 1935; McHugh, 2013; Yates, 1934). Also, Mann-Kendall trend (MK) test in XLSTAT was used in trend and variability analysis of the average monthly, day, daily maximum, and night WBGT at a significance level of ($p < 0.05$).

Validated methods have been developed for calculating indoor and outdoor WBGT from basic weather data (Bernard & Pourmoghani, 1999; ClimateChip, 2016; Liljegren *et al*., 2008). The hourly recordings of weather data (e.g., temperature and humidity) from the Lascar sensors were used for calculating the hourly WBGT indices for the 12 months. The estimated hourly WBGT values were then used to calculate average 24 hour, daytime (8:00 am-4:00 pm), daily maximum (highest WBGT between 12:00 pm-4:00 pm), and nighttime (8:00 pm-6:00 am) WBGT for each month over the 12 month monitoring period in both the working and living environments of the mining workers. As the four Lascar sensors were placed indoors or in full shaded areas outdoors and therefore could not account for measures of globe temperature, the method for calculating WBGT indoors was the best and most appropriate (Bernard & Pourmoghani, 1999). The method states that: $WBGTid = 0.67 * Tnwb + 0.33 * Ta - 0.048 * Log(ws) * (Ta - Tnwb)$, where indoor wind speeds (*ws*) is estimated at 1.0 m/s, natural wet bulb temperature (*Tnwb*) is calculated from dewpoint (*Td)* by iteration, and *Ta* is the ambient temperature (Bernard & Pourmoghani, 1999; Lemke & Kjellstrom, 2012). The WBGT indices were used in connection with international standards (e.g., ISO 7243) for the analysis of risk or safe work to determine appropriate and recommended maximum work-to-rest ratio (Table 7.1) for various kinds of work intensities and type of clothing (ISO, 1989; National Institute of

Occupational Health [NIOSH], 1986; NIOSH, 2016). The outcomes of the analysis were illustrated in tables and figures to facilitate understanding.

Table 7.1. Approved criteria for maximum WBGT exposure limits (º C) based on various work intensities and work-rest proportions for a normal acclimatise worker in light clothing

This image is available from either https://doi.org/10.1007/s00484-021-02164-3 or https://ro.ecu.edu.au/ecuworkspost2013/10525/

Results

The difference in heat exposure risks factors across the background characteristics of mining workers

The differences in workplace heat exposure risks factors across the various groups of mining workers based on demographic characteristics (age, sex and education) were not statistically significant (Table 7.2). Overall, most (91.9%) respondents considered mining workers at risk of workplace heat exposure due to changing climate conditions. A similar proportion (91.2%) of younger respondents compared to the older proportion (90.0%) were at risk of workplace heat exposure. However, the difference in workplace heat exposure risk between age category of mining workers was not statistically significant. A lower proportion (79.7%) of males than (96.7%) females indicated that mining workers were at risk of workplace heat exposure, however this gender disparity was not statistically significant. Furthermore, a slighly lower proportion (88.9%) of respondents who were uneducated (no formal education) than those with formal educataion (92.0%) stated mining workers were at risk of workplace heat exposure, although again this difference was not statistically significant (Table 7.2).

Table 7.2. Results of the difference in heat exposure risk factors across mining workers' demographic characteristics (Chi-Square test) (n= 320)

Environmental-related factors that influence the risk of workplace heat exposure on mining workers were mostly attributed to the heat radiation from the sun and other sources around the workplace (37.5%), the extent of hot air around the workplace (32.5%), and air movement around the workplace (17.3%). Comparatively, an unequal proportion of younger and older respondents identified heat radiation (37.6% vs 35.0%), extent of hot air (31.1% vs 25.0%), and air movement (17.3% vs 17.5%). However, this variation in environmental-related factors that stimulate workplace heat exposure was not statistically significant (Table 7.2). Similarly, more or less males compared to females identified heat radiation (37.2% vs 38.6%) and the extent of hot air (31.5% vs 37.5%) as environmental-related factors that influence workplace heat exposure risk to mining workers. The gender difference was statistically significant ($p < 0.05$) with a very small effect size (Table 7.2). Also, varying proportions of the uneducated compared to the educated respondents specified heat radiation (23.5% vs 37.9%), extent of hot air (35.3% vs 32.4%), and air movement (29.4% vs 16.9%), nonetheless this difference in environmental-related factors of workplace heat exposure risk across the education category was not statistically significant (Table 7.2).

Work-related heat exposure risk factors identified by most respondents included the type of physical workload (22.6%), duration of working hours (20.3%), duration of rest/break hours (12.9%), access to drinking water (11.5%) and access to shade (11.1%). More younger age group compared to their older counterparts identified the type of physical workload (22.9% vs 18.8%) and duration of work (20.5% vs 18.8%) as work-related factors that influence workplace heat exposure, but this difference in age category was not statistically significant (Table 7.2). Also, mixed proportions of males compared to females indicated type of physical workload (20.8% vs 34.7%), duration of break (13.1% vs 11.2%) and duration of working hours (20.8% vs 17.4%) as work-related heat exposure risk factors. The discrepancy in work-related heat exposure risk factors across the sex category was statistically significant ($p < 0.001$) with a small effect size (Table 7.2). A comparison of the respondents' education background showed an imbalance in the proportion of uneducated and educated respondents who identified type of physical workload (11.1% vs 23.1%), duration of working hours (18.5% vs 20.4%) and length of break (25.9% vs 12.4%), though this difference in the education category was not statistically significant (Table 7.2).

Lastly, the respondents were very much concerned (69.1%), moderately concerned (16.6%), a little concerned (9.7%) and not at all concerned (4.7%) about workplace heat exposure risk. The mixed proportion of younger and older respondents were very much concerned (70.8% vs 48.0%) and not all concerned (4.1% vs 12.0%) about workplace heat exposure risk to mining workers, however this disparity between the age category of mining workers was not statistically significant (Table 7.2). Also, unequal proportion of males and females were not at all concerned (5.0% vs 3.3%) and very much concerned (68.0% vs 73.7%) about workplace heat exposure risk. Nevertheless, the gender variation in concerns about workplace heat exposure risk was not statistically significant (Table 7.2). Similarly, different proportions of the uneducated and the educated respondents were not at all concerned (13.3% vs 4.2%) and very much concerned (3.2% vs 68.8%) about workplace heat exposure risk. The dissimilarity in concerns about workplace heat exposure across the education category was statistically significant ($p < 0.05$) with a very small effect size (Table 7.2).

Furthermore, differences in heat exposure risk factors across work characteristics of mining workers are shown in Table 7.3. The difference in workplace heat exposure risk across the proportions of respondents' workload categories (light: 100.0%, moderate: 79.6%, heavy: 95.8%, and very heavy: 98.8%) was statistically significant ($p < 0.001$) with a small effect size. Also, the distinction in workplace heat exposure risk across the category of workload, which comprised fewer (85.8%) respondents with less than 10 hours of work compared to more (95.2%) respondents with 10 hours and more work was statistically significant ($p < 0.05$) with a very small effect size. Moreover, there were slightly more (93.4%) respondents with indoor work environment, and lesser (89.0%) respondents engaged in outdoor work, however this discrepancy in workplace heat exposure risk across the category of work environment was not statistically significant. Similarly, fewer (86.7%) respondents indicated that their job was not at all physically demanding compared to more (93.1%) respondents who indicated that their job was very much physically demanding, but the difference across the category of physical work exertion was not statistically significant. Finally, the variation in workplace heat exposure risk across the category of work around heat sources based on a greater proportion (95.0%) of respondents who affirmed they worked around heat sources as compared to a small (70.7%) portion who did not was statistically significant ($p < 0.001$) with a small effect size (Table 7.3).

Variations in the environmental-related factors which influence the risk of workplace heat exposure based on the categories of workload, work hours, physical work exertion and work proximity to heat sources was statistically significant with exception of work environment. The difference in portions of respondents who identified hot air around the workplace (light: 26.9%, moderate: 23.7%, heavy: 39.2%, & very heavy: 33.0%), amount of air moisture in outdoor setting or workplaces (light: 3.9%, moderate: 10.8%, heavy: 6.4%, & very heavy: 8.0%), airspeed around the workplace (light: 7.7%, moderate: 9.4%, heavy: 14.8%, & very heavy: 27.1%), and heat radiation from the sun and other sources around the workplace (light: 61.5%, moderate: 41.7%, heavy: 37.0%, & very heavy: 31.4%) as environmental-related risk factors across workload was statistically significant ($p < 0.001$) with a small effect size (Table 7.3).

The difference in environmental-related risk factors across the category of work hours, which consisted of fewer respondents as compared to more respondents who stated hot air around the workplace (under 10 hours: 29.6% vs 10 hours and over: 34.5%), amount of air moisture in outdoor setting or workplaces (under 10 hours: 7.9% vs 10 hours and over: 8.0%), and heat radiation from the sun and other sources around the workplace (under 10 hours: 34.5% vs 10 hours and over: 39.6%) was statistically significant ($p < 0.001$) with a small effect size (Table 7.3). Furthermore, a mixed proportion of respondents indicated hot air around the workplace (indoor: 34.4% vs outdoor: 29.1%), amount of air moisture in outdoor setting or workplaces (indoor: 9.0% vs outdoor: 6.1%), airspeed around the workplace (indoor: 15.3% vs outdoor: 20.9%), and heat radiation from the sun and other sources around the workplace (indoor: 37.0% vs outdoor: 38.3%) as environmental-related risk factors, however this inconsistency across the category of work environment was not statistically significant (Table 7.3).

The dissimilarity in environmental-related risk factors across the category of physical work exertion, which comprised lesser respondents compared to more respondents who mentioned hot air around the workplace (not at all demanding: 40.0% vs very demanding: 31.3%), airspeed around the workplace (not at all demanding: 5.3% vs very demanding: 19.3%), and heat radiation from the sun and other sources around the workplace (not at all demanding: 37.3% vs very demanding: 37.5%) was statistically significant ($p < 0.001$) with a small effect size (Table 7.3). The contrast in environmental-related risk factors across the category of work around heat sources as shown by the uneven proportion of respondents who stated hot air around the workplace (yes: 32.9% vs no: 28.0%), amount of air moisture in outdoor setting or workplaces (yes: 7.9% vs no: 18.0%), airspeed around the workplace (yes: 18.5% vs no: 6.0%), and heat radiation from the sun and other sources around the workplace (yes: 37.6% vs no: 36.0%) was statistically significant ($p < 0.001$) with a small effect size (Table 7.3).

Respondents varying views on work-related factors that influence the risk of mining workers to heat exposure based on workload, hours of work, physical work exertion, and working near heat sources were statistically significant except for work environment. The variations in proportion of respondents who identified type of physical workload (light: 48.5%, moderate: 24.8%, heavy: 29.6%, & very heavy: 10.7%), duration of working hours (light:

9.1%, moderate: 21.4%, heavy: 18.6%, & very heavy: 22.6%), duration of rest hours (light: 6.0%, moderate: 7.3%, heavy: 12.2%, & very heavy: 19.0%), and access to drinking water (light: 3.1%, moderate: 9.2%, heavy: 9.7%, & very heavy: 16.3%) as occupational risk factors which influence workplace heat exposure to mining workers across the category of workload was statistically significant ($p < 0.001$) with a small effect size (Table 7.3).

Evidence of different proportions of respondents who recognised type of physical workload (under 10 hours: 19.7% vs 10 hours and over: 24.8%), duration of working hours (under 10 hours: 22.5% vs 10 hours and over: 18.7%), duration of rest hours (under 10 hours: 12.7% vs 10 hours and over: 13.0%), access to shade (under 10 hours: 11.8% vs 10 hours and over: 10.6%), and access to drinking water (under 10 hours: 13.0% vs 10 hours and over: 10.4%) as occupational risk factors which influence workplace heat exposure to mining workers across hours of work category was statistically significant ($p < 0.001$) with a small effect size (Table 7.3).

Also, varying proportions of respondents in the category of work environment regarded the type of physical workload (indoor: 24.6% vs outdoor: 19.4%), duration of working hours (indoor: 20.7% vs outdoor: 19.7%), duration of rest hours (indoor: 11.5% vs outdoor: 15.1%), access to shade (indoor: 8.0% vs outdoor: 12.9%), and access to drinking water (indoor: 10.7% vs outdoor: 12.9%) as work-related risk factors which influence workplace heat exposure to mining workers, nonetheless this difference was not statistically significant (Table 7.3). The difference in proportions of respondents who mentioned type of physical workload (not at all demanding: 43.6% vs very demanding: 19.6%), duration of working hours (not at all demanding: 12.8% vs very demanding: 21.4%), duration of rest hours (not at all demanding: 7.5% vs very demanding: 13.7%), access to shade (not at all demanding: 5.3% vs very demanding: 12.0%), and access to drinking water (not at all demanding: 2.1% vs very demanding: 12.9%) as work-related risk factors which influence workplace heat exposure across the category of physical work exertion was statistically significant ($p < 0.001$) with a small effect size (Table 7.3). Lastly, the discrepancy based on the uneven proportions of respondents who identified type of physical workload (yes: 21.6% vs no: 31.2%), duration of working hours (yes: 20.1% vs no: 22.0%), duration of rest hours (yes: 14.1% vs no: 2.6%), access to shade (yes: 11.8% vs no: 5.2%), and access to drinking water (yes: 12.4% vs no: 3.9%) as work-related risk factors which influence workplace heat exposure across the category of work around heat sources was statistically significant ($p < 0.001$) with a very small effect size (Table 7.3).

Table 7.3. Results of the difference in heat exposure risk factors across mining workers' work characteristics (Chi-Square test) (n= 320)

Aside from workload and proximity of work to heat sources, the divergent opinions of respondents' concerns about workplace heat exposure risk in the categories of hours of work, work environments, and physical work exertions were not statistically significant. The difference in respondents' views including not at all concerned about workplace heat exposure risk (light: 4.8%, moderate: 7.1%, heavy: 4.2%, & very heavy: 2.5%), a little concerned (light: 4.3%, moderate: 15.3%, heavy: 7.5%, & very heavy: 4.9%), moderately concerned (light: 9.5%, moderate: 27.6%, heavy: 13.3%, & very heavy: 9.9%) and very much concerned (light: 71.4 moderate: 50.0%, heavy: 75.0%, & very heavy: 82.7%) across the category of workload was statistically significant ($p < 0.05$) with a very small effect size (Table 7.3).

Also, the varying concerns about workplace heat exposure risk included not at all concerned (under 10 hours: 7.1% vs 10 hours and over: 3.3%), a little concerned (under 10 hours: 9.7% vs 10 hours and over: 9.7%), moderately concerned (under 10 hours: 13.3% vs 10 hours and over: 18.4%) and very much concerned (under 10 hours: 69.9% vs 10 hours and over: 68.6%) about workplace heat exposure risk, however this disparity between the category of hours of work was not significant (Table 7.3).

Furthermore, divergent proportions of respondents' concerns about workplace heat exposure risk comprised not at all concerned (indoor: 5.7% vs outdoor: 2.8%), a little concerned (indoor: 9.0% vs outdoor: 11.0%), moderately concerned (indoor: 16.1% vs outdoor: 17.4%) and very much concerned (indoor: 69.1% vs outdoor: 68.8%), nonetheless this variation between the category of the work environment was not statistically significant (Table 7.3).

In addition, different proportions of respondents' concerns about workplace heat exposure risk included not at all concerned (not at all demanding: 6.7% vs very demanding: 4.2%), a little concerned (not at all demanding: 11.6% vs very demanding: 9.3%), moderately concerned (not at all demanding: 16.7% vs very demanding: 16.5%) and very much concerned (not at all demanding: 65.0% vs very demanding: 70.0%), but this discrepancy across the category of physical work exertion was not statistically significant.

Lastly, the variation in proportions of respondents' concerns about workplace heat exposure risk, which involved not at all concerned (yes: 5.0% vs no: 2.4%), a little concerned (yes: 7.9% vs no: 22.0%), moderately concerned (yes: 16.5% vs no: 17.1%) and very much concerned (yes: 70.6% vs no: 58.5%) between the category of work around heat sources was statistically significant ($p < 0.05$) with a very small effect size (Table 7.3).

The magnitude of heat exposure in the working and living environments of mining workers

In the context of the working environment of mining workers, the magnitudes of maximum average WBGTs (24 hr: 28.6°C, daytime: 29.9°C, daily maximum: 32.0°C, and nighttime: 28.3°C) outdoor (in shade) were much higher compared to maximum average indoor WBGTs (24 hr: 28.1°C, daytime: 29.3°C, daily maximum: 30.5°C, and nighttime: 27.9°C) (Table 7.4 & 7.5). Hence, average maximum daytime and nighttime WBGTs for outdoor working environment were greater than indoor working environment by 0.6°C and 0.4°C respectively.

Also, the maximum average WBGTs (24 hr: 28.3°C and nighttime: 28.3°C) outdoor (in shade) in the living environment were greater by 0.7°C and 2.1°C respectively, than that found within indoor living environment of mining workers (Table 7.4 & 7.5). Conversely, the highest average WBGT values for daytime (29.9°C) and daily maximum (32.0°C) for indoor living environment were greater by 1.6°C and 3.4°C than in the outdoor (shaded) living environment of mining workers (Table 7.5).

Furthermore, maximum average WBGTs (24 hr: 28.1°C and nighttime: 27.9°C) within the indoor working environment were rather higher than the average WBGTs (24 hr: 27.6°C and nighttime: 26.2°C) within the indoor living environment while the maximum average WBGTs (daytime: 29.9°C and daily maximum: 32.0°C) indoor living environment were higher than the maximum average WBGT (daytime: 29.3°C and daily maximum: 30.5°C) indoor working environment (Table 7.4 & 7.5).

Lastly, the maximum average WBGTs (24hr: 28.6°C, daytime: 29.9°C and daily maximum: 32.0°C) across the outdoor working environment were higher compared to the maximum average WBGT (24 hr: 28.3°C, daytime: 28.3°C, and daily maximum: 28.6°C) in the outdoor living environment. However, the maximum average nighttime WBGT for both outdoor working and living environments were the same (Table 7.4 & 7.5).

Table 7.4. Result of desriptive statistics and trend analysis of estimated average monthly WBGT (24hr) from Octorber 2017 to September 2018 measured from Lascar EL-USB-2-LCD data loggers

This image is available from either https://doi.org/10.1007/s00484-021-02164-3 or https://ro.ecu.edu.au/ecuworkspost2013/10525/

Seasonal trends of estimated average WBGT indices in the working environment of mining workers

Patterns of average monthly WBGT (24 hr, daytime, daily maximum, and nighttime) within the working environments are shown in Figure’s 7.1 and 7.2. The seasonal pattern of average WBGT (24 hr) indoors in the working environment was above the mean (27.1 ^{o}C) from March 2018 to May 2018 with a peak (28.1^{o}C) in April 2018 during the onset of the major wet season, and was lowest from August 2018 (26.2^{o}C) to September 2018 (26^{o}C) in the period characterised by a short spell of dry season. Furthermore, the average daytime WBGT during the typical working hours of 8:00 am to 4:00 pm for each month was at a high (29.3 ^{o}C) in April 2018 and a low (27.0 ^{o}C) in September 2018 while the average nighttime WBGT during rest periods (8:00 pm-6:00 am) showed a high (27.9 ^{o}C) and a low (25.6 ^{o}C) in September 2018. Thus, seasonal trends in average WBGT were much higher during the daytime compared to nighttime. The average daily maximum WBGT during the hottest period of the day (12:00 pm-4:00 pm) per month was found to be highest in April 2018 with 30.5 ^{o}C and lowest in September 2018 with 28.6 ^{o}C (Figure 7.1).

This image is available from either https://doi.org/10.1007/s00484-021-02164-3 or https://ro.ecu.edu.au/ecuworkspost2013/10525/

Figure 7.1: Average WBGT indoor in the work environment of mining workers

Source: Field survey, 2017-2018

The level of heat exposure measured as average monthly WBGTs (24 hr, daytime, daily maximum, and nighttime) outdoor in full shade of the working environment of mining workers is shown in Fig. 7.2. The seasonal trend in average WBGT (24 hr) outdoor in full shade of the working environment was above the mean (27.5 ^{o}C) from February 2018 to July 2018, with the highest (28.6 ^{o}C) in March 2018, but was much lower from August 2018 to September 2018, with the lowest (26.2 ^{o}C) in September. Similarly, the magnitude of average daytime WBGT outdoor per month in the working environment showed much higher levels from February 2018 to July 2018, with the highest (29.9 ^{o}C) in March 2018 and lowest (26.9 ^{o}C) in September, while the extent of average nighttime WBGT outdoor for each month in the working environment recorded much greater levels from February 2018 to May 2018 with the highest (28.3 ^{o}C) in March 2018 and the lowest (25.5 ^{o}C) in September 2018. The period of highest average WBGT (daytime and nighttime) occurred during the rainy season while the periods of lowest average WBGT (daytime and nighttime) occurred during the period of a short spell of the dry season. The seasonal trends in WBGT were higher in the daytime than the nighttime. In terms of the average daily maximum WBGT during the hottest part of the day (12:00pm-4:00pm) for each month, the highest (32.0 ^{o}C) was recorded in March 2018, and the lowest (27.8 ^{o}C) occurred in September 2018 (Figure 7.2).

This image is available from either https://doi.org/10.1007/s00484-021-02164-3 or https://ro.ecu.edu.au/ecuworkspost2013/10525/

Figure 7.2: Average WBGT outdoor in full shade in the work environment of mining workers

Source: Field survey, 2017-2018

Seasonal trends of estimated average WBGT indices in the living environment of mining workers

Figure 7.3 shows seasonal fluctuations in average monthly WBGTs (24 hr, daytime, daily maximum, and nighttime) indoors in the living environment of mining workers. The pattern of seasonal variations showed that the average WBGT (24hr) indoors in the living environment was above the mean (26.7 ^{o}C) from February 2018 to May 2018 with a peak (27.6 ^{o}C) in March 2018 during the major rainy season, and the lowest (25.3 ^{o}C) in August 2018 during the short spell of the dry season. Similarly, the average daytime WBGT indoors in the living environment was much higher from February 2018 to May 2018 with the highest average daytime WBGT (29.9 ^{o}C) in March 2018 and the lowest day WBGT (26.1 ^{o}C) in August 2018. Additionally, the average nighttime WGBT per month was fairly consistent across the year except for 1-2 months. Higher seasonal trends of WBGT were recorded during the daytime compared to nighttime. Also, the highest average WBGT (daily maximum) indoors in the living environment during the hottest period (12:00pm-4:00pm) of the day occurred in March 2018 with 32.0 ^{o}C while the lowest (27.0 ^{o}C) occurred in August 2018 (Figure 7.3).

This image is available from either https://doi.org/10.1007/ s00484-021-02164-3 or https://ro.ecu.edu.au/ecuworkspost2013/10525/

Figure 7.3: Average WBGT indoor in the living environment of mining workers

Source: Field survey, 2017-2018

Seasonal variation in average monthly WBGTs (24 hr, daytime, daily maximum and night) outdoors in full shade in the living environment of mining workers is shown in Figure

7.4. The seasonal trend in the average WBGT (24 hr) outdoors (in shade) in the living environment was above the average (27.0 ^{o}C) and were much higher from February 2018 to May 2018 with a maximum (28.3 ^{o}C) in March 2018 during the commencement of the major wet season, and the minimum (25.7 ^{o}C) in August 2018 during the short spell of the dry season. Variations in average daytime WBGT outdoors (shaded) in the living environment showed the highest (28.3 ^{o}C) in March 2018 and the lowest (25.7 ^{o}C) in August 2018. Also, the highest average night WBGT outdoor (shaded) in the living environment was 28.3 ^{o}C in March 2018, and the lowest average night WBGT was 25.8 ^{o}C in August 2018. With regards to the average daily maximum WBGT outdoor in full shade in the living environment, the highest (28.6 ^{o}C) was recorded in March 2018, and the lowest (26.0 ^{o}C) was recorded in August 2018. Unlike the other sites, there was much greater seasonal variation as well as far greater consistency in WBGT across daytime and nightime. Similarly, the daily maximum WBGT was not that much greater than the daytime WBGT (Figure 7.4).

This image is available from either https://doi.org/10.1007/s00484-021-02164-3 or https://ro.ecu.edu.au/ecuworkspost2013/10525/

Figure 7.4: Average WBGT outdoor in full shade in the living environment of mining workers

Source: Field survey, 2017-2018

Discussion

Even though it is not a novelty in heat exposure studies, the assessment of risk and magnitude of heat exposure on mining workers in Ghana is locally innovative. The study relied on results of a survey of heat exposure risk factors and 12 months of estimated WBGT indices. This was complemented by relevant literature to assess the extent of risk and magnitude of local heat exposure on mining workers to enlighten heat exposure management and policies in the mining sector in Ghana and other workplace settings (e.g., agriculture, construction, manufacturing, oil and gas) in tropical regions of the world.

Heat exposure risks of mining workers

Hazards of heat exposure on mining workers were evident in respondents' awareness and apprehensions of heat exposure risk factors. The influencing factors of heat exposure consisted of an awareness of heat exposure risks in the workplace, environmental-related risk factors (e.g., workplace ambient temperature, air moisture, air movement and heat radiation), work-related risk concerns (e.g., type of physical workload, duration of work hours, type of protective clothing, access to cooling system, water and shade) and extent of concerns about workplace heat exposure risk. Like other vulnerable occupational settings, workplace heat exposure commonly affects workers' health, safety, productive capacity, social connectedness, cognitive judgement and by extension the overall productivity of the mining industry (Kjellstrom *et al*., 2016b; Nunfam *et al*., 2018).

In the context of present and predicted rise in temperature and global climate change, the substantial difference in heat exposure risk factors (e.g., environmental risk and work-related risk factors) across workers' gender have useful ramifications for policies on workplace heat exposure. Also, the significant difference in the extent of concerns about workplace heat exposure as a risk factor across workers' education is an important predictor and contributory factor in the formulation and execution of heat stress management education through heat exposure-related health and safety information, communication, education and training (Lee *et al*., 2015). Thus, an informed workplace heat exposure policies based on workers' gender and education can ensure the effective deployment and holistic use of the social and productive human capital potentials of workers for reduced heat exposure-related illnesses, injuries and fatalities, and increased productivity in the mining sector and other vulnerable occupational settings.

Furthermore, the significant disparity in heat exposure risk factors across work characteristics (e.g., workload, hours of work, physical work exertion and proximity to heat sources) has the potential to influence mining workers' health, safety, productive capacity, human and social capital improvement, and the extent of workplace heat exposure adaptation and resilience planning (Nunfam *et al*., 2019). Sustainable productivity of mining does not only depend on access and use of advanced innovative technology but also relies on safe occupational settings. Such safe working environments ought to be devoid of heat exposure risk hazards like excessive ambient temperature and humidity, heat radiation, poor air circulation, and inadequate adaptive capacity of workers.

The magnitude of heat exposure on mining workers

The extent and seasonal trends in the monthly average WBGT (minimum: 25.3 ^{o}C - maximum: 28.6 ^{o}C) from October 2017 to September 2018 are in line with the pattern of Ghana's meteorological data, especially average annual temperatures which generally varies from 24 °C to 30 °C across Ghana (Government of Ghana, 2013, 2015). It also falls within the scale and variability trend of mean annual minimum temperature (22.5 ^{o}C) and maximum temperature (32.4 ^{o}C) estimated from a proximate meteorological data to the study area (Nunfam *et al*., 2019a). Whereas the variability of average WBGT (24 hr, daytime, daily maximum, and nighttime) across the 12 months was not statistically significant (Tables 7.4 & 7.5), the disparities in mean annual temperature and RH (1967-2017) was statistically significant (Nunfam *et al*., 2019a). Similarly, variations in the trend of yearly temperature and RH of nearby meteorological data (1961-2012) in Bawku East in Northern Ghana were significant (Frimpong et al., 2014). Furthermore, studies of heat exposure on farmers demonstrated a strong association (r = 0.988) in WBGT indices between Lascar data loggers and QuesTemp 34, heat monitor equipment (Frimpong et al., 2017). The correlated results of WBGT indices from both equipment and the similarity in degree of average temperature and WBGT values for both periods shows the reliability, precision and effectiveness of the Lascar EL-USB-2-LCD data loggers in assessing the magnitude of heat exposure.

Based on the Lascar sensors, the recorded magnitude of monthly average WBGT outdoors (27.5 ^{o}C) and monthly average WBGT indoors (27.1 ^{o}C) within the working environment of the mining workers is below the core body temperature (37 ^{o}C) (Kjellstrom et al., 2016a). Temperatures of this magnitude have the cooling potential of allowing heat generated in the body to evaporate effectively via sweating (Kjellstrom et al., 2018). However, the amount of estimated average WBGT is reasonably high with potentially harmful heat exposure risk and impact on mining workers' work capacity and performance within such working environments. The tendency for work capacity in the mining sector, which is characterised by moderate to heavy labour intensity, to reduce when hourly WBGT exceeds 26.0 ^{o}C or become burdensome to perform at WBGT above 32.0 ^{o}C is highly probable (Kjellstrom *et al*., 2016a). Similarly, the risk of workers to heat exposure could be exacerbated by the estimated maximum average WBGTs (daytime and daily maximum) of above 29.3 ^{o}C in both indoor and outdoor working environments. Therefore, mining workers with heavy work intensity who are exposed to average maximum WBGT (>29.3 ^{o}C), which is higher than the recommended criteria for maximum WBGT exposure limits (27.5 ^{o}C) will need to have at least 75% work and 25% rest particularly for acclimatised workers in light clothing. However, in the hottest part of the day in March-April when WBGT exceeds 32.0 ^{o}C, mining workers should be taking longer breaks or perhaps not even working at all to cope with this level of heat (Table 7.1) (ISO, 1989; NIOSH, 2016). Due to the potential heat exposure risk of high temperature to mining workers, regulation 180 of the Minerals and Mining Regulation of 2012 (L.I.2182) enjoins a mine manager to ensure that the wet bulb temperature at the working environment in the mine does not exceed 32.5 ^{o}C and workers should be provided with longer breaks and reduced working time when the wet bulb temperature exceeds 27 ^{o}C in the mine (Government of Ghana, 2012). Work characterised by physical exertion as it pertains to the mining sector becomes unsafe under wet bulb temperatures above 32 ^{o}C (Buzan *et al*., 2015; Liang *et al*., 2011).

The gravity of the inherently imminent heat stress hazard associated with the findings for mining workers is that WBGT indices were probably underestimated by excluding globe temperature because the WBGT indices were recorded in full shaded area (ClimateChip, 2016). Moreover, most mining work is not only heavy and physically exerting, but are done under full sunshine or underground in protective clothing, for more extended hours, and with the aid of plants and equipment characterised by heat radiation. Under the circumstance, heat exposure policies without adequate ventilation and cooling systems, shade, acclimatisation programmes, frequent rehydration, rest/work schedule, measured workload, and light coloured and cooling garments, mine workers may be highly vulnerable to heat-related illness, injuries and death.

Furthermore, the extent of monthly average WBGT outdoors (27.0 ^{o}C) in the shade and monthly average WBGT indoors (26.7 ^{o}C) recorded within the living environment of the mining workers were relatively high. Aside the maximum average nighttime WBGT indoors (26.7 ^{o}C) of the living environment, the highest average WBGTs (24hr, daytime, daily maximum, and nighttime) within the indoor and outdoor living environments were above WBGT (27.5 ^{o}C). However, resting environments with maximum WBGT exposure limits (27.5 ^{o}C) for workers engaged in heavy workload are required to have 75% work intensity and 25% break duration as recommended in Table 7.1 (ISO, 1989; NIOSH, 2016). Similarly, mining companies are mandated by regulation to ensure that the wet bulb temperature at the working environment is not above 32.5 ^{o}C and workers are allowed to observe longer rest hours and working time reduced when the wet bulb temperature exceeds 27 ^{o}C in the mine (Government of Ghana, 2012). Notably, midday temperatures were possibly underestimated by 0.2-5 ^{o}C because the intensity of heat radiation from the sun was excluded based on methods of WBGT calculations as the Lascar sensors were placed in full shaded areas (ClimateChip, 2016). Also, seasonal variability in the magnitude of average WBGT in the working and living environments showed that the highest monthly average WBGT occurred in the period March to April which is associated with the risk of hot and humid conditions in Ghana. This finding is similar to the seasonal variations of temperature in southern Ghana, where the highest average maximum temperature typically occurred in the period February to April (Ghana Meteorological Agency, 2016).

The adaptation policies and heat exposure management of mining firms ought to consider the scale of average WBGT (24hr, daytime, daily maximum, and nighttime) values and the approved criteria for maximum WBGT exposure threshold limits based on work/rest intensity (Table 7.1) (ISO, 1989; NIOSH, 2016). This has the utmost significance to reduce the risk of mine workers to heat exposure-related illnesses, injuries and fatalities. In most developed economies and large-scale multi-national mining firms, compared to most artisanal and small-scale mining companies, the heat exposure policies based on ISO 7243 and NIOSH approved WBGT heat exposure limits are often implemented (Table 7.1). Such policies are mostly informed by engineering, administrative, education and training, regulatory and social protection strategies as part of adaptation and resilience control measures to reduce the risk and impact of heat exposure on workers as temperature, and climate change intensifies (Kjellstrom *et al*., 2016b; Lucas *et al*., 2014).

Conclusions and policy recommendations

The intensifying temperature and global climate warming in the 21st Century and beyond have the propensity to increase exposure to more intense heat across the world, including many occupational and living environments. The study provides current and comprehensive local insight on risk and magnitude of heat exposure on mining workers based on WBGT estimates derived from basic meteorological measurements from Lascar data loggers for 12 months. The variation in environmental and work-based heat exposure risk factors across workers' gender and the disparity in the extent of concern about workplace heat exposure risk across workers' education were significant. The substantial discrepancy in heat exposure risk factors across work characteristics (e.g., workload, hours of work, physical work exertion and proximity to heat sources) has the potential to compromise mining workers' health and safety, productive capacity, social well-being, adaptive capacity and resilience. The Lascar data loggers were reliable and useful in measuring the magnitude of heat exposure precisely and suitably as a less expensive alternative to other indices. The scope of indoor/outdoor average WBGT (24hr, daytime, daily maximum, and nighttime) estimates within the working and living environment of mining workers were relatively high with potential heat exposure risk and impact on mining workers without adequate heat exposure management and adaptation strategies. Hence, a concerted global and local effort at providing adequate and effective adaptation policies and heat exposure management for various cohorts of workers involved in heavy and physically exerting jobs in coverall for more extended hours in hot and humid conditions is imperative. This will reduce the risk of heat stress, improve productive capacity and performance, and boost the social health, adaptive capacity and resilience of mining workers.

CHAPTER EIGHT: BARRIERS TO OCCUPATIONAL HEAT STRESS ADAPTATION OF MINING WORKERS IN GHANA

Abstract

Increasing temperature and climate warming impacts are aggravating the vulnerability of workers to occupational heat stress. Adaptation and social protection strategies have become crucial to enhance workers' health, safety, productive capacity and social lives. However, the effective implementation of work-related heat stress adaptation mechanisms appears to be receiving little attention. This study assessed the barriers to occupational heat stress adaptation and social protection strategies of mining workers in Ghana. Based on a mixed methods approach, focus group discussions and questionnaires were used to elicit data from 320 mining workers. Workers' adaptation strategies (water intake, wearing loose and light-coloured clothing, participating in training programmes, taking regular breaks, use of mechanical equipment, use of cooling systems and housing designs) varied significantly across the type of mining activity ($p<0.001$). Workers' social protection measures were adequate. The disparities in workers' social protection measures significantly differed across the type of mining activity ($p<0.001$). Barriers of workers to the implementation of relevant adaptation strategies (inadequate knowledge of coping and adaptive behaviour, lack of regular training on adaptation measures, lack of specific heat-related policy regulations, lack of management commitment, and the lack of access to innovative technology and equipment) also differed across the type of mining activity ($p<0.001$). Adaptation policy options and recommendations centred on overcoming the barriers that constrain the adaptive capacity of workers and employers has the potential to reduce workers' vulnerability to occupational heat stress.

Keywords: Adaptation strategies; barriers; Ghana; mining workers; occupational heat stress; social protection

Introduction

Excessive heat exposure based on intensifying global temperatures and climate warming is seen as a potential existential risk to humans, the environment and global development (United Nations [UN], 2009). In particular, extreme heat exposure in workplaces is a recognised fundamental danger to the physiological health, safety, economic productivity, psychological and social lives of working people (Kjellstrom *et al*., 2016a; Kjellstrom *et al*., 2016b). For this reason, the primary development agenda of the world dubbed the United

Nation's Sustainable Development Goals (SDGs) has been designed to improve the lives of people. The SDGs accentuate the need to promote healthy lives and well-being, guarantee decent jobs and economic growth, and fight increasing temperature and other climate change impacts (Leal Filho *et al*., 2018; UN, 2015; Xue *et al*., 2018).

In tropical and sub-tropical areas of the world, the occurrences of rising heat exposure in work and living environments are being complicated by episodes of high temperature and relative humidity in the context of global climate change due to human-induced Greenhouse Gas (GHG) emissions. The consequence of heat stress risk and impact on workers due to intense heat exposure are commonly manifested in heat-related morbidities, poor mental judgment, lack of vigilance and concentration, reduced productive capacity and physical performance, and poor social well-being (Kjellstrom *et al*., 2009b; Lundgren *et al*., 2013; Wyon *et al*., 1996). Empirical and conceptual studies have demonstrated that intensive physical workloads in hot environments coupled with high relative humidity increases core body temperature, reduces physical work capacity, lessens mental concentration, intensifies the possibility of heat-related morbidities and enhances the threat of heat exhaustion and heat-related mortality (Bridger, 2003; Ramsey, 1995; Richards & Hales, 1987).

The quest to combat the risk and magnitude of the impacts of rising global temperature on the world's population, including workers, has stimulated substantial and diverse research interests, international framework conventions, standards, guidelines, conferences, and collaborations within and between UN agencies and Intergovernmental organisations. For example, after the First World Climate Conference in Geneva in 1979, the Intergovernmental Panel on Climate Change was established (IPCC) in 1988, the United Nation Framework Convention on Climate Change (UNFCCC) in 1992, and 24 Conferences of Parties (COP) with the first in Berlin in 1995 and the last in 2018 in Poland. Similar notable actions include the Kyoto Protocol and Paris Agreement (IPCC, 2014a; Roberts, 2016; Rogelj *et al*., 2016; UNFCCC, 2006). Similarly, guidelines and standards for governments and labour organisations to address the health and safety impacts of heat exposure on workers and employers include International Organisation for Standardisation (ISO), National Institute for Occupational Safety and Health (NIOSH), and International Labour Organisation (ILO) policy guidelines and codes of practice on hot workplace environment (ILO, 2001, 2016; ISO, 1989; NIOSH, 2016). Fundamentally, these measures have sought to enhance adaptive capacity, strengthen resilience, and reduce vulnerability to increasing temperature and climate change impacts, and commit to fostering mitigation, adaptation and social protection of people (IPCC, 2014b; Roberts, 2016; Rogelj *et al*., 2016; UNFCCC, 2006).

The risk and impact of workplace heat exposure on workers' socioeconomic and health conditions is a significant characteristic of climate change with the tendency to undermine realisation of the SDGs (Kjellstrom *et al*., 2016b). Hence, preventive and control strategies have been advocated to address occupational heat stress threats to reduce susceptibility, improve resilience and adaptive capacity of working people and their families, socioeconomic units, and communities to ensure sustainable well-being (IPCC, 2014b; Kjellstrom *et al*., 2016b). Aside from mitigation measures, several scholars have identified adaptation and social protection policies and practices as the most appropriate and viable strategies for managing occupational heat stress risk and impacts on people including workers (see Spector & Sheffield, 2014; Venugopal et al., 2016; Venugopal *et al*., 2015; Xiang *et al*., 2016).

Adaptation encompasses reducing actual workplace heat exposure, avoiding heat stress, and protecting workers from occupational heat stress. Successful interventions relating to coping and adaptation strategies mainly comprise engineering solutions, administrative controls, and education and training regimes (Kjellstrom *et al*., 2016b). It also involves bolstering policy and regulatory guidelines, varying structures of economies to focus on non-outdoor work, compensations for production losses, and social protection of workers (Davies *et al*., 2009; Giovannetti, 2010; Kjellstrom *et al*., 2016b; Lundgren *et al*., 2013). Social protection comprises collective and individualised policies, programmes, and actions directed at preventing, reducing, and eliminating poverty, deprivation, and social exclusion. It also seeks to boost resilience and opportunities by promoting human and social capital of workers to ensure decent and productive employment (UNICEF, 2012; World Bank, 2012). Social safety policies are exemplified in workers' social security, superannuation, and pension schemes as well as insurance policies and labour market interventions (e.g., health insurance, labour standards, minimum wage legislation, credit schemes, and workers interest groups), benevolent reliefs and aids to workplace disaster (Davies *et al*., 2009).

However, these adaptation and social protection mechanisms are often inadequately implemented at the individual and organisational level to reduce workers' vulnerability and boost their resilience and adaptive capacity to occupational heat stress and climate change (Kjellstrom *et al*., 2016a; Venugopal *et al*., 2016). A variety of multifaceted factors, as illustrated in various studies in the US and Australia, for instance, impede the smooth and effective implementation of adaptation to heat exposure, which include inadequate education and awareness campaigns, lack of health and safety training, lack of obligation from management, low compliance of heat stress prevention policies, and insufficient financial resources (Lam *et al*., 2013; Riley *et al*., 2012; Xiang *et al*., 2015).

Several types of outdoor workers (e.g., construction, military, agriculture, manufacturing, and mining) in tropical developing regions, including Ghana, are particularly susceptible to occupational heat stress stemming from rising temperature, outdoor radiant heat, and high humidity, in the context climate change (Kjellstrom *et al*., 2009b; Lucas *et al*., 2014). Both the work and living environments of mining workers are often associated with the risk of heat stress due to actions, events, and interventions typical of surface and underground mining activities. Hence, mining workers in both Small-Scale Mining (SSM) including artisanal mining and Large-Scale Mining (LSM), are at risk of heat stress-induced factors such as high temperature, radiant heat, hot and humid conditions, air movement, heavy physical activity, individual acclimatisation, and use of protective clothing. SSM usually involves local people with inadequate funding and low technical expertise who use labour intensive methods and basic equipment (e.g., shovels, pickaxes, and sluice) to semi-mechanised mining operations (e.g., pumps, blowers, generators, small excavators and washing plants) (McQuilken & Hilson, 2016). This unsafe condition is compounded by the predicted rise in temperature in tropical developing countries like Ghana, which is also associated with major impediments such as poverty, low adaptive capacity, inadequate innovative technology and lack of knowledge of the available heat stress adaptation strategies. This ultimately affects the health and safety, productive ability, and social lives of mining workers leading to loss of productivity and employment opportunities for mining companies (Nunfam *et al*., 2019a; 2019b).

Given the tendency of workers' vulnerability to occupational heat stress and climate change impacts, effective adaptation and social protection strategies have become crucial to enhance workers' health and safety and improve their productive capacity, physical performance, and social well-being. Hence, several studies have delved into the concerns about workplace heat stress, climate change and adaptation strategies expressed by various types of workers across the world (Frimpong *et al*., 2017; Kjellstrom *et al*., 2016a; Nunfam *et al*., 2018; Venugopal *et al*., 2016; Xiang *et al*., 2016). However, current research interest in Ghana's mining industry seems to focus on issues about health and environmental impact assessment of mining activities on air and water pollution, ecosystem and land degradation (Amponsah-Tawiah & Dartey-Baah, 2011; Aryee *et al*., 2003; Basu *et al*., 2015; Mensah *et al*., 2014). Unlike the agricultural and analogous industries (Frimpong *et al*., 2016; Frimpong *et al*., 2015), no studies are highlighting the barriers to adaptation and social protection of mining workers (SSM and LSM) to occupational heat stress in Ghana. This study also assessed the hypothesis that there is no significant difference in the adaptation strategies, social protection measures and the barriers to occupational heat stress adaptation between the two types of mining workers (SSM and LSM).

Materials and methods

Philosophical underpinning and design of the study

The pragmatist philosophical viewpoint guided the methodology employed in this study. Hence, the mixed methods research approach, involving descriptive and explanatory cross-sectional research strategies, was adopted to highlight the research gap (Creswell, 2013; Creswell & Plano Clark, 2017). The mixed methods research design was deemed most appropriate for using both quantitative and qualitative data to provide a complementary and collaborative account of the barriers to occupational heat stress adaptation and social protection strategies of mining workers in Ghana at a point in time (Creswell & Plano Clark, 2017; Mertens, 2015).

Research location, population, sampling process and sample size

The study was conducted in Ghana's Western Region. The area is noted for both SSM and LSM activities in the country. Ghana is a lower middle-income country located in the West African Sub-region and is characterised by tropical climate conditions with a high predisposition to the risk of heat exposure in the context of low technological advancement, inadequate adaptive capacity and labour intensive mining activities, especially among the SSM companies (Ghana Statistical Service[GSS], 2013; Government of Ghana, 2015). The study focused on mining workers across five mining sites in the Western Region of Ghana as shown in Figure 8.1 (Nunfam *et al*., 2019a).

The target population was over a million mining workers including workers directly involved in the SSM sector (McQuilken & Hilson, 2016) and 9,939 workers engaged by 13 LSM companies as of 2015 but have subsequently increased to 10,503 and 11,628 workers in 2016 and 2017 respectively (Ghana Chamber of Mines [GCM], 2018). Five out of the 13 LSM companies and eight out of an estimated 177 SSM companies were purposively selected based on their willingness and interest to participate in the study. Based on the selected mining companies, the study randomly selected 320 respondents consisting of SSM (161) and LSM (159) mining workers who expressed consent and interest to participate in the study.

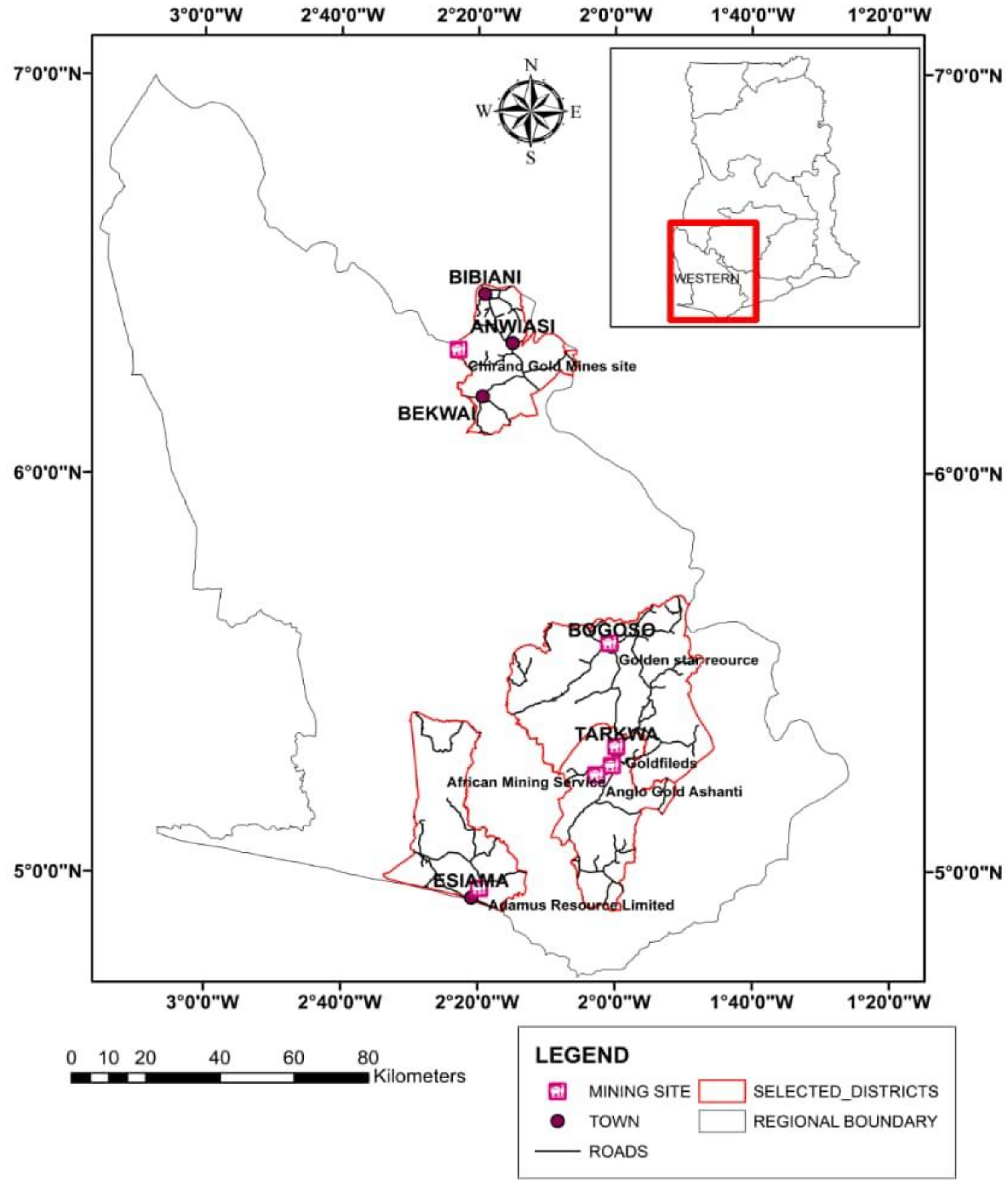


Fig 8.1. A map showing five mining sites located in the Western Region[2] of Ghana

Source: Department of Geography and Regional Planning, University of Cape Coast, 2018

[2] This map does not reflect the new region of Western North created from the former Western Region. Note that Chirano Gold mines site is now located in the Western North Region.

Data sources and collection process

Data for this study were elicited from both primary and secondary sources to ensure reliability and adequacy of results. Guided focus group discussions (FGD) and questionnaires constituted the instruments used to obtain primary data from the mining workers, while the secondary data was sourced from theoretical and empirical literature. Also, the FGD consisted of a set of open-ended questions, while the questionnaire comprised both closed-ended and Likert-type question items with statements measured on a response scale including Strongly agree (SA), Agree (A), Undecided (U), Disagree (D), and Strongly disagree (SD). The content and design of the instruments were guided by a validated instrument of the High Occupational Temperature Health and Productivity Suppression (HOTHAPS) programme and other empirical studies related to climate change, heat exposure impact on health, productivity and adaptation strategies (Kjellstrom *et al*., 2009a; Sheridan, 2007; Xiang *et al*., 2015). Before data collection, the adapted instruments were reviewed by experts and pretested in Ghana to ascertain its validity and reliability. The FGD guide and self-reported questionnaire consisted of question items centred on respondents' background characteristics, adaptation strategies, social protection measures, and barriers to the adaptation of mining workers to occupational heat stress. Two FGDs were conducted, one for the SSM (FGD1) and the other for LSM (FGD2) workers who were made up of eight members in each category.

Data processing and analysis

The qualitative data was processed with NVivo version 11, while the quantitative aspect of the data was processed with IBM Statistical Product and Service Solution (SPSS) version 25 and Microsoft Excel 2016. Thematic analysis was used to synthesise the qualitative data into themes arising from the quotations, texts and extracts of the FGDs. These themes aided in the description and interpretation of data related to any relationships and discrepancies in adaptation strategies of mining workers to occupational heat stress. Similarly, descriptive statistics (e.g., *frequency, percent, M, SD*) and inferential statistics (e.g., *Chi-Square* [χ^2]) were conducted to assess the disparities in the adaptation strategies, social protection measures and the barriers to occupational heat stress adaptation between the SSM and LSM workers at the level of significance ($p < 0.05$). The effect size criteria (very small: 0.01, small: 0.20, medium: 0.50, large: 0.80, very large: 1.20, & huge: 2.0) was employed to determine the extent of significant difference between the variables (Cohen, 1988; Sawilowsky, 2009). Likelihood ratio other than Pearson Chi-Square was used where assumptions of Chi-Square were violated

(Fisher, 1935; McHugh, 2013; Yates, 1934). The results of the analysis were illustrated in tables and charts where appropriate.

Results

Background characteristics of respondents

In terms of demographic characteristics, the gender composition comprised 80.9% males including SSM (89.4%) and LSM (72.3%), and 19.1% females consisting of SSM (10.6%) and LSM (27.7%). The respondents had a minimum age (21 years) and a maximum age (61 years) with a mean age of 35.1 years (*SD*=8.20). The majority (43.8%) of respondents were workers within the ages of 25-34 years and was followed by workers (34.1%) within the ages of 35-44 years. Most of the SSM workers (44.7%) and LSM workers (42.8%) were within the ages of 25-34 years. Similarly, most (37.8%) respondents had secondary education (SSM: 32.3% and LSM: 43.4%), and the least (2.8%) had no formal education (SSM:5.6% and LSM: 0.0%). However, most (49.1%) SSM workers had basic education while most (43.4%) LSM workers had secondary education (Table 8.1).

Based on work characteristics, the respondents' years of work experience ranged from 1 to 21 years with an average work experience of 7.7 years (*SD*=4.43). Most (41.8%) respondents consisting of workers of SSM (41.6%) and LSM (42.1%) worked for less than five years while the least (26.6%) respondents comprising workers of SSM (31.1%) and LSM (22.0%) worked for over ten years. Majority (62.8%) of the respondents including SSM (70.8%) and LSM workers (64.8%) described their workload as heavy while the least (6.6%) respondents comprising SSM (5.0%) and LSM (8.2%) workers described their workload as light (Table 8.1). In addition, the majority (66.0%) including SSM (58.4%) and LSM (73.6%) workers described their work environment as outdoors while the least (34.0%) of respondents of SSM (41.8%) and LSM (26.4%) described their work environment as indoors. In terms of working around heat sources, the majority (87.2%) respondents comprising both SSM (92.5%) and LSM (81.8%) workers answered in the affirmative. Most (47.2%) respondents consisting of SSM (68.6%) and LSM (26.5%) workers often worked around heat sources, while only 17.2%, including SSM (8.8%) and LSM (25.7%) workers, did not usually work around heat sources (Table 8.1).

Table 8.1. Background characteristics of the mining workers (n=320); SSM=Small-scale mining; LSM=Large-scale mining; f=frequency; M=mean; SD=Standard deviation

Characteristics	Type of mining activity SSM F (%)	LSM F (%)	Total F (%)
Sex			
Male	144(89.4)	115(72.3)	259(80.9)
Female	17(10.6)	44(27.7)	61(19.1)
Age group (M = 35.1; SD = 8.20)			
< 25	16(9.9)	11(6.9)	27(8.4)
25-34	72(44.7)	68(42.8)	140(43.8)
35-44	52(32.3)	57(35.9)	109(34.1)
45-54	18(11.2)	17(10.7)	35(10.9)
55+	3(1.9)	6(3.7)	9(2.8)
Level of education			
No formal education	9(5.6)	0(0.0)	9(2.8)
Basic education	79(49.1)	22(13.8)	101(31.6)
Secondary education	52(32.3)	69(43.4)	12137.8)
Tertiary education	21(13.0)	68(42.8)	89(27.8)
Years of working experience (M = 7.71; SD = 4.434)			
<5	67(41.6)	67(42.1)	134(41.8)
5-9	44(27.3)	57(35.9)	101(31.6)
10+	50(31.1)	35(22.0)	85(26.6)
Workload			
Light	8(5.0)	13(8.2)	21(6.6)
Medium	39(24.2)	59(37.1)	98(30.6)
Heavy	114(70.8)	87(54.8)	201(62.8)
Working hours			
8-10	124(77.0)	32(20.1)	156(48.8)
11-13	34(21.1)	127(79.9)	161(50.3)
14-16	3(1.9)	0(0.0)	3(0.9)
Workplace environment			
Outdoor	94(54.8)	117(73.6)	211(66.0)
Indoor	67(41.8)	42(26.4)	109(34.0)
Work around heat sources			
Yes	149(92.5)	130(81.8)	279(87.2)
No	12(7.5)	29(18.2)	41(12.8)
Frequency of work around heat sources			
Never	14(8.8)	41(25.7)	55(17.2)
Sometimes	26(16.1)	49(30.8)	75(23.4)
Often	109(68.8)	42(26.5)	151(47.2)
No response	12(7.5)	27(17.0)	39(12.2)

Source: Field survey, 2017

Adaptation of mining workers to occupational heat stress

The extent of workers' vulnerability drives their adaptation to the risk and impact of occupational heat stress. The study assessed adaptation of mining workers to occupational heat stress based on their adaptation strategies and social protection measures to occupational heat stress.

Adaptation strategies of mining workers to occupational heat stress

Table 8.2 shows the results of the variation in adaptation strategies of mining workers to occupational heat stress across the two types of mining workers. The assessment was based on statements related to adaptation strategies of workers measured on a Likert-scale response items. Accordingly, as to whether mining workers frequently drank lots of cool water before feeling thirsty, the majority (over 67%) of both types of mining workers answered positively. The assertion of drinking lots of water as a way of adapting to occupational heat stress was supported by discussants during the FGDs of the SSM and LSM workers as follows: S*o far as you are doing hard work, you will need water, even if you are working at the surface or in the hole [underground] you often drink water (Participant, SSM workers). The things we do to protect ourselves include the water we drink (Participant, L SM workers).* Nevertheless, fewer (67.7%) SSM workers as compared to more (81.1%) LSM workers answered in the affirmative while more (23.6%) SSM workers and fewer (10.6%) LSM workers answered in the negative. The variation in response to the statement that mining workers frequently drank lots of cool water before feeling thirsty between workers of SSM and LSM was statistically significant ($p<.001$) with a small effect size (Table 8.2).

Responses showed that most workers of both SSM (45.3%) and LSM (62.2%) operations agreed to the wearing of loose and light-coloured clothing while working in hot weather conditions. Similarly, participants of the FGD observed that they wore light shirts and overalls that allowed them to feel the air around as shown in the following comments: *If you are working in the heat you wear shirts that are light that will allow air to penetrate it to help you not to feel the heat (Participant, SSM workers). As you can see we wear these overall. They are somehow not heavy but loose so you can feel the air blowing when you are in the air condition room or working outside (Participant, LSM workers).* However, a smaller proportion (45.3%) of SSM compared to LSM (62.2%) agreed with wearing loose/light clothing, whilst fewer SSM (16.2%) and more (37.8%) LSM workers disagreed. The discrepancy in whether mining workers wore loose and light-coloured clothing while working in hot weather conditions between SSM and LSM workers was statistically significant ($p<.001$) with large effect size (Table 8.2).

Furthermore, most workers of both SSM and LSM did not drink coffee, soft drinks, caffeinated energy drinks and alcohol when working in a hot environment. Similarly, the use of drinks like alcohol when working in hot conditions was not supported by members of the FGDs. For instance, a participant of the FGD with the SSM workers indicated that:

> *The heat does not go with 'akpeteshie'* [local alcoholic beverages] *for if you are drunk and you enter the hole [underground], it is easy to die, but if you are normal without it, you are able to detect the heat early which usually saves you. If you also smoke and use snuff it is likely the heat stress will affect you (Participant, SSM workers).*

Also, a member of the FGD involving the LSM workers explained that: *We are not allowed by the company policy to drink alcohol when working. Someone was punished because of [alcoholic] drink (Participant, LSM workers).* Comparatively, fewer (21.2%) SSM workers and more (47.8%) LSM workers answered positively while greater proportion (72.0%) of SSM and a lesser portion (46.5%) of LSM responded negatively. The difference as to whether mining workers drank coffee, soft drinks, caffeinated energy drinks and alcohol when working in hot environment between SSM and LSM workers was statistically significant ($p<.001$) with a small effect size (Table 8.2).

The responses indicated that the majority of both SSM (80.8%) and LSM (74.8%) workers acknowledged they took regular breaks away from hot conditions in a cooler or shaded area. The following extracts from the FGDs with SSM and LSM workers showed that mining workers took some breaks away from hot weather conditions. *This work cannot be done without break. We break to eat and rest like 15 to 30 minutes before we start to work again (Participant, SSM workers). We break for a while like half an hour and cool ourselves in the offices where we do the paperwork and stuff (Participant, LSM workers).* In comparison, a greater portion (80.8%) of SSM and a lesser proportion of LSM (74.8%) affirmed taking regular breaks away from hot conditions in cooler or shaded area while fewer (19.3%) SSM workers compared to more (22.6%) LSM workers answered otherwise. This distinction in whether mining workers took regular breaks away from hot conditions in a cooler or shaded area across the type of mining workers was statistically significant ($p<.05$) with a small effect size (Table 8.2).

The majority of the SSM (80.1%) and LSM (86.2%) respondents were of the view that mining workers used mechanical equipment to reduce the need for strenuous physical workload. Relatively smaller portions (80.1%) of SSM and a slightly higher proportion (86.2%) of LSM workers confirmed that mining workers used mechanical equipment to reduce the need for strenuous physical workload while more (17.4%) SSM and less (11.9%) LSM workers disagreed (Table 8.2). However, the difference in mining workers' use of mechanical equipment to reduce the need for strenuous physical workload between SSM and LSM workers was not statistically significant.

Table 8.2: Results of the difference in adaptation strategies of mining workers to occupational heat stress across the type of mining activity (Chi-Square test) (*n=320; n (SSM) =161; n (LSM) =159*)

Statement	SA		A		U		D		SD		Chi-Square
	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	
Frequently drink lots of cool water before feeling thirsty	19.9	43.4	47.8	37.7	8.7	8.2	8.7	7.5	14.9	3.1	$\chi^2(4) = 28.292$, $p < .001$, Cramer's $V = .297$
Wear loose and light-coloured clothing while working in hot weather conditions	13.0	30.8	32.3	31.4	38.5	0.0	7.5	29.6	8.7	8.2	$\chi^2(4) = 94.030$, $p < .001$, Cramer's $V = .542$
Drink coffee, soft drinks, caffeinated energy drinks and alcohol when working in hot environment and tired	7.5	17.6	13.7	30.2	6.8	5.7	16.1	15.7	55.9	30.8	$\chi^2(4) = 28.359$, $p < .001$, Cramer's $V = .298$
Take regular breaks away from hot conditions in a cooler or shaded area	60.9	39.0	19.9	35.8	0.0	2.5	5.6	11.9	13.7	10.7	$\chi^2(4) = 23.323$, $p < .05$, Cramer's $V = .270$
Used to working in the heat without any medication to cope with heat stress	13.0	25.2	56.5	15.7	8.7	5.7	10.6	28.3	11.2	25.2	$\chi^2(4) = 65.537$, $p < .05$, Cramer's $V = .453$
Use mechanical equipment to reduce the need for strenuous physical workload	21.7	34.6	58.4	51.6	2.5	1.9	8.7	6.9	8.7	5.0	$\chi^2(4) = 7.390$, $p > .05$
Plan and carry out heavy routine outdoor work during the early morning or evening hours or in shaded areas during hot weather	14.3	40.3	24.2	44.7	44.7	5.7	8.1	6.3	8.7	3.1	$\chi^2(4) = 82.276$, $p < .001$, Cramer's $V = .507$
Participate in training programmes on working safely in the heat	26.7	52.2	50.3	39.0	1.9	1.9	9.3	4.4	11.8	2.5	$\chi^2(4) = 27.903$, $p < .001$, Cramer's $V = .295$
Share unavoidable heavier jobs and rotate jobs on shift schedules	68.3	42.8	17.4	45.9	3.1	1.9	3.1	3.1	8.1	6.3	$\chi^2(4) = 31.661$, $p < .001$, Cramer's $V = .310$
Slow down work at my pace to meet hot weather conditions	19.9	31.4	12.4	19.5	48.4	10.7	9.3	17.0	9.9	21.4	$\chi^2(4) = 55.390$, $p < .001$, Cramer's $V = .416$
Use personal protective equipment like sunglasses, wide-brimmed hats and hand gloves during hot weather conditions	64.0	64.2	11.2	25.8	5.6	2.5	7.5	2.5	11.8	5.0	$\chi^2(4) = 19.364$, $p < .05$, Cramer's $V = .246$
Use cooling systems like air conditions and electric fans during hot weather conditions	59.0	36.5	18.0	39.6	2.5	3.1	8.1	17.6	12.4	3.1	$\chi^2(4) = 36.101$, $p < .001$, Cramer's $V = .336$
Live in a house designed to allow proper air flow and escape of heat through windows and roofs	64.6	48.4	15.5	28.3	0.6	0.6	6.2	18.2	13.0	4.4	$\chi^2(4) = 25.987$, $p < .001$, Cramer's $V = .285$

Source: Field survey, 2017

Similarly, fewer (38.5%) SSM workers compared to LSM workers (85.0%) agreed that mining workers planned and carried out heavy routine outdoor work during the early morning or evening hours or in shaded areas during hot weather. In contrast, more (16.8%) SSM workers and a smaller portion (9.4%) of LSM workers answered in the negative. The variation in whether mining workers planned and carried out heavy routine outdoor work during the early morning or evening hours or in shaded areas during hot weather was statistically significant ($p<.001$) with a medium effect size (Table 8.2).

Most of the SSM and LSM workers participated in training programmes on working safely in the heat. Fewer (77.0%) SSM workers than LSM workers (91.2%) acknowledged that they participated in training programmes on working safely in the heat, whereas more (21.1%) SSM workers and less (6.9%) LSM workers disagreed. The discrepancy in mining workers participation in training programmes on working safely in the heat was statistically significant ($p<.001$) with a small effect size (Table 8.2).

With regards to whether mining workers shared unavoidable heavier jobs and rotated jobs on shifts schedules, over 85% of both SSM and LSM workers responded positively. Thus, 85.7% and 88.7% of SSM and LSM workers respectively answered in the affirmative but SSM (11.2%) and LSM (9.4%) workers responded otherwise. The variation in mining workers response to sharing unavoidable heavier jobs and rotated jobs on shifts schedules was statistically significant ($p<.001$) with a small effect size (Table 8.2).

Additionally, a lower proportion (32.3%) of SSM workers and a higher portion (50.9%) of LSM workers claimed that mining workers slowed down work at their own pace to meet hot weather conditions, while much more workers of SSM (48.8%) than LSM (10.7%) were undecided. However, more SSM workers (19.3%) than LSM workers (7.5%) were in disagreement. The distinction in mining workers' views of slowing down work at their own pace to meet hot weather conditions was statistically significant ($p<.001$) again with a small effect size (Table 8.2).

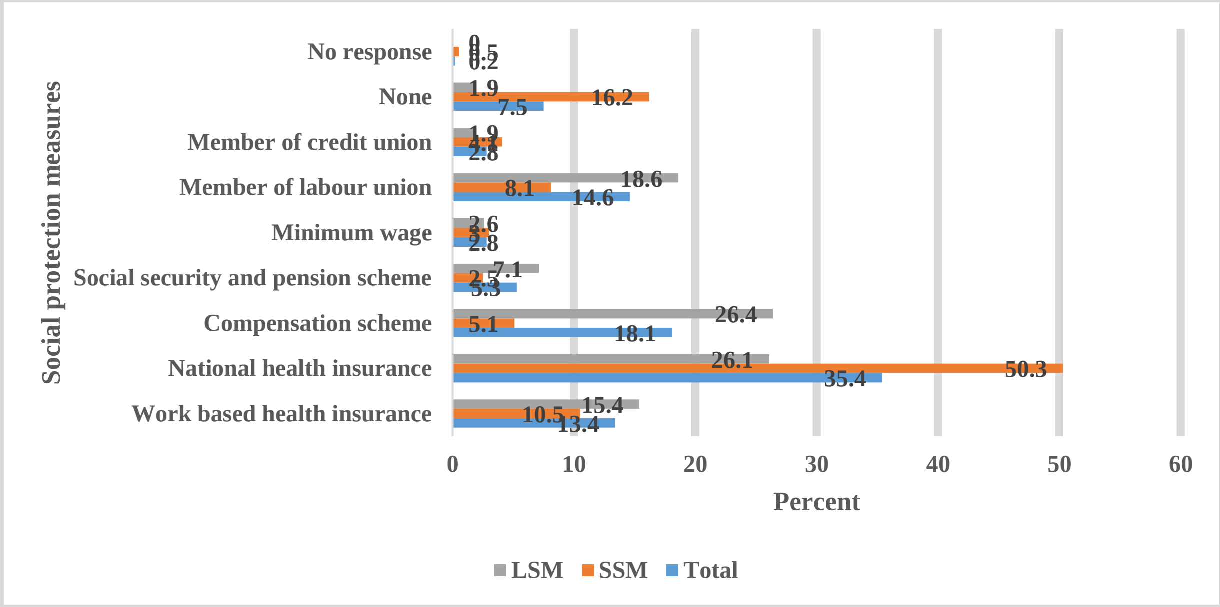
The majority (> 70%) of SSM and LSM workers were in agreement that mining workers used personal protective equipment like sunglasses, wide-brimmed hats and hand gloves during hot weather conditions. Comparatively fewer (72.5%) SSM workers and more (90.0%) LSM responded affirmatively, while more (19.3%) SSM workers and fewer (7.5%) LSM workers answered negatively. The difference in mining workers use of personal protective equipment like sunglasses, wide-brimmed has, and hand gloves during hot weather conditions were statistically significant ($p<.05$) with a small effect size (Table 8.2).

The responses demonstrated that over 76% of respondents (SSM and LSM) confirmed that mining workers use cooling systems like air conditions and electric fans during hot weather conditions. Participants re-echoed the use of cooling mechanisms in hot weather conditions during the FGDs. This is evident in the following statements: *If you are working under air condition or using a fan for hours, you will not sweat and will not feel the heat (Participant, SSM workers). The things we do to protect ourselves include…, the air conditions we use and we go to cool places for fresh air for a while (Participant, LSM workers).* Respondents' divergent opinions showed that a little more (77.0%) SSM and less (76.1%) LSM workers affirmed the use of cooling systems during hot conditions while very similar proportion of SSM (20.5%) and LSM (20.7%) workers had a contrary view. The contrast in mining workers use of cooling systems like air conditions and electric fans during hot weather conditions was statistically significant ($p<.001$) with a small effect size (Table 8.2).

Lastly, as shown in Table 8.2, more than 76% (SSM and LSM) workers acknowledged that mining workers live in houses designed to allow proper air flow and escape of heat through windows and roofs. Considerably, more (80.1%) SSM workers compared to fewer (76.7%) answered in the affirmative whereas lesser portion (19.2%) of SSM and more (22.6%) of LSM workers disagreed. The variation in respondents' view that mining workers live in houses designed to allow proper air flow and escape of heat through windows and roofs were statistically significant ($p<.001$) with a small effect size.

Social protection measures of mining workers to occupational heat stress

Figue 8.2 shows the results of the variation in social protection strategies of mining workers to cope with occupational heat stress, highlighting the differenes between SSM and LSM workers. Social protection measures commonly adopted among the respondents include national health insurance (35.4%), compensation scheme (18.1%), member of a labour union (14.6%), and work-based health insurance (13.4%). Similarly, the discrepancies in the proportion of respondents who identified national health insurance (SSM: 50.3% vs LSM:26.1%), compensation scheme (SSM: 5.1% vs LSM:26.4%), member of labour union (SSM: 8.1% vs LSM:18.6%), and work-based health insurance (SSM: 10.5% vs LSM:15.4%) were statistically significant ($p<.001$) with a small effect size.



(Pearson Chi-Square: χ^2 (6) = 64.433, p < .001, V = .449)

Figure 8.2: Results of the difference in social protection measures of mining workers to occupational heat stress across the type of mining activity

Source: Field survey, 2017

Barriers to the effective adaptation of mining workers to occupational heat stress

Even though there are adaptation and social protection measures to occupational heat stress among mining workers, there are factors that impede the effective implementation of the workers' adaptation strategies. Consequently, a high proportion (over 85%) of both SSM and LSM workers alluded to inadequate knowledge of coping and adaptive behaviour as a challenge to effective execution of the adaptation and social protection measures to occupational heat stress. Fewer SSM workers (85.7%) than LSM workers (91.2%) confirmed the challenge of inadequate knowledge of coping and adaptive behaviour, whilst more SSM (10.0%) than the LSM workers (8.8%) disagreed with this impediment. The difference in inadequate knowledge of coping and adaptive behaviour between SSM and LSM workers was statistically significant ($p<.001$) with a small effect size (Table 8.3).

The majority (> 83%) of SSM and LSM workers agreed to lack of regular training on occupational heat stress risk, work safety and adaptation measures as an impediment to effective implementation of adaptation and social protection strategies to heat stress. Thus, virtually similar proportions of SSM (83.8%) and LSM (84.9%) workers answered in the affirmative whilst fewer (12.5%) SSM and more (15.1%) LSM workers answered in the negative. The variation in lack of regular training on heat stress risk, work safety and adaptation measures between SSM and LSM workers was statistically significant ($p<.001$) with a small effect size (Table 8.3).

Table 8.3: Results of the difference in barriers to effective adaptation strategies of mining workers to occupational heat stress across the type of mining activity (Chi-Square test) (*n=320; n(SSM)=161; n(LSM)=159*)

Statement	SA		A		U		D		SD		Chi-Square
	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	SSM %	LSM %	
Inadequate knowledge of coping and adaptive behaviour	60.2	23.3	25.5	67.9	4.3	0.0	5.0	4.4	5.0	4.4	$\chi^2(4) = 64.117$, $p < .001$, Cramer's $V = .448$
Lack of regular training on heat stress risk, work safety and adaptation measures	59.0	34.6	24.8	50.3	3.7	0.0	7.5	9.4	5.0	5.7	$\chi^2(4) = 30.381$, $p < .001$, Cramer's $V = .308$
Lack of specific heat-related policies and regulation on work health and safety	57.1	34.0	32.3	56.0	1.9	0.6	6.2	5.0	2.5	4.4	$\chi^2(4) = 21.628$, $p < .001$, Cramer's $V = .260$
Poor compliance and implementation of heat stress guidelines, policies and programme	54.7	45.3	30.4	39.6	5.0	0.6	6.8	5.7	3.1	8.8	$\chi^2(4) = 23.240$, $p < .05$, Cramer's $V = .203$
Inadequate financial resources to support engineering control of heat stress	53.4	31.4	28.6	38.4	5.0	4.4	5.0	13.2	1.8	12.6	$\chi^2(4) = 19.000$, $p < .05$, Cramer's $V = .244$
Lack of management commitment to heat-related health and safety measures	57.8	24.5	18.6	58.5	5.6	1.3	9.9	12.6	8.1	3.1	$\chi^2(4) = 62.804$, $p < .001$, Cramer's $V = .433$
Lack of access to innovative technology and equipment for mining work in hot weather conditions	62.7	27.0	19.3	57.9	4.3	1.3	9.9	10.7	3.7	3.1	$\chi^2(4) = 56.502$, $p < .001$, Cramer's $V = .420$

Source: Field survey, 2017

Furthermore, more than 89% of both SSM and LSM workers acknowledged that lack of specific heat-related policies and regulation on work health and safety was a barrier to effective implementation of occupational heat stress adaptation and social protection of mining workers. Irrespective of their area of employment, nearly the same SSM (85.1%) LSM(84.9%) workers agreed to lack of specific heat-related policies and regulation on work health and safety as a barrier. However, less (8.7%) SSM and more (9.4%) LSM workers disagreed. The difference in lack of specific heat-related policies and regulation on work health and safety as a barrier to occupational heat stress adaptation was statistically significant ($p<.001$) with a small effect size (Table 8.3).

In addition, the majority (>84%) of respondents identified with poor compliance and implementation of heat stress guidelines, policies and programmes as a factor that inhibits effective adaptation to occupational heat stress. Almost the same proportion of SSM (85.1%) workers and LSM (84.9%) workers supported the statement that poor compliance and implementation of heat stress guidelines policies and programmes inhibited effective adaptation to occupational heat stress, whereas less (9.9%) SSM and more (14.5%) were not in support. The discrepancy in poor compliance and implementation of heat stress guidelines, policies and programmes as a barrier to occupational heat stress adaptation was statistically significant ($p<.05$) with a small effect size (Table 8.3).

Also, over 69% (both SSM and LSM) workers answered positively to the statement that inadequate financial resources to support engineering control of heat stress impaired effective implementation of occupational heat stress adaptation. Mostly, a greater proportion (82.0%) of SSM and a fewer portion (69.8%) answered in agreement to inadequate financial resources to support engineering control of heat stress as a factor that hinders adaptation to occupational heat stress while less (5.8%) and far more (25.8%) answered in disagreement. The variation in inadequate financial resources to support engineering control of heat stress as an impediment to the effective operation of occupational heat stress adaptation was statistically significant ($p<.05$) with a small effect size (Table 8.3).

Moreover, more than 76% of respondents supported the statement that lack of management commitment to heat-related health and safety measures thwart effective implementation of occupational heat stress adaptation. Fewer (76.4%) SSM and more (83.0%) LSM workers answered in the affirmation that lack of management commitment to heat-related health and safety measures impeded effective adaptation and social protection strategies to occupational heat stress. In contrast, more (18.0%) and less (15.7%) answered in the negative. The difference in the lack of management commitment to heat-related health and safety measures between SSM and LSM workers that impede effective implementation of occupational heat stress adaptation was statistically significant (*p<.001*) with a small effect size (Table 8.3).

Finally, as to whether the lack of access to innovative technology and equipment for mining work in hot weather conditions weakened the effective execution of occupational heat stress adaptation, the majority (>80%) of the respondents answered positively. Comparatively, less (82.0%) SSM and more (84.9%) LSM workers affirmed that lack of access to innovative technology and equipment for mining work in hot weather conditions inhibited adequate occupational heat stress adaptation while nearly the same proportion of SSM (13.6%) and LSM(13.8%) workers was in disagreement. The dissimilarity in lack of access to innovative technology and equipment for mining work in hot weather conditions as a factor that affects effective implementation of occupational heat stress adaptation was statistically significant (*p<.001*) with a small effect size (Table 8.3).

Discussion

This is probably the first and most contemporary thorough study using the mixed methods strategy to assess the barriers to occupational heat stress adaptation and social protection strategies of mining workers in Ghana. The narrative was based on results of self-reported survey and FGDs amongst SSM and LSM workers and related to theoretical and empirical studies to give an account of mining workers' background characteristics, adaptation strategies to occupational heat stress, social protection measures, and barriers to occupational heat stress adaptation strategies to enlighten policy decisions in the mining industry.

Mining workers' background characteristics

The background information consisted of the demographic and work characteristics of mining workers. More males compared to their female colleagues dominated the gender composition of both SSM and LSM workers in the study. Unequal gender representation with male dominance is not atypical in the mining industry (Abrahamsson *et al*., 2014; ABS, 2016; Bowers *et al*., 2018). The younger and energetic workers (SSM and LSM) compared to the older counterparts were more likely to work for extra hours for more income irrespective of the risk of heat-related morbidity and its attendant impacts on productive capacity and social well-being (Jia *et al*., 2016; Xiang *et al*., 2014). Most SSM workers had only basic or no formal education, while most LSM workers had at least basic education to tertiary education. The extent of mining workers' attitude and behaviour based on their sex composition, age and education should be considered in workplace health and safety policies aimed to enhance adaptive capacity and resilience to occupational heat stress.

Most SSM and LSM workers had an average of seven years work experience, with a heavy workload in outdoor work environments and around heat sources and they generally lacked adequate adaptive capacity and resilience, thus placing them at risk of suffering occupational heat-related morbidity and mortality. Workplace health and safety management policies based on heat exposure risk and impact, adaptation and social protection measures to occupational heat stress tend to facilitate workers' adaptive capacity, boost resilience and improve productivity. Occupation health and safety policies founded on reduced workload, working hours on humid and hot days, physically demanding occupations, outdoor work often done near heat sources, and sustained awareness, education and training on heat exposure risk and adaptation can improve workers' adaptive capacity and resilience (Nunfam *et al*., 2019a).

Adaptation strategies to occupational heat stress

Various studies in the last decade have underscored the socioeconomic, health, safety, and productivity consequences and adaptation experiences of heat exposed workers in hot and humid workplaces and living environments (Kjellstrom *et al*., 2018; Kjellstrom *et al*., 2016b; Krishnamurthy *et al*., 2017; Nunfam *et al*., 2018). The socioeconomic, health and safety ramifications of occupational heat stress of such workers include heat exposure-related illnesses, injuries, poor social well-being, loss of productive capacity, lack of concentration and poor mental judgement (Lao *et al*., 2016; Nunfam *et al*., 2019b; Venugopal *et al*., 2016). Hence, adaptation strategies have emerged as one of the important and locally based appropriate options for avoiding and adjusting to occupational heat stress risk and impacts. Generally, though most workers across both types of mining employed adequate occupational heat adaptation strategies, there were some disparities between SSM and LSM workers. For instance, more SSM workers than LSM workers took regular breaks away from hot conditions in a cooler or shaded area, used cooling systems like air conditioners and electric fans during hot weather conditions, and lived in houses designed to allow proper air flow and escape of heat through windows and roofs. However, more workers of LSM compared to SSM regularly drank a lot of cool water before feeling thirsty, wore loose and light-coloured clothing while working in hot weather conditions, used mechanical equipment to reduce the need for strenuous physical workload, participated in training programmes on working safely in the heat, shared unavoidable heavier jobs and rotated jobs on shift schedules, and used personal protectitive equipment like sunglasses, wide-brimmed hats, and hand gloves during hot weather conditions.

The specified adaptation strategies and the significant discrepancies in the adaptation strategies of mining workers to occupational heat stress across the type of mining activity are valuable factors with considerable implications for workplace health and safety policies geared towards protecting workers from occupational heat stress hazards and impacts. Multiple studies have re-echoed similar findings of this study and emphasised the relevance of effective implementation of adaptation strategies (e.g., water ingestion, rehydration, taking regular rests and breaks, use of cooling systems and housing designs) in safeguarding workers from heat-related morbidity, reduced productive ability, social well-being and possible mortality (Flocks *et al*., 2013; Nunfam *et al*., 2019b; Pradhan *et al*., 2013; Xiang *et al*., 2016). Mitigation and adaptation to heat exposure and climate change relate to engineering and administrative controls, training and education, compensation schemes, and social protection measure of heat exposed workers (Kjellstrom *et al*., 2016b; NIOSH, 2016). Thus, a sustained awareness crusade and effective implementation of heat exposure policies facilitate workers' adaptive capacity and resilience. It also boosts policy decisions and efforts at combating intensifying temperature and other impacts of global climate warming.

Social protection measures to occupational heat stress

Increasing temperature is steadily worsening the socioeconomic, safety and health repercussions of occupational heat stress on workers. Apart from mitigation and adaptation strategies, adequate resources directed at planning and enforcing social protection policies tends to reduce susceptibility and hazards to heat stress and enhance adaptive capacity and resilience of workers (Kjellstrom *et al*., 2016b; Venugopal *et al*., 2016; Venugopal *et al*., 2015). The results of the study based on social protection measures (e.g., national health insurance, compensation, work-based health insurance, member of labour and credit unions), as corroborated in various conceptual and empirical studies, highlight the importance of workers' knowledge and use of social protection strategies in shielding employers and employees from excessive heat exposure (see Davies *et al*., 2009; Frimpong *et al*., 2015; Kjellstrom *et al*., 2016b). Social protection strategies of workers across both types of mining was quite adequate, however, SSM workers adopted more of national health insurance while LSM used more of compensation, work-based health insurance and membership of labour. The need for social protection policies as one of the variables of safeguarding workers is informed by international standards, guidelines and framework conventions targeted at reducing vulnerability and impacts of occupational heat exposure driven by increasing thermal stress (ILO, 2016; ISO, 1989; NIOSH, 2016). Hence, heat exposure management and workplace policies and actions intended to ensure workers' health, safety, efficiency, productive capacity and social well-being need to integrate social protection measures aimed at reducing vulnerability and promoting adaptive capacity and resilience.

Barriers to effective execution of occupational heat stress adaptation

Essentially, comparable results on barriers to adaptation strategies of mining workers to occupational heat stress have been reported in analogous studies (Frimpong *et al*., 2016; Lam *et al*., 2013; Xiang *et al*., 2015). The factors that impede effective implementation of occupational heat stress adaptation strategies of workers varied significantly between workers of SSM and LSM. For example, lack of adequate knowledge and coping behaviour, lack of regular training on heat stress, work safety and adaptation measures, lack of management's commitment to heat-related health and safety measures and lack of access to innovative technology and equipment for mining work in hot weather condition were more strongly associated with LSM compared to SSM. However, issues that hinder more SSM than LSM workers from effectively executing the adaptation strategies to occupational heat stress included lack of specific heat-related policies and regulation on work health and safety, poor compliance and implementation of heat stress guideline, policies and programmes, and inadequate financial resources to support engineering control of heat stress. Similarly, socio-cultural and economic barriers, lack of information and knowledge, policy and regulatory impediments were found to constrain the capacity of workers from various sectors (e.g., agriculture, manufacturing, mining, and construction) to effectively manage risks and impacts associated with heat exposure (Frimpong *et al*., 2016; Natural Capital Economics, 2018; Xiang *et al*., 2014). The evidence of substantial differences in barriers experienced by mining workers to effectively carry out the adaptation strategies to occupational heat stress across the type of mining activity was most likely linked to the significant variations in workers' educational level, their work characteristics, and previous occupational heat stress risk experience (Nunfam *et al*., 2019a).

Conclusions and policy recommendations

SSM and LSM workers affirmed the use of adaptation and social protection measures to reduce or adjust to occupational heat stress and the barriers that impede effective implementation of the adaptation strategies of mining workers. The workers' adaptation strategies, social protection measures, and the barriers to occupational heat stress adaptation differed significantly between SSM and LSM workers. SSM workers resorted to using regular breaks, cooling systems, and housing designs while LSM workers were associated more with frequently drinking water, wearing loose and light-coloured clothing, participating in training programmes, sharing and rotating unavoidable heavier jobs, and greater use of PPE as occupational heat stress adaptation strategies. Similarly, SSM workers relied on the national health insurance whereas the LSM workers tended to use strategies such as compensation, labour union and work-based health insurance more as social protection measures. Furthermore, SSM workers were inhibited by lack of specific heat-related policies and regulations and poor compliance and implementation of heat stress guidelines while LSM workers were challenged by inadequate knowledge of coping and adaptive behaviour, lack of regular training on heat stress risk, safety and adaptation measures, and lack of management commitment to heat-related health and safety measures, and the lack of access to innovative technology and equipment for mining work in hot weather conditions.

The observed variations in occupational heat stress adaptation and social protection strategies, as well as the barriers to occupational heat stress adaptation strategies should inform policy framework on occupational health and safety and workplace heat stress management in Ghana's mining industry. Stakeholders in the country's mining sector, including workers, should be at the centre of occupational heat stress adaptation policy planning, formulation and implementation to ensure the adequate management of workplace heat exposure dangers associated with global climate warming. Adaptation policy should focus on reducing impediments and barriers constraining workers and employers' capacity to manage heat exposure risk and impacts. Thus, a combined effort involving important stakeholders in the mining industry can significantly promote workers' health, safety, productive ability and social well-being as well as improve their adaptive capacity and enlighten policy formation and operation in the mining industry.

SECTION V: SYNTHESIS AND CONCLUSIONS OF THE RESEARCH

Overview

In this study, the social impacts of climate change and occupational heat stress and adaptations strategies of mining workers were assessed. The methodological approach of convergent mixed methods was employed to assess and understand mining workers' perceptions and lived experiences of social impacts of climate change, occupational heat stress and adaptation strategies in Ghana. The preceding sections of eight chapters were devoted to elaborating the research context, literature review, methodology, and research results of this thesis. SECTION V presents the synthesis and conclusions of the research as illustrated in chapter nine. Chapter Nine describes the summary and synthesis of the key research results, the conclusions and implications of the research for policy options, and recommendations and direction for future research. It also specifies the significance and contributions of the research to knowledge as well as the limitations of the thesis, and reflections on my PhD journey.

CHAPTER NINE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary and synthesis of key research results

This study sought to assess the social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana, based on the theoretical perspectives of the SIA, social risk assessment, and adaptation and resilience planning.

The systematic review and narrative synthesis of the literature on social impacts of occupational heat stress and adaptation strategies of workers revealed inadequate use of convergent mixed methods in studies related to workers heat exposure. This study also found no evidence of studies conducted in Africa that assesses the social impacts of occupational heat stress and adaptation strategies of workers, though work settings are increasingly under the threat of heat exposure. The review and synthesis of the 25 studies yielded three themes, namely, (1) workers' awareness of occupational heat stress; (2) social impacts of occupational heat stress; and (3) adaptation to occupational heat stress. The results indicated that the awareness of occupational heat stress among workers varied and their social impacts were related to workers' health and safety, productivity and social well-being. The review also unearthed the myriad of social impacts of heat stress, including heat illnesses, injuries, deaths, productive losses, and inadequate social well-being, and adaptation strategies in policy decisions, illustrating that there are sustainable approaches to enhance adaptive capacity of workers.

The second review and synthesis of the literature in chapter two centred on proposing a conceptual framework illustrating the nexus between social impacts and adaptation strategies of workers to occupational heat stress. The review resulted in three syntheses, namely, (1) work-related heat risk; (2) social impacts due to work-related heat stress risk; and (3) work-related heat stress adaptation. This study also found that the concerns of social dimensions and occupational heat stress impacts on workers seem to have received little attention in empirical, review and conceptual studies. In this regard, this synthesis formed the basis of a framework proposed above, which delineated the linkage between social dimensions and impacts, and adaptation strategies, to occupational heat stress and the SDGs. The results further showed that the social dimensions and potential effects of heat stress on occupations relates to workers' productive capacity, health and safety, psychological behaviour and social lives and well-being.

Following the systematic review of the literature, there was evidence of limited research studies characterised by mixed methods research coming from the developing world with reference to Africa compared to the developed countries. Aside from a few studies (Miller, 2014; Nunfam *et al*., 2018; Venugopal *et al*., 2016a) there were no mixed methods empirical studies conducted to assess the social impacts of occupational heat stress on mining workers in Africa. MMR is a pragmatic approach to collecting, analysing and combining both quantitative and qualitative strategies, data and findings to inform inferences drawn from one or more studies to provide a holistic understanding of research phenomenon. The convergent mixed methods, other than the sequential or transformative inquiry strategy, was considered appropriate as it required a relatively shorter time for the collection, analysis and integration of both quantitative and qualitative data simultaneously to determine the convergence or divergence of results. The use of the concurrent mixed methods strategy involving 320 surveys and two FGDs revealed the utility of applying current tenets of MMR comprising methodological eclecticism, paradigm heterogeneity, diverse research designs, analytical techniques and integration approaches in assessing the social impacts of occupational heat stress on mining workers in Ghana. The results also showed that multiple data collection, analysis and integration enhanced our in-depth understanding of the social impacts of occupational heat stress on mining workers in Ghana as compared to a single research strategy.

Based on the gaps in literature and the quest for answers to the fundamental research question: “What are the social impacts of climate change and occupational heat stress and adaptation strategies of mining workers?” the empirical results of this study were presented in chapters five, six, seven and eight. In Chapter Five, the perspectives of supervisors and other stakeholders on climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana were reported. The concurrent mixed methods were used to elicit data from 19 respondents using survey questionnaires and three interviews, which was interpreted with descriptive statistics and thematic analysis. The results indicated that supervisors’ climate change risks perceptions were adequate and workplace heat exposure risks concerns were moderate. The supervisors reported that workers heat stress experiences were heat-related illness and minor injuries. However, the differences in supervisors’ climate change risk perceptions and occupational heat stress risk experiences across job experience and adaptation strategies across educational status were significant.

Chapter Six described the perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. Based on the mixed methods research strategy, 320 surveys and two focus groups were used in data collection and analysed with both quantitative and qualitative methods. The results indicated that workers' climate change risk perception, as corroborated by trends in climate data, was reasonable. However, workers’ concerns about climate change effects and workplace heat exposure risks, heat-related morbidities experienced by workers, and their use of heat stress prevention measures significantly differed between SSM and LSM.

Chapter Seven highlighted the risk and magnitude of heat exposure on mining workers in Ghana. Questionnaires and temperature data loggers were used to assess the risk and degree of heat exposure in the working and living environments of the Ghanaian miners. The quantitative analysis revealed that the difference in heat exposure risk factors across workers' gender, education level, workload, work hours, physical work exertion, and proximity to heat sources was significant. The extent of Wet Bulb Globe Temperatures (WBGTs) in the work and living settings showed that workers were exposed to rather high heat conditions with the propensity to raise their heat stress risk. Mean WBGTs in the working environment (24 hr, daytime, daily maximum and night-time) were 27.1^{o}C, 28.2^{o}C, 29.6^{o}C and 26.5^{o}C (indoors) and 27.5^{o}C, 28.2^{o}C, 29.2^{o}C and 26.9^{o}C (outdoors), respectively. Thus, mining workers associated with heavy work intensity and exposed to an average maximum WBGT (>29.1^{o}C), which is above the standard criteria for maximum WBGT exposure limits (27.5^{o}C) will need to have at least 75% work and 25% rest especially for acclimatised workers in light clothing. The mean WBGTs (24 hr, daytime, daily maximum, and night-time) were 26.7^{o}C, 28.1^{o}C, 29.7^{o}C and 25.4^{o}C (indoor), and 27.0^{o}C, 27.0^{o}C, 27.3^{o}C and 27.0^{o}C (outdoor), in the miners living environment, respectively. Similarly, living environments with maximum WBGT exposure limits (27.5 ^{o}C) for workers engaged in heavy workload are required to have 75% work intensity and 25% break duration.

Chapter Eight outlined the barriers to occupational heat stress adaptation of mining workers in Ghana. The mixed methods approach questionnaires and focus group discussions were employed in the collection of data from 320 respondents, which were statistically and thematically analysed. The workers' adaptation strategies (e.g., water intake, wearing loose and light-coloured clothing, participating in training programmes, taking regular breaks, use of mechanical equipment, use of cooling systems and housing designs) varied significantly across the type of mining activity. Workers' social protection measures were adequate, however the disparities significantly differed across the type of mining activity. Barriers for workers to the implementation of the adaptation strategies (e.g., inadequate knowledge of adaptive behaviour, lack of regular training on adaptation measures, lack of specific heat-related policy regulations, lack of management commitment, and the lack of access to innovative technology and equipment) differed across the type of mining activity.

Conclusions

The following conclusions were drawn based on the key findings arising from the research outputs outlined in this thesis:

1. There was evidence from the literature that workers' perceptions and experiences that occupational heat stress and adaptation strategies, epitomised as natural and seasonal phenomenon, were adequate but diverse. The social impacts of occupational heat stress on workers were related to their health and safety, productivity and social well-being. Sustainable adaptation and social protection strategies of workers to occupational heat stress depend on financial resource availability and cooperative effort to overcome the barriers to adaptation. The implication of this state of evidence-based knowledge is to inform occupational heat stress adaptation and resilience policies for sustainable development. Evidence-based knowledge on social impacts of occupational heat stress is valuable and should be integrated into policy decisions, encourage further development of the SIA framework, and inform the development of social impact analysis of human-induced climate change.
2. The conceptual framework showed that the social dimensions and potential impacts of heat stress on occupations relate to workers' productive capacity, health and safety, psychological behaviour and social lives. The framework further demonstrated that the risks and impacts of work-related heat stress hinge on the extent of employees' susceptibility and adaptive capacity and which has implication for the realisation of the SDGs. The research and policy implications are that ecological and social risks, and environmental health scientists, as well as governments in developing countries, would need to promote research, socially inclusive, climate-resilient policies and operations to improve progress towards the SDGs. It also contributes to the ongoing discourse, policy and research effort on climate change to ensure an inclusive sustainable development to guarantee healthy lives, combat increasing ambient temperature and promote decent jobs.
3. The usefulness of MMR characterised by methodological eclecticism, paradigm heterogeneity, and multiple research designs and methods comprising data collection, analysis and integration are feasible in occupational heat exposure studies. The high degree of corroboration and complementarity on account of merging the quantitative and qualitative findings resulted in key themes (specifically, health and safety concerns, psychological and behavioural effects, productivity issues and social well-being concerns) being identified as social impacts of occupational heat stress on mining

workers. The observed social impacts of occupational heat stress and the associated significant differences across the type of mining activity (i.e. SSM and LSM) should inform national and workplace policy agendas on heat stress management, workplace health and safety, and adaptation strategies in the mining industry.

4. Supervisors and stakeholders were adequately aware of climate change risks and their concern about workplace heat exposure was moderate. Mining workers had experiences of heat-related illnesses and minor injuries, and their awareness and use of adaptation strategies included drinking adequate water, use of cooling systems, taking work breaks and rest, and wearing loose and light-coloured clothing. Climate change risk perception and occupational heat stress risk experiences were associated with years of OHS experience while preventive and control measures of occupational heat stress due to climate change risk perception were associated with educational level. Job experience and educational attainment are essential to any effective climate change risk perception and adaptation strategies to occupational heat stress due to climate change. Adequate knowledge of climate change, occupational heat stress risks, and adaptation strategies among supervisors and stakeholders are important for policy decisions on education and training to reduce risk associated with climate change impacts and heat exposure, and heat stress management among mining workers to guarantee healthy lives, promote well-being, ensure decent jobs and work capacity.
5. Mining workers' climate change risk perceptions were reasonable. However, workers' concerns about climate change effects and workplace heat exposure risks, heat-related morbidities experienced by workers, and their use of heat stress prevention measures significantly differed across the type of mining activity. The differences between the types of mining activity were evident in workers' gender, educational attainment, workload, working hours, physical job exertion, working near heat sources, exposure to heat radiation, hot air, and air speed. The differences between the type of mining activity were also exemplified in work-related factors such as break/rest hours, access to drinking water, and type of protective clothing, the type of heat-related injury experiences, use of clothing, drinking sufficient water, use of cooling systems, and resting in shade. Workplace policies on health and safety, heat stress management, and workers' adaptive capacity in the mining sector should be informed by these inconsistencies across the type of mining activity. Mining workers and other stakeholders should be part of the main focus of occupational heat stress and climate

change adaptation interventions, and planning to manage the risks climate change poses to their lives and livelihoods.

6. The disparity in environmental and work-based heat exposure risk factors across workers' gender, education level, workload, work hours, physical work exertion, and proximity to heat sources was significant. The magnitude of heat exposure conditions in the work and living environments of workers was high and the possibility of heat stress risk and impact on mining workers without adequate heat exposure management and adaptation strategies is high. The extent of observed risks and magnitude of heat exposure on mining workers and its potential to compromise mining workers' health and safety, productive capacity, social well-being, adaptive capacity and resilience is valuable for policy decisions on heat exposure management.
7. Both SSM and LSM workers were effective in the use adaptation and social protection strategies to reduce or adjust to occupational heat stress and the barriers that impede its effectiveness among mining workers. The workers' adaptation strategies, social protection measures, and the barriers to occupational heat stress adaptation however differed significantly between SSM and LSM workers. Overall, workers of LSM compared to SSM were better at effectively using the adaptation and social protection strategies of occupational heat stress. The observed variations in occupational heat stress adaptation and social protection strategies, as well as the barriers to occupational heat stress adaptation strategies, are a significant basis that should inform policy frameworks on occupational health and safety and workplace heat stress management in the mining industry.
8. As slightly more SSM workers as compared to LSM workers were adequately informed about climate change, however this disparity was not significant. Greater proportions of SSM workers compared to LSM identified irregular rainfall and storms, and frequent floods, whereas a slightly greater proportion of LSM compared to SSM identified rising sea levels as a sign of climate change. This difference in climate change signs and effects between SSM and LSM was statistically significant. The variation in the extent of injury experience of workers between SSM and LSM was significant as more workers of LSM experienced minor to moderate injuries while more SSM workers experienced serious injuries.
9. SSM workers resorted to using regular breaks, cooling systems, and housing designs while LSM workers were associated with frequently drinking more water, wearing loose and light-coloured clothing, participating in training programmes, sharing and

rotating unavoidable heavier jobs, and greater use of PPE as occupational heat stress adaptation strategies. This difference in occupational heat stress adaptation was significant.

Recommendations of the study

In cognisance of the conclusions and implications of this study, the following recommendations are highlighted:

1. An effective workplace heat management policy requires adequate understanding of occupational heat stress risks and adaptation policies among the supervisors (e.g., workplace hygienists; health, safety, and environmental officers) and stakeholders (e.g., GCM, IDMC, and GNASSM) of mining companies and continued education and training of mining workers in Ghana.
2. Ghanaian mining workers and other stakeholders (e.g., GCM, IDMC, and GNASSM) should be part of the main focus of occupational heat stress and climate change adaptation intervention and planning to manage the risks climate change poses to their lives and livelihoods.
3. A concerted effort among stakeholders (e.g., mine workers, GCM, IDMC, and GNASSM) is required to promote mining workers' health and safety, productive capacity, and effective performance and to enhance their adaptive capacity and inform policy decisions and enforcement in the mining industry.
4. A concerted global and local effort by mining companies, GCM, IDMC and GNASSM at providing adequate and effective adaptation policies and heat exposure management for various cohorts of workers exposed to hot and humid conditions is imperative to reduce the risk of heat stress, improve productive capacity and performance, and boost the social health, adaptive capacity and resilience of mining workers.
5. A collaborative effort by mining companies, GCM, IDMC and GNASSM at providing adaptation policy options centred on overcoming the barriers that constrain the adaptive capacity of workers and employers has the potential to reduce workers' vulnerability to occupational heat stress.
6. A combined effort involving all major stakeholders (e.g., mine workers, GCM, IDMC, and GNASSM) in the mining industry can significantly promote workers' health, safety, productive ability and social well-being as well as improve their adaptive capacity and enlighten policy formation and operation in the mining industry.

Significance

This study has been significant because, it is the first study on SIA of mining workers in Ghana, and also the first study to use the convergent mixed methods to assess the social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana. It has therefore provided the desired research data and added to the existing fundamental knowledge on the social dimensions and impacts of climate change and occupational heat stress on workplace health and safety, productivity, and social lives of mining workers, particularly in Africa. This study further demonstrated the viability of employing a variety of methodologies that straddle between quantitative and qualitative research strategies to thoroughly investigate climate change and heat exposure risks and impacts as well as deepened our understanding of the social impacts of occupational heat on mining workers. It also serves as a reliable source of data for relevant stakeholders in the mining industry such as governments, minerals commissions, chambers of mines, and specifically the Ghana National Association of Small Scale Miners (GNASSM), its employees, as well as students, researchers, and other stakeholders interested in mixed methods research approach, climate change and heat stress impacts, and adaptation policies. Additionally, it contributes to the knowledge and fills the gaps in the existing literature on climate change social impact analysis as well as the use of integrated theories, multiple research philosophies, data collection, analysis and integration, other than a single method studies, to enhance our understanding of the social impacts of occupational heat stress on mining workers. Furthermore, the study serves as a source of policy planning, formulations and implementation of programmes for the government, mining companies, and relevant key stakeholders to promote adaptation policies intended to reduce vulnerability and improve adaptive capacity and resilience for sustainable development. The study should thus enhance the SIA process relating to climate change and integrate significant social impacts of heat stress and climate change into meaningful SIA, as well as informing national and international policy planning and implementation on heat adaptation strategies for workers as well as the ongoing climate change social impact analysis for sustainable development.

Limitations of the study

Notwithstanding the strengths and significant contributions of this study, there are some limitations. The study relied on participants' recollections of their perceptions of climate change and lived experiences of occupational heat stress impact, however this may be associated with the possibility of reminiscence bias. However, this shortcoming did not in any way affect the validity and reliability of this research because surveying large numbers and a diverse range of workers and stakeholders helped to minimise the effects of such biases.

The use of nonparametric statistical tests in this study may have resulted in the probability of an analysis process which lacks significant statistical power-efficiency and rigor associated with the application of parametric statistical tests. Though the study fell short of using parametric test statistics such as regression analysis to establish cause-effect relationships among the variables of the study, its ultimate objective was realised as the use of nonparametric statistics was justified because of the nature of the data set.

The use of the systematic literature review based on selection criteria (e.g., time constraints from 2007 to 2017, only publications in the English language, and quality of studies) may have resulted in missing very important studies relevant to the objectives of the study. However, the included studies provided detailed data and a contemporary view of the social impacts of occupational heat stress and adaptation strategies of workers.

WBGT indices were probably underestimated by excluding global temperatures since the WBGT indices were recorded in full shaded areas (ClimateChip, 2016), however this does not compromise the integrity of the research. Unlike the other indices, the WBGT remains the most preferred and relatively simple, flexible and usable instrument to measure heat exposure conditions.

Further research

The following suggestions for further research should inspire future researchers to continue this important field of research:

1. The relationship between heat exposure and adaptation strategies of mining workers in Ghana, and the moderating effect of barriers of adaptation to occupational heat stress.
2. The association between heat exposure and health and safety, productivity, psychological behaviour, and social well-being of mining workers in Ghana, and the mediating role of adaptation strategies.
3. Social impacts of climate change and occupational heat stress and adaptation strategies of workers in manufacturing, agriculture, construction, oil and gas, firefighting, armed forces and other cohort of workers in Africa.
4. This study did not comprehensively capture policy frameworks and interventions as well as the health and safety discourse under the umbrella of corporate social responsibility and employees' safety, although not untypical of scientific investigations into mining in Africa.

Reflections

The achievement of every dream is perhaps based on actions towards one's vision and passion in the journey of life. My passion to be a research fellow/professor in a university and a role model for my family and community motivated me to pursue this PhD. The first step of my PhD research journey, like a journey of a thousand miles, started when I accepted an offer of admission and scholarship to study at ECU. The PhD journey began on 25th July 2016 and progressed steadily through three stages, namely, early-candidature, mid-candidature and late-candidature. Each milestone was characterised by very significant activities and outcomes with evidence, lessons and challenges, but ended with well-developed research and professional skills. The final copy of my PhD thesis was submitted for examination in October 2019, which ostensibly set the stage for the end of the journey.

I was full of joy and enthusiasm at the onset of the early-candidature following the first and warm welcome meeting with my principal supervisor. Subsequently, after my PhD supervisory team was constituted, we had a familiarisation meeting and shared ideas and strategies which marked the beginning of the PhD thesis with publications. The regular meetings and contact with my supervisory team coupled with the induction ceremony for PhD students as well as my participation in several research training activities organised by the ECU Graduate Research School boosted my research and professional skills and give me a sense of career validation and direction. The research training also helped to prepare me for the confirmation of candidature during the early-candidature. Subsequently, my candidature was confirmed within one year after working hard and with the guidance of my supervisors, successfully developed and presented my research proposal in a seminar, submitted the research proposal and ethics application for approval. The first year of my PhD studies in my early-candidature was overwhelming and associated with frustrating periods of loneliness and uncertainty as a result of working throughout the day and deep into the night, delay in ethics approval, limited social interactions, and missing my family, friends and associates in Ghana. However, my experiences and challenges taught me good lessons (e.g., humility, perseverance, resilience and patience) and I was able to: (1) acquire a high level critical thinking and problem solving (e.g., identify a research problem, conceptualise research, and identify key theories and methodologies); (2) justify my research philosophy and design and evaluate theoretical concepts and arguments; (3) use endnote to manage references; (4) understand different data sets and their analytical permutations; (5) familiarise myself with ECU and national policies related to ethical research conduct and design of ethically sound research; (6) develop a research plan with suitable scope, timelines, resources, expertise and budget; (7) write in an academic style using the language of the discipline and high level English grammar skills; (8) identify prospects for publishing my thesis outputs; (9) communicate the significance of my research proposal; (10) identify researchers within my discipline and suitable supervisors; and (11) take ownership and management of my research project.

Mid-candidature was the second milestone of my PhD research journey. The first phase of this journey comprised key activities such as contacting the participants for data collection and analysis while the second phase consisted of the publication of results and thesis preparation. During the fieldwork, I encountered several challenges with data collection and my interactions with the mining companies and participants to create rapport and gain their confidence, informed consent and willingness to participate in the research project. Not only were some mining companies not interested in my research, I experienced several disappointments such as failure to honour scheduled interviews and focus group sessions, picking-up calls, and delay in reply to letters perhaps due to the policies and operational schedules of the mining companies. Also, travelling several kilometres on bumpy and dusty roads and sometimes in the night for scheduled appointment which was sometimes dishonoured for some reason was very discouraging. These disappointing situations were made worse when the government banned mining activities among the SSM companies in Ghana. Albeit, after several months of persistence and patience, some mining companies, individual participants and officials of the regulatory bodies were happy and willing to participate in the study by filling out the survey questionnaires or take part in scheduled interviews and focus groups. The second stage of preparing manuscripts for publications after the data processing was equally challenging. For instance, my first manuscript was rejected at the first instance, and this was disheartening but eventually got accepted and published in another journal. This outcome inspired, strengthened and energised me to keep moving as Martin Luther King Jr. said: "…we must keep moving, we must keep going. If you can't fly, run. If you can't run walk, crawl, but by all means, keep moving". Based on my experiences (e.g., lessons and challenges) during the mid-candidature, I developed the skills and capacity to situate my research in my field of knowledge; source the latest references in my field; analyse data rigorously using relevant research software (e.g., SPSS and NVivo); conduct research to the highest standards of quality, integrity and ethics; develop my creative writing skills and maintain an authorial presence in my writing; recognise the importance of communicating to different audiences (e.g., international conferences and journals); establish national and/or international contacts in my field; work collaboratively and negotiate team roles to achieve research outcomes; and recognise my personal traits that influence leadership capabilities and research team dynamics. During this period two manuscripts from my thesis were prepared, reviewed by my supervisors and submitted to two international journals of high repute for review and publication.

The geographical principle of temperature inversion is that the higher you go up the atmosphere, the cooler it becomes. However, the higher I travelled in this PhD research journey, the higher the pressure due to the requirements of a thesis with publication to effectively disseminate my research and have a portion or parts of my thesis published. I was also expected to write, polish and prepare the entire thesis with publications for submission and examination, and yet the end of my scholarship period was fast approaching. At this point, the repeated rejection of some manuscripts after several months of review was not only frustrating but meant spending more time to rethink and restructure the papers. Nonetheless, with guidance and encouragement from my supervisors, friends and other PhD colleagues as well as incorporating the comments and suggestions from anonymous reviewers, I got three more papers published with highly esteemed international journals in my field over time. I had to also ask for an extension of my scholarship for three months to produce and submit three more manuscripts to international journals for review, put the entire thesis together for submission and examination. My experiences at this stage also helped to: (1) enhance my intellectual independence to reflect critically on the contribution of my research to knowledge; (2) critically assess and synthesise relevant information from a variety of sources; evaluate findings critically with valid interpretation of data; (3) enhance my expertise in writing, editing and formatting large documents; (4) produce outputs for academic publications; (5) improve my relationships and links with important people in the field; and (6) show initiative and research leadership.

Overall, my experiences throughout this PhD research journey can be described as one associated with period of ups and downs. The moments of uncertainties, frustrations and discouragements were related to rejection of manuscripts and limited social interactions while the exciting times were associated with encouraging comments from my supervisors and publications of my manuscripts. These awesome and exciting experiences have helped to build the character of self-discipline, resilience, critical thinking, and perseverance in me and also improve on my abilities of work-life balance, team work, project management, human relations and other relevant research and professional skills.

REFERENCES

Abrahamsson, L., Segerstedt, E., Nygren, M., Johansson, J., Johansson, B., Edman, I., & Åkerlund, A. (2014). Mining and Sustainable Development: Gender, Diversity and Work Conditions in Mining. http://www.diva-portal.org/smash/get/diva2:995297/FULLTEXT01.pdf

ABS. (2016). *Labour Force, Australia, Detailed, Quarterly*. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/mf/6291.0.55.003

Acharya, P., Boggess, B., & Zhang, K. (2018). Assessing heat stress and health among construction workers in a changing climate: a review. *International Journal of Environmental Research and Public Health, 15*(2), 247. doi:ARTN 247 10.3390/ijerph15020247 http://www.mdpi.com/1660-4601/15/2/247/html

Adam-Poupart, A., Labreche, F., Smargiassi, A., Duguay, P., Busque, M. A., Gagne, C., . . . Zayed, J. (2013). Climate change and occupational health and safety in a temperate climate: potential impacts and research priorities in Quebec, Canada. *Ind Health, 51*(1), 68-78.

Adger, W. N. (2006). Vulnerability. *Global environmental change, 16*(3), 268-281.

Adjaye, K. E., & Ampofo, K. (2017). The employment, income and foreign exchange effects of small-scale mining ('Galamsey'). *Ghana Growth and Development Platform Working Paper 4*. Retrieved from Accra, Ghana http://www.ghanagdp.org

Adusei-Asante, K. (2017). Towards developing policy impact assessment framework: An introduction. *Proceedings of the 37th Annual Conference of the International Association for Impact Assessment*, 6pp., Online, IAIA. http://conferences.iaia.org/2017/final-papers.php

Agresti, A. (1996). Introduction to Categorical Data Analysis. John Wiley and Sons: New York, NY, USA, pp. 231–236.

Ajuang, C. O., Abuom, P. O., Bosire, E. K., Dida, G. O., & Anyona, D. N. (2016). Determinants of climate change awareness level in upper Nyakach Division, Kisumu County, Kenya. *SpringerPlus, 5*(1), 1015. https://doi:10.1186/s40064-016-2699-y

Aldunce, P., Indvik, K., Borquez, R., Adler, C., & Galaz, V. (2014). Resilience in the context of climate change: A systematic review of the literature to aid a navigation of diversity. *Group of social studies-human dimension center for climate and resilience research-cr2 http://www.cr2.cl/wp-content/uploads/2016/06/Aldunce-et-al-2014-Working-paper-Conceptualization-Resilience.pdf Retrieved on 03/03/2017.*

Alexander, C., Bynum, N., Johnson, E., King, U., Mustonen, T., Neofotis, P., . . . Weeks, B. (2011). Linking indigenous and scientific knowledge of climate change. *BioScience, 61*(6), 477-484. https://doi:10.1525/bio.2011.61.6.10

Amponsah-Tawiah, K., & Dartey-Baah, K. (2011). The mining industry in Ghana: A blessing or a curse. *International Journal of Business and Social Science, 2*(12). https://pdfs.semanticscholar.org/23b3/41893980832be50fff5e4fd289362afed41e.pdf

Amundsen, H. (2012). Illusions of Resilience? An Analysis of Community Responses to Change in Northern Norway. *Ecology and Society, 17*(4).

Arbury, S., Jacklitsch, B., Farquah, O., Hodgson, M., Lamson, G., Martin, H., & Profitt, A. (2014). Heat illness and death among workers-United States, 2012-2013. *MMWR. Morbidity and Mortality Weekly Report, 63*(31), 661-665. Retrieved on 20/02/2018 from http://europepmc.org/articles/pmc4584656

Arundel, A. V., Sterling, E. M., Biggin, J. H., & Sterling, T. D. (1986). Indirect health effects of relative humidity in indoor environments. *Environ Health Perspect, 65*, 351-361. https://doi:10.1289/ehp.8665351

Aryee, B. N. A., Ntibery, B. K., & Atorkui, E. (2003). Trends in the small-scale mining of precious minerals in Ghana: A perspective on its environmental impact. *Journal of Cleaner Production, 11*(2), 131-140. https://doi.org/10.1016/S0959-6526(02)00043-4

Asante, F.A. & Amuakwa-Mensah, F. (2015). Climate change and variability in Ghana: Stocktaking. *Climate*, 3, 78-99. https://doi.10.3390/cli3010078

Aswani, S., Vaccaro, I., Abernethy, K., Albert, S., & de Pablo, J. F. L. (2015). Can perceptions of environmental and climate change in island communities assist in adaptation planning locally? *Environ Manage, 56*(6), pp.1487-1501. https://link.springer.com/article/10.1007/s00267-015-0572-3

Aven, T., & Renn, O. (2009). On risk defined as an event where the outcome is uncertain. *Journal of risk research, 12*(1), 1-11. doi:Pii 907920869 10.1080/13669870802488883

Ayyappan, R., Sankar, S., Rajkumar, P., & Balakrishnan, K. (2009). Work-related heat stress concerns in automotive industries: A case study from Chennai, India. *Global Health Action, 2*, 58-64. https://doi:10.3402/gha.v2i0.2060

Balakrishnan, K., Ramalingam, A., Dasu, V., Stephen, J. C., Sivaperumal, M. R., Kumarasamy, D., . . . Sambandam, S. (2010). Case studies on heat stress related perceptions in different industrial sectors in southern India. *Global Health Action, 3*. https://doi:10.3402/gha.v3i0.5635

Bank of Ghana. (2018). *Monetary Policy Summary*. Retrieved from Accra, Ghana: https://www.bog.gov.gh/privatecontent/MPC_Press_Releases/Monetary_Policy_Report_May_2018.pdf

Baptiste, A. K. (2017). Climate change knowledge, concerns, and behaviours among Caribbean fishers. *Journal of Environmental Studies and Sciences, 8*(1), 51-62. https://doi:10.1007/s13412-017-0434-9

Basu, N., Renne, E. P., & Long, R. N. (2015). An Integrated Assessment Approach to Address Artisanal and Small-Scale Gold Mining in Ghana. *International Journal of Environmental Research and Public Health, 12*(9), 11683-11698. https://doi.org/10.3390/ijerph120911683

Becken, S., Lama, A. K., & Espiner, S. (2013). The cultural context of climate change impacts: Perceptions among community members in the Annapurna Conservation Area, Nepal. *Environmental Development, 8*, 22-37. doi:10.1016/j.enyclev.2013.05.007

Becker, H. A. (2001). Social impact assessment. *European Journal of Operational Research, 128*(2), 311-321.

Belyaeva, M., & Bokusheva, R. (2018). Will climate change benefit or hurt Russian grain production? A statistical evidence from a panel approach. *Climatic Change, 149*(2), 205-217. https://doi:10.1007/s10584-018-2221-3

Bernard, H. R. (2017). *Research methods in anthropology: Qualitative and quantitative approaches* (6 ed.). London: Rowman & Littlefield.

Bernard, T. E., & Pourmoghani, M. (1999). Prediction of workplace wet bulb global temperature. *Appl Occup Environ Hyg, 14*(2), 126-134. https://doi:10.1080/104732299303296

Berry, H. L., Bowen, K., & Kjellstrom, T. (2010). Climate change and mental health: a causal pathways framework. *International Journal of Public Health, 55*(2), 123-132. https://link.springer.com/article/10.1007/s00038-009-0112-0

Bhamra, R., Dani, S., & Burnard, K. (2011). Resilience: the concept, a literature review and future directions. *International Journal of Production Research, 49*(18), 5375-5393.

Biesta, G. (2010). Pragmatism and the philosophical foundations of mixed methods research. *Sage handbook of mixed methods in social and behavioral research, 2*, 95-118.

Birchall, S. J., Murphy, M., & Milne, M. (2016). Mixed Methods Research: A Comprehensive Approach for Study into the New Zealand Voluntary Carbon Market. *The Qualitative Report, 21*(7), 1351-1365.

Boeckmann, M., & Rohn, I. (2014). Is planned adaptation to heat reducing heat-related mortality and illness? A systematic review. *BMC Public Health*, *14*(1), 1112. https://doi.org/10.1186/1471-2458-14-1112

Bolitho, A., & Miller, F. (2017). Heat as emergency, heat as chronic stress: Policy and institutional responses to vulnerability to extreme heat. *Local Environment, 22*(6), 682-698. https://doi.org/10.1080/13549839.2016.1254169

Boring, E. G. (1953). The role of theory in experimental psychology. *Am J Psychol, 66*(2), 169-184.

Bowers, J., Lo, J., Miller, P., Mawren, D., & Jones, B. (2018). Psychological distress in remote mining and construction workers in Australia. *Med J Aust, 208*(9), 391-397. https://www.mja.com.au/system/files/issues/208_09/10.5694mja17.00950.pdf

Brace, C., & Geoghegan, H. (2011). Human geographies of climate change: Landscape, temporality, and lay knowledge. *Progress in Human Geography, 35*(3), 284-302. https://doi:10.1177/0309132510376259

Brechin, S. R. (2016). Climate change mitigation and the collective action problem: Exploring country differences in greenhouse gas contributions. Paper presented at the *Sociological Forum*. http://onlinelibrary.wiley.com/doi/10.1111/socf.12276/full

Brechin, S. R., & Bhandari, M. (2011). Perceptions of climate change worldwide. *Wiley Interdisciplinary Reviews-Climate Change*, *2*(6), 871-885. https://doi:10.1002/wcc.146

Bridger, R. S. (2003). *Introduction to ergonomics* (2nd ed.). London and New York: Routledge, Taylor and Francis.

Brode, P., Fiala, D., Blazejczyk, K., Holmer, I., Jendritzky, G., Kampmann, B., . . . Havenith, G. (2012). Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). *Int J Biometeorol*, *56*(3), 481-494. https://doi:10.1007/s00484-011-0454-1

Brundtland, G. H. (1985). World commission on environment and development. *Environmental policy and law, 14*(1), 26-30. https://doi:10.1016/S0378-777X(85)80040-8

Bryman, A. (2006). Integrating quantitative and qualitative research: how is it done? *Qualitative research, 6*(1), 97-113.

Burdge, R. J., & Vanclay, F. (1995). Social impact assessment. *Environmental and social impact assessment*, 31-65.

Burdge, R. J., & Vanclay, F. (1996). Social Impact Assessment: A Contribution to the State of the Art Series. *Impact Assessment, 14*(1), 59-86. doi:10.1080/07349165.1996.9725886

Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, *527*(7577), 235-239. https://www.nature.com/articles/nature15725doi:10.1038/nature15725

Burningham, K., & Obrien, M. (1994). Global environmental values and local contexts of action. *Sociology-the Journal of the British Sociological Association*, *28*(4), 913-932. https://doi:10.1177/0038038594028004007

Buzan, J. R., Oleson, K., & Huber, M. (2015). Implementation and comparison of a suite of heat stress metrics within the Community Land Model version 4.5. *Geoscientific Model Development*, *8*(2), 151-170. https://doi:10.5194/gmd-8-151-2015

Byass, P., Twine, W., Collinson, M., Tollman, S., & Kjellstrom, T. (2010). Assessing a population's exposure to heat and humidity: an empirical approach. *Glob Health Action*, *3*. https://doi:10.3402/gha.v3i0.5421

Campbell, D. T., & Fiske, D. W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychol Bull*, *56*(2), 81-105.

Campbell-Lendrum, D., Chadee, D., Honda, Y., Liu, Q., Olwoch, J., Revich, B., & Sauerborn, R. (2014). Human health: Impacts, adaptation, and co-benefits. *Climate change*, 17-19.

Carlton, S. J., & Jacobson, S. K. (2013). Climate change and coastal environmental risk perceptions in Florida. *J Environ Manage*, *130*, 32-39. https://doi:10.1016/j.jenvman.2013.08.038

Centers for Disease Control & Prevention (CDCP). (2008). Heat-related deaths among crop workers--United States, 1992--2006. *MMWR: Morbidity and Mortality Weekly Report*, *57*(24), 649-653. Retrieved on 2/02/2017 from https://www.safetylit.org/citations/index.php?fuseaction=citations.viewdetails&citationIds[]=citjournalarticle_88362_15

Cichon, M. (2013). The social protection floors recommendation, 2012 (No. 202): Can a six-page document change the course of social history? *International Social Security Review*, *66*(3-4), 21-43. http://onlinelibrary.wiley.com/doi/10.1111/issr.12017/full

ClimateChip. (2016, September 9, 2016). Basic local heat monitoring and occupational exposure assessment. Retrieved from http://climatechip.org/Local_Monitoring 23/01/2017

Cohen, J., 1988. *Statistical power analysis for the behavioural sciences* (2 ed.). Hillsdale, NJ: Erlbaum Associates.

Cooke, A., Smith, D., & Booth, A. (2012). Beyond PICO the SPIDER tool for qualitative evidence synthesis. *Qualitative Health Research, 22*(10), 1435-1443. http://journals.sagepub.com/doi/abs/10.1177/1049732312452938

Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., . . . Patterson, C. (2009). Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. *Lancet, 373*(9676), 1693-1733. https://doi.org/10.1016/S0140-6736(09)60935-1

Creswell, J. W. (2002). *Educational research: Planning, conducting, and evaluating quantitative.* London: Prentice Hall. http://basu.nahad.ir/uploads/creswell.pdf

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. London: Sage publications.

Creswell, J. W. (2015). *A concise introduction to mixed methods research*: SAGE publications.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research* (3rd ed.). London: Sage publications.

Creswell, J. W., & Plano Clark, V. L. (2017). *Designing and conducting mixed methods research* (3rd ed.). London: Sage publications.

Crowe, J., Moya-Bonilla, J. M., RomÃĄn-Solano, B., & Robles-RamÃrez, A. (2010). Heat exposure in sugarcane workers in Costa Rica during the non-harvest season. *Global Health Action, 3*. https://doi.org/10.3402/gha.v3i0.5619

Crowe, J., van Wendel de Joode, B., & Wesseling, C. (2009). A pilot field evaluation on heat stress in sugarcane workers in Costa Rica: What to do next? *Glob Health Action, 2*. https://doi:10.3402/gha.v2i0.2062

Crowe, J., Wesseling, C., Solano, B. R., Umaña, M. P., Ramírez, A. R., Kjellstrom, T., . . . Nilsson, M. (2013). Heat exposure in sugarcane harvesters in Costa Rica. *American Journal of Industrial Medicine, 56*(10), 1157-1164. http://onlinelibrary.wiley.com/doi/10.1002/ajim.22204/full

Davidson, D. J., Williamson, T., & Parkins, J. R. (2003). Understanding climate change risk and vulnerability in northern forest-based communities. *Canadian Journal of Forest Research, 33*(11), 2252-2261. https://doi.org/10.1139/x03-138

Davies, M., Oswald, K., & IDS, T. M. (2009). *Climate change adaptation, disaster risk reduction and social protection*. Unclassified DCD/DAC (2009) 15/ADD, 141. http://onlinelibrary.wiley.com/doi/10.1111/j.2040-0209.2009.00320_2.x/full

Delgado-Cortez, O. (2009). Heat stress assessment among workers in a Nicaraguan sugarcane farm. *Glob Health Action, 2*. https://doi.org/10.3402/gha.v2i0.2069

Denzin, N. K. (1978). *The research act: A theoretical introduction to sociological methods*. New York: Praeger.

Denzin, N. K. (2008). The new paradigm dialogs and qualitative inquiry. *International Journal of Qualitative Studies in Education, 21*(4), 315-325. doi:10.1080/09518390802136995

Dessler, A. E., & Parson, E. A. (2019). *The science and politics of global climate change: A guide to the debate*: Cambridge University Press

DeVries, M. W., & Wilkerson, B. (2003). Stress, work and mental health: a global perspective. *Acta neuropsychiatrica, 15*(1), 44-53. http://onlinelibrary.wiley.com/doi/10.1034/j.1601-5215.2003.00017.x/full

Dixon-Woods, M., Agarwal, S., Jones, D., Young, B., & Sutton, A. (2005). Synthesising qualitative and quantitative evidence: a review of possible methods. *J Health Serv Res Policy, 10*(1), 45-53. https://doi.org/10.1177%2F135581960501000110

Donoghue, A. M. (2004). Heat illness in the US mining industry. *American Journal of Industrial Medicine, 45*(4) pp. 351-356. https://onlinelibrary.wiley.com/doi/pdf/10.1002/ajim.10345

Donoghue, A. M., Sinclair, M.J., & Bates, G.P. (2000). Heat exhaustion in a deep underground metalliferous mine. *Occupational and Environmental Medicine, 57*(3) pp. 165-174. http://oem.bmj.com/content/57/3/165

Dreyer, M., Renn, O., Cope, S., & Frewer, L. J. (2010). Including social impact assessment in food safety governance. *Food Control, 21*(12), 1620-1628. doi:10.1016/j.foodcont.2009.05.007

Dunne, J. P., Stouffer, R. J., & John, J. G. (2013). Reductions in labour capacity from heat stress under climate warming. *Nature Climate Change, 3*(6), 563-566. https://www.nature.com/articles/nclimate1827 doi:10.1038/nclimate1827

Dutta, P., Rajiva, A., Andhare, D., Azhar, G., Tiwari, A., Sheffield, P., . . . Climate Study, G. (2015). Perceived heat stress and health effects on construction workers. *Indian Journal of Occupational and Environmental Medicine, 19*(3). https://dx.doi.org/10.4103%2F0019-5278.174002

Ebi, K. L., & Otmani Del Barrio, M. (2017). Lessons Learned on Health Adaptation to Climate Variability and Change: Experiences Across Low- and Middle-Income Countries *Environ Health Perspect, 125*(6), 065001. https://doi.org/10.1289/EHP405

Epstein, Y., & Moran, D. S. (2019). Extremes of temperature and hydration *Travel Medicine* (pp. 407-415): Elsevier.

Esteves Gonçlves da Costa, B., & Cukerman, H.L. (2019). How anthropogenic climate change prevailed: A case study of controversies around global warming on Portuguese Wikipeidia. *New Media and Society*, 1461444819838227

Esteves, A. M., & Vanclay, F. (2009). Social Development Needs Analysis as a tool for SIA to guide corporate-community investment: Applications in the minerals industry. *Environmental Impact Assessment Review, 29*(2), 137-145. doi:10.1016/j.eiar.2008.08.004

Esteves, A. M., Franks, D., & Vanclay, F. (2012). Social impact assessment: The state of the art. *Impact assessment and project appraisal, 30*(1), 34-42. doi:10.1080/14615517.2012.660356

Evadzi, P. I. K., Scheffran, J., Zorita, E., & Hunicke, B. (2018). Awareness of sea-level response under climate change on the coast of Ghana. *Journal of Coastal Conservation, 22*(1), pp. 183-197. http://doi:10.1007/s11852-017-0569-6

Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs—principles and practices. *Health services research*, *48*(6pt2), 2134-2156.

Fetters, M. D., & Freshwater, D. (2015). The 1+ 1= 3 Integration Challenge. In: SAGE Publications Sage CA: Los Angeles, CA.

Finsterbusch, K. (1977). The potential role of social impact assessment in instituting public policies. *Methodology of social impact assessment. Pennsylvania: Dowden, Hutchinson & Ross*, 2-12.

Finsterbusch, K. (1995). In Praise of Sia — a Personal Review of the Field of Social Impact Assessment: Feasibility, Justification, History, Methods, Issues. *Impact Assessment, 13*(3), 229-252. doi:10.1080/07349165.1995.9726096

Fisher, R.A. (1935). The logic of inductive inference *J. R. Stat. Soc. 98*, pp. 39-54. http://www.jstor.org/citation/info/10.2307/2342435

Fleischer, N. L., Tiesman, H. M., Sumitani, J., Mize, T., Amarnath, K. K., Bayakly, A. R., & Murphy, M. W. (2013). Public health impact of heat-related illness among migrant farmworkers. *Journal of Agricultural Safety and Health, 19*(2), 140. https://doi.org/10.1016/j.amepre.2012.10.020

Flocks, J., Vi Thien Mac, V., Runkle, J., Tovar-Aguilar, J. A., Economos, J., & McCauley, L. A. (2013). Female farmworkers' perceptions of heat-related illness and pregnancy health. *J Agromedicine, 18*(4), 350-358. https://doi:10.1080/1059924X.2013.826607

Ford, J. D., Pearce, T., Prno, J., Duerden, F., Ford, L.B., Beaumier, M., & Smith, T. (2010). Perceptions of climate change risks in primary resource use industries: a survey of the

Canadian mining sector. *Regional Environmental Change, 10*(1), pp. 65-81. https://link.springer.com/article/10.1007/s10113-009-0094-8

Ford, J. D., Smit, B., & Wandel, J. (2006). Vulnerability to climate change in the Arctic: A case study from Arctic Bay, Canada. *Global Environmental Change-Human and Policy Dimensions, 16*(2), 145-160. https://doi.org/10.1016/j.gloenvcha.2005.11.007

Franke, T. M., Ho, T., Christie, C. A., 2012. The chi-square test: Often used and more often misinterpreted. *American Journal of Evaluation, 33*(3), pp. 448-458. https://doi.org/10.1177/1098214011426594

Frimpong, K., Oosthuizen, J., & Van Etten, E. (2014). Recent trends in temperature and relative humidity in Bawku East, Northern Ghana. *Journal of Geography and Geology, 6*(2), p69.

Frimpong, K., Van Etten, E. J., Oosthuzien, J., & Nunfam, V. F. (2017). Heat exposure on farmers in northeast Ghana. *Int J Biometeorol, 61*(3), pp. 397-406. https://link.springer.com/article/10.1007/s00484-016-1219-7

Frimpong, K., van Etten, E., & Oosthuizen, J. (2016). Barriers of adaptation to heat stress in northeast Ghana. *The Journal of Climate Change: Impacts and Responses, 8*(2), 53-65. https://doi.org/10.18848/1835-7156/CGP/v08i02/53-65

Frimpong, K., Van Etten, E., Oosthuzien, J., & Nunfam, V. F. (2015). Review of climate change adaptation and social protection policies of Ghana: the extent of reducing impacts of climate change and heat stress vulnerability of smallholder farmers. *International Journal of Social Ecology and Sustainable Development (IJSESD), 6*(4), 1-14. https://www.igi-global.com/article/review-of-climate-change-adaptation-and-social-protection-policies-of-ghana/142144doi:10.4018/IJSESD.2015100101

Frommer, B. (2013). Climate change and the resilient society: utopia or realistic option for German regions? *Natural hazards, 67*(1), 99-115. doi:10.1007/s11069-012-0421-0

Fussel, H. M., & Klein, R. J. T. (2006). Climate change vulnerability assessments: An evolution of conceptual thinking. *Climatic change, 75*(3), 301-329. doi:10.1007/s10584-006-0329-3

Gasper, R., Blohm, A., & Ruth, M. (2011). Social and economic impacts of climate change on the urban environment. *Current Opinion in Environmental Sustainability, 3*(3), 150-157. https://doi.org/10.1016/j.cosust.2010.12.009

Gibson, O. & Pattisson, P. (2014). Qatar World Cup: 185 Nepalese died in 2013 - official records. *Guardian*.Jan. 24. http://www.theguardian.com/world/2014/jan/24/qatar-2022-world-cup-185-nepaleseworkers-died-2013

Giovannetti, G. (2010). Social Protection for Inclusive Development. A New Perspective in EU Cooperation with Africa.

Gough, D., Oliver, S., & Thomas, J. (2017). *An introduction to systematic reviews.* London: Sage.

Ghana Chamber of Mines (GCM) (2015). *Performance of the Mining Industry in 2015*. Retrieved from Accra: Retrieved from https://ghanachamberofmines.org/media-press/our-publications/

Ghana Chamber of Mines (GCM). (2018). *Performance of the mining industry in 2017*. Retrieved from Accra, Ghana: https://ghanachamberofmines.org/wp-content/uploads/2016/11/Performance-of-the-Industry-2017.pdf

Ghana Meteorological Agency (2016). Climatology. Retrieved from Accra, Ghana: http://www.meteo.gov.gh/website/index.php?option=com_content&view=article&id=62:climatology&catid=40:feat

Ghana Revenue Authority. (2018). *2017 Sectoral Revenue Collection*. Retrieved from Accra: Ghana

Ghana Statistical Service(GSS). (2013). *2010 Population and Housing Census National Analytical Report*. Retrieved from Accra, Ghana: http://www.statsghana.gov.gh/gssmain/storage/img/marqueeupdater/Census2010_Summary_report_of_final_results.pdf

Ghana Statistical Service (GSS). (2015). *Revised 2014 Annual Gross Domestic Product*. Retrieved from Accra, Ghana: http://www.statsghana.gov.gh/docfiles/GDP/GDP2016/Revised_Annual_2015_GDP_September%202016%20Edition.pdf.

Ghana Statistical Service(GSS). (2019). *Rebased 2013-2018 Annual Gross Domestic Product*. Retrieved from Accra, Ghana: http://www.statsghana.gov.gh/gssmain/storage/img/marqueeupdater/Annual_2013_2018_GDP_April%202019%20Edition.pdf

Goldman, L., & Baum, S. (2000). Introduction. *Social Impact Analysis: An Applied Anthropology Manual*, 1-34.

Government of Ghana (2012). Minerals and Mining (Health, Safety, Technical) Regulation, 2012. (L. I. 2182). Accra, Ghana: Ghana Publishing Company Limited

Government of Ghana (2013). *Ghana National Climate Change Policy 2013.* Accra, Ghana: Government of Ghana. Retrieved from http://www.un-page.org/files/public/ghanaclimatechangepolicy.pdf

Government of Ghana (2015). *Ghana's Third National Communication Report to the UNFCCC.* Accra, Ghana: MESTI, Government of Ghana. Retrieved from https://unfccc.int/resource/docs/natc/ghanc3.pdf.

Greene, J. C. (2006). Toward a methodology of mixed methods social inquiry. *Research in the Schools, 13*(1), 93-98.

Greene, J. C. (2015). Preserving distinctions within the multimethod and mixed methods research merger. In *The Oxford handbook of multimethod and mixed methods research inquiry*.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. *Educational evaluation and policy analysis, 11*(3), 255-274.

Guetterman, T. C., Fetters, M. D., & Creswell, J. W. (2015). Integrating Quantitative and Qualitative Results in Health Science Mixed Methods Research Through Joint Displays. *Annals of Family Medicine*, *13*(6), 554-561. https://doi:10.1370/afm.1865

Hagen, B., Middel, A., & Pijawka, D. (2016). European climate change perceptions: public support for mitigation and adaptation policies. *Environmental Policy and Governance,* 26, pp.170–183. https://doi.org/10.1002/eet.1701

Haines, A., & Patz, J. A. (2004). Health effects of climate change. *Jama, 291*(1), pp. 99-103. https://jamanetwork.com/journals/jama/fullarticle/197911

Haines, A., Smith, K. R., Anderson, D., Epstein, P. R., McMichael, A. J., Roberts, I., . . . Woods, J. (2007). Policies for accelerating access to clean energy, improving health, advancing development, and mitigating climate change. *The Lancet, 370*(9594), 1264-1281. https://doi.org/10.1016/S0140-6736(07)61257-4

Hanna, E. G., Kjellstrom, T., Bennett, C., & Dear, K. (2011). Climate change and rising heat: Population health implications for working people in Australia. *Asia Pac J Public Health, 23*(2 Suppl), 14S-26. http://journals.sagepub.com/doi/abs/10.1177/1010539510391457

Hesse-Biber, S. N. (2010). *Mixed methods research: Merging theory with practice*: Guilford Press.

Hilson, G. (2019). Why is there a large-scale mining 'bias' in sub-Saharan Africa? *Land Use Policy, 81*, 852-861.

Hilson, G. & J. McQuilken, 2014. 'Four Decades of Support for Artisanal and Small-Scale Mining in Sub-Saharan Africa: A Critical Review.' The Extractive Industries and Society 1: 104–18. doi.org/10.1016/j. exis.2014.01.002

Hoiling, C., Schindler, D., Walker, B. W., & Roughgarden, J. (1997). Biodiversity in the functioning of ecosystems: an ecological synthesis. *Biodiversity loss: economic and ecological issues*, 44.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics*, *4*(1), 1-23.

Hoogendoorn, G., Fitchett, J. M. (2018). Tourism and climate change: a review of threats and adaptation strategies for Africa. *Current Issues in Tourism*, *21*(7), pp. 742-759. https://doi:10.1080/13683500.2016.1188893

Huang, C., Barnett, A. G., Wang, X., Vaneckova, P., FitzGerald, G., & Tong, S. (2011). Projecting future heat-related mortality under climate change scenarios: a systematic review. *Environmental Health Perspectives*, *119*(12), 1681. https://dx.doi.org/10.1289%2Fehp.1103456

Hunt, A. P. (2011). *Heat strain, hydration status, and symptoms of heat illness in surface mine workers* The Queensland University of Technology. https://eprints.qut.edu.au/44039/

Hyatt, O. M., Lemke, B., & Kjellstrom, T. (2010). Regional maps of occupational heat exposure: Past, present, and potential future. *Global Health Action*, *3*(1), 5715. http://www.tandfonline.com/doi/abs/10.3402/gha.v3i0.5715@zgha20.2010.3.issue-s3

ILO. (2001). *Guidelines on occupational safety and health management systems, ILO-OSH 2001* Retrieved from Geneva: https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/normativeinstrument/wcms_107727.pdf

ILO. (2016). *Standards and other instruments on occupational safety and health*. Retrieved from Geneva: http://www.ilo.org/safework/info/standards-and-instruments/lang--en/index.htm

IPCC. (2001). *Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (James J. McCarth, Osvaldo F. Canziani, Neil A. Leary, David J. Dokken, & Kasey S. White Eds.). Cambridge, United Kingdom and New York, NY, USA,: Cambridge University Press.

IPCC. (2007). *Climate change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to Fourth Assessment Report of the IPCC*. Retrieved from UK

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. The contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (WG1 AR5)*. Cambridge, United Kingdom and New York, NY, USA: Intergovernmental Panel on Climate Change.

IPCC. (2014a). *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (V. R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, a. P.R. Mastrandrea, & L. L. White Eds.). Cambridge University Press, Cambridge,: United Kingdom and New York, NY, USA, .

IPCC. (2014b). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from Cambridge, United Kingdom and New York, NY, USA,. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf

IPCC. (2014c). *Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from Cambridge, United Kingdom and New York, NY, USA,: http://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf

IPCC. (2015). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel & J. C. Minx Eds. Vol. 3). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

ISO. (1989). *ISO 7243: Hot Environments- Estimation of the Heat Stress on Working Man, Based on the WBGT-index (Wet Bulb Globe Temperature)*. Retrieved from Geneva:

Jacklitsch, B. L. (2017). *Assessing heat-related knowledge, perceptions, and needs among emergency oil spill cleanup responders.* University of Cincinnati. http://rave.ohiolink.edu/etdc/view?acc_num=ucin1509983799665014

Jia, Y. A., Rowlinson, S., & Ciccarelli, M. (2016). Climatic and psychosocial risks of heat illness incidents on construction site. *Appl Ergon, 53 Pt A*, 25-35. https://doi:10.1016/j.apergo.2015.08.008

Jick, T. D. (1979). Mixing qualitative and quantitative methods: Triangulation in action. *Administrative science quarterly, 24*(4), 602-611.

JoannaBriggsInstitute (JBI). (2014). *Joanna Briggs Institute Reviewers' Manual 2014 Edition [Internet]*. Adelaide: JBI; 2014 [cited 2015 May 15].

João, E., Vanclay, F., & den Broeder, L. (2011). Emphasising enhancement in all forms of impact assessment: introduction to a special issue. *Impact assessment and project appraisal*, *29*(3), 170-180.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational researcher, 33*(7), 14-26.

Kalkstein, L., Koppe, C., Orlandini, S., Sheridan, S., & Smoyer-Tomic, K. (2009). Health impacts of heat: present realities and potential impacts of climate change. *Distributional Impacts of Climate Change and Disasters. Cheltenham: Edward Elgar*, 69-81. https://books.google.com.au/books?hl=en&lr=&id=KxT3_I0ddYEC&oi=fnd&pg=PA69&dq=Health+impacts+of+heat:+present+realities+and+potential+impacts+of+climate+change

Kelly, P. M., & Adger, W. N. (2000). Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change, 47*(4), 325-352. https://link.springer.com/article/10.1023%2FA%3A1005627828199

Kiros, G., Shetty, A., & Nandagiri, L. (2016). Analysis of variability and trends in rainfall over northern Ethiopia. *Arabian Journal of Geosciences, 9*(6), 451. https://doi:ARTN45110.1007/s12517-016-2471-1

Kjellstrom, T., & Crowe, J. (2011). Climate change, workplace heat exposure, and occupational health and productivity in Central America. *Int J Occup Environ Health, 17*(3), 270-281. http://www.tandfonline.com/doi/abs/10.1179/107735211799041931

Kjellstrom, T. (2012). *The "HOTHAPS" program for climate change impact assessment and prevention***.** Paper presented at the 30th International Congress on Occupational Health (March 18-23, 2012).

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., & Hyatt, O. (2016a). Heat, human performance, and occupational health: A key issue for the assessment of global climate change impacts. *Annu Rev Public Health, 37*, 97-112. https://doi.org/10.1146/annurev-publhealth-032315-021740

Kjellstrom, T., Butler, A. J., Lucas, R. M., & Bonita, R. (2010). Public health impact of global heating due to climate change: potential effects on chronic non-communicable diseases. *International Journal of Public Health, 55*(2), 97-103. https://doi.org/10.1007/s00038-009-0090-2

Kjellstrom, T., Freyberg, C., Lemke, B., Otto, M., & Briggs, D. (2018). Estimating population heat exposure and impacts on working people in conjunction with climate change. *International Journal of Biometeorology, 62*(3), 291-306.

Kjellstrom, T., Gabrysch, S., Lemke, B., & Dear, K. (2009a). The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: an invitation to carry out field studies. *Global Health Action, 2*, pp. 81-87. https://doi.org/10.3402/gha.v2i0.2082

Kjellstrom, T., Holmer, I., & Lemke, B. (2009b). Workplace heat stress, health and productivity - an increasing challenge for low-and middle-income countries during climate change. *Glob Health Action, 2*, 46-51. http://www.tandfonline.com/doi/abs/10.3402/gha.v2i0.2047@zgha20.2009.2.issue-s3

Kjellstrom, T., Kovats, R. S., Lloyd, S. J., Holt, T., & Tol, R. S. J. (2009c). The Direct Impact of Climate Change on Regional Labor Productivity. *Archives of Environmental & Occupational Health, 64*(4), 217-227. https://doi.org/10.1080/19338240903352776

Kjellstrom, T., Lemke, B., & Hyatt, O. (2011). Increased workplace heat exposure due to climate change: a potential threat to occupational health, worker productivity and local economic development in Asia and the Pacific region. *Asian-Pacific Newsletter., 18*(1), 6-11. https://doi.org/10.1179/107735211799041931

Kjellstrom, T., & McMichael, A. J. (2013). Climate change threats to population health and well-being: the imperative of protective solutions that will last. *Global Health Action, 6*, 20816. http://doi:10.3402/gha.v6i0.20816

Kjellstrom, T., Otto, M., Lemke, B., Hyatt, O., Briggs, D., Freyberg, C., & Lines, L. (2016b). *Climate change and labour: Impacts of heat in the workplace climate change, workplace environmental conditions, occupational health risks, and productivity –an emerging global challenge to decent work, sustainable development and social equity.* Retrieved from http://www.ilo.org/wcmsp5/groups/public/---ed_emp/---gjp/documents/publication/wcms_476194.pdf

Klein, J. A., Hopping, K. A., Yeh, E. T., Nyima, Y., Boone, R. B., & Galvin, K. A. (2014). Unexpected climate impacts on the Tibetan Plateau: Local and scientific knowledge in findings of delayed summer. *Global Environmental Change-Human and Policy Dimensions, 28*, 141-152. https://doi:10.1016/j.gloenvcha.2014.03.007

Knight, K. W. (2016). Public awareness and perception of climate change: a quantitative cross-national study. *Environmental Sociology, 2*(1), 101-113. https://doi:10.1080/23251042.2015.1128055

Krishnamurthy, M., Ramalingam, P., Perumal, K., Kamalakannan, L. P., Chinnadurai, J., Shanmugam, R., . . . Venugopal, V. (2017). Occupational heat stress impacts on health and productivity in a steel industry in Southern India. *Safety and Health at Work, 8*(1), 99-104. doi: http://dx.doi.org/10.1016/j.shaw.2016.08.005

Lam, M., Krenz, J., Palmandez, P., Negrete, M., Perla, M., Murphy-Robinson, H., & Spector, J. T. (2013). Identification of barriers to the prevention and treatment of heat-related illness in Latino farmworkers using activity-oriented, participatory rural appraisal focus group methods. *BMC Public Health, 13*(1), https://bmcpublichealth.biomedcentral.com/track/pdf/10.1186/1471-2458-13-1004

Langkulsen, U., Vichit-Vadakan, N., & Taptagaporn, S. (2010). Health impact of climate change on occupational health and productivity in Thailand. *Global Health Action, 3*. https://doi.org/10.3402/gha.v3i0.5607@zgha20.2010.3.issue-s3

Lao, J., Hansen, A., Nitschke, M., Hanson-Easey, S., & Pisaniello, D. (2016). Working smart: An exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia. *Safety Science, 82*, 228-235. doi: http://dx.doi.org/10.1016/j.ssci.2015.09.026

Leal Filho, W., Azeiteiro, U., Alves, F., Pace, P., Mifsud, M., Brandli, L., . . . Disterheft, A., (2018). Reinvigorating the sustainable development research agenda: the role of the sustainable development goals (SDG). *International Journal of Sustainable Development & World Ecology, 25*(2), 131-142. https://doi.org/10.1080/13504509.2017.1342103

Lee, T. M., Markowitz, E. M., Howe, P. D., Ko, C. Y., & Leiserowitz, A. A. (2015). Predictors of public climate change awareness and risk perception around the world. *Nature Climate Change, 5*(11), 1014-+. https://doi:10.1038/Nclimate2728

Lemke, B., & Kjellstrom, T. (2012). Calculating workplace WBGT from meteorological data: a tool for climate change assessment. *Ind Health, 50*(4), 267-278.

Li, M. M., Gu, S.H., Bi, P., Yang, J., & Lui, Q.Y. (2015). Heat Waves and Morbidity: Current Knowledge and Further Direction-A Comprehensive Literature Review. *International Journal of Environmental Research and Public Health, 12*(5), pp. 5256-5283. http://dx.doi.org/10.3390/ijerph120505256

Liang, C. Z., Zheng, G. Z., Zhu, N., Tian, Z., Lu, S. L., & Chen, Y. (2011). A new environmental heat stress index for indoor hot and humid environments based on Cox regression. *Building and Environment, 46*(12), 2472-2479. https://doi:10.1016/j.buildenv.2011.06.013

Liljegren, J. C., Carhart, R. A., Lawday, P., Tschopp, S., & Sharp, R. (2008). Modelling the wet bulb globe temperature using standard meteorological measurements. *J Occup Environ Hyg*, *5*(10), 645-655. https://doi:10.1080/15459620802310770

Lloyd, E. L. (1994). ABC of sports medicine. Temperature and performance--II: Heat. *BMJ: British Medical Journal*, *309*(6954), 587. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2541424/pdf/bmj00455-0041.pdf

Lockie, S. (2001). SIA in review: setting the agenda for impact assessment in the 21st century. *Impact assessment and project appraisal*, *19*(4), 277-287. doi:10.3152/147154601781766952

Lorenzoni, I., Pidgeon, N. F. (2006). Public views on climate change: European and USA perspectives. *Climatic Change, 77*(1-2), pp. 73-95. https://doi:10.1007/s10584-006-9072-z

Lucas, R. A., Epstein, Y., & Kjellstrom, T. (2014). Excessive occupational heat exposure: A significant ergonomic challenge and health risk for current and future workers. *Extrem Physiol Med*, *3*(1), 14. https://doi.org/10.1186/2046-7648-3-14

Lundgren, K., Kuklane, K., Gao, C., & Holmér, I. (2013). Effects of heat stress on working populations when facing climate change. *Industrial Health*, *51*(1), 3-15. https://doi.org/10.2486/indhealth.2012-0089

Lundgren, K., Kuklane, K., & Venugopal, V. (2014). Occupational heat stress and associated productivity loss estimation using the PHS model (ISO 7933): a case study from workplaces in Chennai, India. *Global Health Action*, *7*. http://doi:Artn2528310.3402/Gha.V7.25283

Luo, H. M., Turner, L. R., Hurst, C., Mai, H. M., Zhang, Y. R., & Tong, S. L. (2014). Exposure to ambient heat and urolithiasis among outdoor workers in Guangzhou, China. *Science of the Total Environment*, *472*, 1130-1136. https://doi.org/10.1016/j.scitotenv.2013.11.042

Luyt, R. (2012). A Framework for Mixing Methods in Quantitative Measurement Development, Validation, and Revision: A Case Study. *Journal of Mixed Methods Research*, *6*(4), 294-316. https://doi:10.1177/1558689811427912

Maguire, M., & Delahunt, B. (2017). Doing a thematic analysis: A practical, step-by-step guide for learning and teaching scholars. *AISHE-J: The All Ireland Journal of Teaching and Learning in Higher Education*, *9*(3). https://ojs.aishe.org/aishe/index.php/aishe-j/article/view/335

Mahmoudi, H., Renn, O., Vanclay, F., Hoffmann, V., & Karami, E. (2013). A framework for combining social impact assessment and risk assessment. *Environmental Impact Assessment Review, 43,* 1-8. http://doi:10.1016/j.eiar.2013.05.003

Maloney, S. K., & Forbes, C. F. (2011). What effect will a few degrees of climate change have on human heat balance? Implications for human activity. *International Journal of Biometeorology, 55*(2), 147-160. https://link.springer.com/article/10.1007/s00484-010-0320-6

Maté, J., Siegel, R., Oosthuizen, J., Laursen, P. B., & Watson, G. (2016). Effect of Liquid versus Ice Slurry Ingestion on Core Temperature during Simulated Mining Conditions. *Open Journal of Preventive Medicine, 6*(01), 21. http://ro.ecu.edu.au/ecuworkspost2013/3416/doi:10.4236/ojpm.2016.61002

Mathee, A., Oba, J., & Rose, A. (2010). Climate change impacts on working people (the HOTHAPS initiative): findings of the South African pilot study. *Glob Health Action, 3*. https://doi.org/10.3402/gha.v3i0.5612

Mattah, P. A. D., Futagbi, G., & Mattah, M. M. (2018). Awareness of environmental change, climate variability, and their role in prevalence of mosquitoes among urban dwellers in Southern Ghana. *Journal of Environmental and Public Health, 2018*. https://doi:Artn 534262410.1155/2018/5342624

Mays, N., Pope, C., & Popay, J. (2005). Systematically reviewing qualitative and quantitative evidence to inform management and policy-making in the health field. *Journal of Health Services Research & Policy, 10*(1_suppl), 6-20. http://journals.sagepub.com/doi/abs/10.1258/1355819054308576

McHugh, M. L. (2013). The chi-square test of independence. *Biochem Med (Zagreb), 23*(2), pp. 143-149. https://doi.org/10.11613/BM.2013.018

McMahon, G., & Moreira, S. (2014). The contribution of the mining sector to socioeconomic and human development. https://doi:openknowledge.worldbank.org/bitstream/handle/10986/18660/872980nwp0mini00box385186b00public0.pdf?sequence=1

McMichael, A. J., Campbell-Lendrum, D. H., & Corvalán, C. F. (2003). *Climate change and human health: risks and responses*. Geneva: World Health Organization.

McMichael, A. J., Woodruff, R.E., & Hale, S. (2006). Climate change and human health: present and future risks. *The Lancet, 367*(9513), pp. 859-869. https://doi.org/10.1016/S0140-6736(06)68079-3

McQuilken, J., & Hilson, G. (2016). *Artisanal and small-scale gold mining in Ghana Evidence to inform an 'action dialogue'*. Retrieved from London: http://pubs.iied.org/16618IIED/

Mensah, A. K., Mahiri, I. O., Owusu, O., Mireku, O. D., Wireko, I., & Kissi, E. A. (2014). Environmental Impacts of Mining: A Study of Mining Communities in Ghana.

Mertens, D. M. (2003). Mixed methods and the politics of human research: The transformative-emancipatory perspective. *Handbook of mixed methods in social and behavioral research*, 135-164.

Mertens, D. M. (2014). *Research and evaluation in education and psychology: Integrating diversity with quantitative, qualitative, and mixed methods*: Sage publications.

Mertens, D. M. (2015). Mixed methods and wicked problems. *Journal of Mixed Methods Research, 9*(1), 3-6. https://doi:10.1177/1558689814562944

Miller, F. (2014). Too hot to handle: Assessing the social impacts of extreme heat. Paper presented at the *Turning up the heat: A symposium for SIA practitioners and researchers*. http://web.science.mq.edu.au/downloads/sia/fiona-miller.pdf

Mirabelli, M. C., Quandt, S. A., Crain, R., Grzywacz, J. G., Robinson, E. N., Vallejos, Q. M., & Arcury, T. A. (2010). Symptoms of heat illness among Latino farm workers in North Carolina. *American Journal of Preventive Medicine, 39*(5), 468-471. https://doi:10.1016/j.amepre.2010.07.008

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., . . . Stewart, L. A. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews, 4*(1), 1. https://doi.org/10.1186/2046-4053-4-1

Moretti, D., & Garrett, N. (2018). Artisanal and small-scale mining governance: The 'emerging issue' of 'unregulated mining' in Lao PDR. *The Pick*, 311.

Mundial, B. (2012). Resilience, equity and opportunity: The World Bank's social protection and labour strategy 2012–2022. *Informe de Consultorías, Banco Mundial, Washington DC*. http://documents.worldbank.org/curated/en/443791468157506768/Resilience-equity-and-opportunity-the-World-Banks-social-protection-and-labor-strategy-2012-2022

NASA, 2018a. Global climate change: vital signs of the planet-sea level. Retrieved from https://climate.nasa.gov/vital-signs/sea-level/.

NASA, 2018b. Sea level change: observation from space-understanding sea level projections. Retrieved from https://sealevel.nasa.gov/understanding-sea-level/projections/

empirical-projections.

Natural Capital Economics. (2018). *Heatwaves in Victoria: A vulnerability assessment. Report prepared for the Department of Environment, Land, Water and Planning, VIC*. Retrieved from https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0029/399440/Heatwaves_VulnerabilityAssessment_2018.pdf

Neely, R. (2012). Bahamians and climate change: an analysis of perception of risk and climate change literacy. Doctoral dissertation, Florida Agricultural and Mechanical University, USA (2012).

Neuman, W. L., & Kreuger, L. (2003). *Social work research methods: Qualitative and quantitative approaches.* Allyn and Bacon.

Neuman, W. L., & Robson, K. (2012). Basics of social research: Qualitative and quantitative approaches. Allyn and Bacon.

Ngulube, P. (2010). Mapping mixed methods research in library and information science journals in Sub-Saharan Africa 2004–2008. *The international information & library review, 42*(4), 252-261.

Ngulube, P., & Ngulube, B. (2015). Mixed Methods Research in the South African Journal of Economic and Management Sciences: An Investigation of Trends in the Literature. *South African Journal of Economic and Management Sciences, 18*(1), 1-13.

Ngwenya, B., Oosthuizen, J., Cross, M., & Frimpong, K. (2018). Emerging heat-related climate change influences; a public health challenge to health care practitioners and policymakers: Insight from Bulawayo, Zimbabwe. *International Journal of Disaster Risk Reduction*, *27*, 596-601. https://doi:10.1016/j.ijdrr.2017.10.012

NIOSH. (1986). *Criteria for a recommended standards: Occupational exposure to hot environments (Revised criteria 1986).* Atlanta: Center for Disease Control and Prevention (CDC) Retrieved from Available at: http://www.cdc.gov/niosh/docs/86-113.pdf.

NIOSH. (2010). NIOSH: Workplace Safety and Health *US Centers for Disease Control and Prevention. Updated November* (Vol. 18).

NIOSH. (2016). *NIOSH criteria for a recommended standard: occupational exposure to heat and hot environments*. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health Retrieved from https://www.cdc.gov/niosh/docs/2016-106/pdfs/2016-106.pdf 26/10/2017

Noblit, G. W., & Hare, R. D. (1988). *Meta-ethnography: Synthesising qualitative studies* (Vol. 11). United Kingdom: Sage Publications. https://books.google.com.au/books?hl=en&lr=&id=fQQb4FP4NSgC&oi=fnd&pg=PA10&dq=Meta-ethnography:+Synthesising+qualitative+studies+(Vol.+11)

Nunfam, V. F., Adusei-Asante, K., Van Etten, E. J., Oosthuizen, J., & Frimpong, K. (2018). Social impacts of occupational heat stress and adaptation strategies of workers: A narrative synthesis of the literature. *Sci Total Environ*, *643*, 1542-1552. https://doi:10.1016/j.scitotenv.2018.06.255

Nunfam, V. F., Adusei-Asante, K., Van Etten, E. J., Oosthuizen, J., Adams, S., & Frimpong, K. (2019). The nexus between social impacts and adaptation strategies of workers to occupational heat stress: a conceptual framework. *Int J Biometeorol*, *63*(291), 1-14.

Nunfam, V. F., Oosthuizen, J., Adusei-Asante, K., Van Etten, E. J., & Frimpong, K. (2019a). Perceptions of climate change and occupational heat stress risks and adaptation strategies of mining workers in Ghana. *Sci Total Environ*, *657*, 365-378. https://doi:10.1016/j.scitotenv.2018.11.480

Nunfam, V. F., Van Etten, E. J., Oosthuizen, J., Adusei-Asante, K., & Frimpong, K. (2019b). Climate change and occupational heat stress risks and adaptation strategies of mining workers: Perspectives of supervisors and other stakeholders in Ghana. *Environ Res*, *169*, 147-155. https://doi:10.1016/j.envres.2018.11.004

O'Cathain, A., Murphy, E., & Nicholl, J. (2007). Integration and publications as indicators of "yield" from mixed methods studies. *Journal of Mixed Methods Research*, *1*(2), 147-163. https://doi:10.1177/1558689806299094

Orlove, B., Roncoli, C., Kabugo, M., & Majugu, A. (2010). Indigenous climate knowledge in southern Uganda: the multiple components of a dynamic regional system. *Climatic Change*, *100*(2), 243-265. https://doi:10.1007/s10584-009-9586-2

Pallant, J. (2010). *Manual, SPSS Survival: A step by step guide to data analysis using SPSS.* Berkshire UK: McGraw-Hill Education.

Park, J., Kim, Y., & Oh, I. (2017). Factors affecting heat-related diseases in outdoor workers exposed to extreme heat. *Ann Occup Environ Med*, *29*(1), 30. https://doi:10.1186/s40557-017-0183-y

Parsons, K. (2009). Maintaining health, comfort and productivity in heat waves. *Glob Health Action*, *2*(1), 2057. https://doi:10.3402/gha.v2i0.2057

Parsons, K. (2013). Occupational health impacts of climate change: current and future ISO standards for the assessment of heat stress. *Ind Health, 51*(1), 86-100. https://doi.org/10.2486/indhealth.2012-0165

Parsons, K. (2014). *Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance* (3 ed.). Boca Raton, NewYork and London: CRC Press.

Petticrew, M., & Roberts, H. (2008). *Systematic reviews in the social sciences: A practical guide*. US: Black well Publishing.

Plano Clark, V. L., & Ivankova, N. V. (2016). *Mixed methods research: A guide to the field* (Vol. 3): Sage Publications.

Pogge, T., & Sengupta, M. (2015). The Sustainable Development Goals (SDGs) as drafted: Nice idea, poor execution. *Wash. Int'l LJ, 24*, 571. http://heinonline.org/HOL/Page?handle=hein.journals/pacrimlp24&div=27&g_sent=1&casa_token=&collection=journals

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., . . . Duffy, S. (2006). *Guidance on the conduct of narrative synthesis in systematic reviews.* A Product from the ESRC Methods Programme Version, 1, b92. https://doi:10.13140/2.1.1018.4643

Pradhan, B., Shrestha, S., Shrestha, R., Pradhanang, S., Kayastha, B., & Pradhan, P. (2013). Assessing climate change and heat stress responses in the Tarai Region of Nepal. *Industrial Health, 51*(1), 101-112. https://doi.org/10.2486/indhealth.2012-0166

Pugliese, A., & Ray, J. (2009). A heated debate: global attitudes toward climate change. *Harvard International Review, 31*(3), 64. https://search.proquest.com/docview/230941451/fulltext/71E78B21BDC14B6BPQ/1?accountid=10675

Ramsey, J. D. (1995). Task performance in heat: a review. *Ergonomics, 38*(1), 154-165. https://doi:10.1080/00140139508925092

Rattle, R., Kwiatkowski, R. E., Becker, H., & Vanclay, F. (2003). Integrating health and social impact assessment. *The International Handbook of Social Impact Assessment. Conceptual and Methodological Advances (Becker HA, Vanclay F, eds). Cheltenham, UK: Edward Elgar*, 92-107.

Renn, O. (2008). *Risk governance: coping with uncertainty in a complex world*. London: Earthscan

Renn, O., & Walker, K. D. (2008). *Global Risk Governance: Concept and Practice Using the IRGC Framework. International Risk Governance Council (IRGC) Book Series on Global Risk Governance*: Springer.

Rhodes, C. J. (2016). The 2015 Paris climate change conference: COP21. *Science Progress, 99*(1), 97-104. https://doi.org/10.3184/003685016X14528569315192

Richards, D. A. B., & Hales, J. R. S. (1987). *Heat stress: physical exertion and environment*: Menzies Foundation.

Riedlinger, D., & Berkes, F. (2001). Contributions of traditional knowledge to understanding climate change in the Canadian Arctic. *Polar record, 37*(203), 315-328.

Riley, K., Delp, L., Cornelio, D., & Jacobs, S. (2012). From Agricultural Fields to Urban Asphalt: The Role of Worker Education to Promote California's Heat Illness Prevention Standard. *Journal of Agricultural Safety and Health, 18*(4), 325. https://doi:http://dx.doi.org/10.2190/NS.22.3.e

Ritchie, J., Lewis, J., Nicholls, C. M., & Ormston, R. (2013). *Qualitative research practice: A guide for social science students and researchers* (2 ed.). Los Angeles: Sage.

Roberts, D. (2016). A global roadmap for climate change action: From COP17 in Durban to COP21 in Paris. *South African Journal of Science, 112*(5-6), 9-11. https://doi:10.17159/sajs.2016/a0158

Robine, J.-M., Cheung, S. L. K., Le Roy, S., Van Oyen, H., Griffiths, C., Michel, J.-P., & Herrmann, F. R. (2008). Death toll exceeded 70,000 in Europe during the summer of 2003. *Comptes Rendus Biologies, 331*(2), 171-178. https://doi.org/10.1016/j.crvi.2007.12.001

Rogelj, J., Den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., . . . Meinshausen, M. (2016). Paris Agreement climate proposals need a boost to keep warming well below 2 C. *Nature, 534*(7609), 631-639.

Rosa, E. A. (1998). Metatheoretical foundations for post-normal risk. *Journal of risk research, 1*(1), 15-44.

Roth, R. (2004). Spatial organisation of environmental knowledge: Conservation conflicts in the inhabited forest of northern Thailand. *Ecology and Society, 9*(3).

Sahu, S., Sett, M., & Kjellstrom, T. (2013). Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: Implications for a climate change future. *Industrial Health, 51*(4), 424-431. https://doi.org/10.2486/indhealth.2013-0006

Sarantakos, S. (2012). *Social research.* London: Palgrave Macmillan.

Sawilowsky, S. S. (2009). New Effect Size Rules of Thumb. *Journal of Modern Applied Statistical Methods, 8*(2), 597-599. https://doi:10.22237/jmasm/125703510

Scheffran, J., & Remling, E. (2013). *The social dimensions of human security under a changing climate.* http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A755553&dswid=topdog

Schulte, P., Bhattacharya, A., Butler, C., Chun, H., Jacklitsch, B., Jacobs, T., . . . Shire, J. (2016). Advancing the framework for considering the effects of climate change on worker safety and health. *Journal of Occupational and Environmental Hygiene, 13*(11), 847-865. https://doi.org/10.1080/15459624.2016.1179388

Schulte, P. A., & Chun, H. (2009). Climate change and occupational safety and health: establishing a preliminary framework. *J Occup Environ Hyg, 6*(9), pp. 542-554. https://doi.org/10.1080/15459620903066008

Searle, K., & Gow, K. (2010). Do concerns about climate change lead to distress? *International Journal of Climate Change Strategies and Management*, *2*(4), pp. 362-379. https://doi.org/10.1108/17568691011089891

Sett, M., & Sahu, S. (2014). Effects of occupational heat exposure on female brick workers in West Bengal, India. *Glob Health Action, 7*(1), 21923. https://doi.org/10.3402/gha.v7.21923

Sheridan, S. C. (2007). A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness. *International Journal of Biometeorology*, *52*(1), p. 3-15. https://link.springer.com/article/10.1007/s00484-006-0052-9

Sieber, S. D. (1973). The integration of fieldwork and survey methods. *American Journal of Sociology, 78*(6), 1335-1359.

Singh, S., Hanna, E. G., & Kjellstrom, T. (2015). Working in Australia's heat: Health promotion concerns for health and productivity. *Health Promot Int, 30*(2), 239-250. https://doi.org/10.1093/heapro/dat027

Slootweg, R., Vanclay, F., & van Schooten, M. (2001). Function evaluation as a framework for the integration of social and environmental impact assessment. *Impact assessment and project appraisal, 19*(1), 19-28.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change-Human and Policy Dimensions, 16*(3), 282-292. doi:10.1016/j.gloenvcha.2006.03.008

Smith, K. R., Woodward, A., Campbell-Lendrum, D., Chadee, D., Honda, Y., Liu, Q., . . . Sauerborn, R. (2014). Human health: Impacts, adaptation, and co-benefits. *Climate Change*, 709-754.

Sovacool, B. K., D'Agostino, A. L., Meenawat, H., & Rawlani, A. (2012). Expert views of climate change adaptation in least developed Asia. *J Environ Manage, 97*, 78-88. doi:10.1016/j.jenvman.2011.11.005

Spector, J. T., & Sheffield, P. E. (2014). Re-evaluating occupational heat stress in a changing climate. *Annals of Occupational Hygiene, 58*(8), 936-942. https://doi.org/10.1093/annhyg/meu073

Steadman, R. G. (1984). A universal scale of apparent temperature. *Journal of Climate and Applied Meteorology, 23*(12), 1674-1687. https://doi:10.1175/1520-0450(1984)023<1674:Ausoat>2.0.Co;2

Stoecklin-Marois, M., Hennessy-Burt, T., Mitchell, D., & Schenker, M. (2013). Heat-related illness knowledge and practices among California hired farm workers in the MICASA study. *Industrial Health, 51*(1), 47-55. https://doi.org/10.2486/indhealth.2012-0128

Takyi, S. A. (2014). Review of social impacts assessment (SIA): Approach, importance, challenges and policy implications. *International Journal of Arts & Sciences, 7*(5), 217.

Tanyanyiwa, V. I., & Kanyepi, T. (2015). Mixed Methods Research Strategies in Climate Change Adaptation in Mt Darwin District, Zimbabwe. *International Journal of Innovative Research and Development|| ISSN 2278–0211, 4*(9).

Tashakkori, A., & Teddlie, C. (2010). *Sage handbook of mixed methods in social & behavioral research*: Sage.

Tashakkori, A., & Teddlie, C. (2011). Mixed methods research: Contemporary issues in an emerging field. *The Sage Handbook of Qualitative Research*, 285-300.

Tashakkori, A., Teddlie, C., & Teddlie, C. B. (1998). *Mixed methodology: Combining qualitative and quantitative approaches* (Vol. 46). Thousand Oaks, CA: Sage.

Tawatsupa, B., Lim, L. L., Kjellstrom, T., Seubsman, S.-a., Sleigh, A., & Team, T. C. S. (2010). The association between overall health, psychological distress, and occupational heat stress among a large national cohort of 40,913 Thai workers. *Global Health Action, 3*. https://doi.org/10.3402/gha.v3i0.5034

Tawatsupa, B., Lim, L. L., Kjellstrom, T., Seubsman, S.-a., Sleigh, A., & Team, T. C. S. (2012). Association between occupational heat stress and kidney disease among 37 816 workers in the Thai Cohort Study (TCS). *Journal of Epidemiology, 22*(3), 251-260. https://doi.org/10.2188/jea.JE20110082

Tawatsupa, B., Yiengprugsawan, V., Kjellstrom, T., Berecki-Gisolf, J., Seubsman, S. A., & Sleigh, A. (2013). Association between heat stress and occupational injury among Thai workers: findings of the Thai Cohort Study. *Industrial Health, 51*(1), 34-46. https://doi.org/10.2486/indhealth.2012-0138

Tabari, H., Taye, M. T., & Willems, P. (2015). Statistical assessment of precipitation trends in the upper Blue Nile River basin. *Stochastic Environmental Research and Risk Assessment, 29*(7), 1751-1761. https://doi:10.1007/s00477-015-1046-0

Teddlie, C., & Tashakkori, A. (2012). Common "core" characteristics of mixed methods research: A review of critical issues and call for greater convergence. *American Behavioral Scientist, 56*(6), 774-788.

Tenkorang, E. Y., & Osei-Kufuor, P. (2014). The Impact of Gold Mining on Local Farming Communities in Ghana. *Journal of Global Initiatives: Policy, Pedagogy, Perspective, 8*(1), 3.

Teye, J. K. (2012). Benefits, challenges, and dynamism of positionalities associated with mixed methods research in developing countries: Evidence from Ghana. *Journal of Mixed Methods Research, 6*(4), 379-391. https://doi:10.1177/1558689812453332

Thomas, A., & Benjamin, L. (2018). Perceptions of climate change risk in The Bahamas. *Journal of Environmental Studies and Sciences, 8*(1), 63-72. https://doi.org/10.1007/s13412-017-0429-6

Tripathi, A., & Mishra, A. K. (2017). Knowledge and passive adaptation to climate change: An example from Indian farmers. *Climate Risk Management, 16*, 195-207. https://doi:10.1016/j.crm.2016.11.002

Turnbull, D. (2002). Performance and narrative, bodies and movement in the construction of places and objects, spaces and knowledge - The case of the Maltese megaliths. *Theory Culture & Society, 19*(5-6), 125-+. https://doi:10.1177/026327602761899183

UNICEF. (2012). *Integrated social protection systems: enhancing equity for children*. Retrieved from New York: https://www.unicef.org/socialpolicy/files/Presentation_Jennifer_Yablonski_UNICEF__20_Feb_2012.pdf

United Nations (UN). (2015). *Transforming our world: The 2030 agenda for sustainable development*. New York: United Nations https://sustainabledevelopment.un.org/post2015/transformingourworld

United Nations (UN)Press release. (2009). *Transcript of press conference by Secretary-General Ban Ki-moon at United Nations Headquarters, January 12 [Press release]*. Retrieved from http://www.un.org/press/en/2009/sgsm12044.doc.htm

United Nations Framework Convention on Climate Change (UNFCCC) (2010). *United Nation Framework Convention on Climate Change: Full Text of the Convention*. United Nation Framework Convention on Climate Change. Bonn. Retrieved from http://unfccc.int/essential_background/convention/background/items/2536.php

United Nations Framework Convention on Climate Change (UNFCCC). (2006). *United Nations Framework Convention on Climate Change: Handbook* (D. Blobel & N. Meyer-Ohlendorf Eds.). Bonn, Germany: United Nations Framework Convention on Climate Change (UNFCCC).

United Nations (UN). (2011). *The social dimensions of climate change: Discussion draft*. Geneva. Retrieved on 23/10/2017 from https://www.iom.int/jahia/webdav/shared/shared/mainsite/activities/env_degradation/cop17/SDCC-Social-dimensions-of-climate-change-Paper.pdf

van Oldenborgh, G. J., Philip, S., Kew, S., van Weele, M., Uhe, P., Otto, F., . . . AchutaRao, K. (2018). Extreme heat in India and anthropogenic climate change. *Natural Hazards and Earth System Sciences, 18*(1), 365-381. https://doi:10.5194/nhess-18-365-2018

Vanclay, F. (2003). International principles for social impact assessment. *Impact Assessment and Project Appraisal, 21*(1), 5-12. https://doi.org/10.3152/147154603781766491

Vanclay, F. (2004). The Triple Bottom Line and Impact Assessment: How Do Tbl, Eia, Sia, Sea and Ems Relate to Each Other? *Journal of Environmental Assessment Policy and Management, 06*(03), 265-288. doi:10.1142/s1464333204001729

Vanclay, F. (2006). Principles for social impact assessment: A critical comparison between the international and US documents. *Environmental Impact Assessment Review, 26*(1), 3-14. doi:10.1016/j.eiar.2005.05.002

Vanclay, F., & Esteves, A. M. (2011). *New directions in social impact assessment: conceptual and methodological advances*: Edward Elgar Publishing.

Vanclay, F., Esteves, A. M., Aucamp, I., & Franks, D. M. (2015). *Social Impact Assessment: Guidance for Assessing and Managing the Social Impacts of Projects.* Fargo ND: International Association for Impact Assessment. https://espace.library.uq.edu.au/data/UQ_355365/UQ355365.pdf?

Varghese, B. M., Hansen, A., Bi, P., Pisaniello, D., 2018. Are workers at risk of occupational injuries due to heat exposure? A comprehensive literature review. *Safety Science*. https://doi.org/10.1016/j.ssci.2018.04.027

Venugopal, V., Chinnadurai, J. S., Lucas, R. A. I., & Kjellstrom, T. (2016b). Occupational heat stress profiles in selected workplaces in India. *International Journal of Environmental Research and Public Health, 13*(1), 1-13. http://dx.doi.org/10.3390/ijerph13010089

Venugopal, V., Chinnadurai, J. S., Lucas, R. A., & Kjellstrom, T. (2015). Occupational heat stress profiles in selected workplaces in India. *Int J Environ Res Public Health, 13*(1), 1-13. https://doi:10.3390/ijerph13010089

Venugopal, V., Chinnadurai, J., Lucas, R., Vishwanathan, V., Rajiva, A., & Kjellstrom, T. (2016a). The social implications of occupational heat stress on migrant workers engaged in public construction: A case study from Southern India. *International Journal of the Constructed Environment*, *7*(2). https://doi.org/10.18848/2154-8587/CGP/v07i02/25-36

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., . . . Pritchard, R. (2002). Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation ecology, 6*(1).

Webb, E. J., Campbell, D. T., Schwartz, R. D., & Sechrest, L. (1999). *Unobtrusive measures* (Vol. 2): Sage Publications.

Wesseling, C., Crowe, J., Hogstedt, C., Jakobsson, K., Lucas, R., & Wegman, D. (2013). Mesoamerican nephropathy: a report from the first international research workshop on men.http://repositorio.una.ac.cr/bitstream/handle/11056/8584/seriesaludytrabajo10.pdf?sequence=1&tnqh_x0026;isAllowed=y

White, G. (2011). *Climate change and migration: security and borders in a warming world*: Oxford University Press

Wilbanks, T. J. (2002). Geographic scaling issues in integrated assessments of climate change. *Integrated Assessment*, *3*(2-3), 100-114.

Wolf, C. (1975). Social Impact Assessment. Test Edition. AAAS Study Guides on Contemporary Problems.

World Bank. (2012). *Resilience, equity, and opportunity: the World Bank's social protection and labour strategy 2012-2022* Retrieved from Washington, DC: http://documents.worldbank.org/curated/en/443791468157506768/Resilience-equity-and-opportunity-the-World-Banks-social-protection-and-labor-strategy-2012-2022

World Meteorological Organization (WMO) & World Health Organization(WHO). (2015). *Heat waves and health: Guidance on warning-system development*. Geneva. Retrieved on 11/12/2016 from http://www4.unfccc.int/nap/Country%20Documents/General/HeatWavesandHealthGuidance_26July2010.pdf

Wyndham, C. (1994). A survey of the causal factors in heat stroke and of their prevention in the gold mining industry. *Journal of the South African Institute of Mining and Metallurgy, 94*(3), 165-188.

Wyon, D. P., Wyon, I., & Norin, F. (1996). Effects of moderate heat stress on driver vigilance in a moving vehicle. *Ergonomics, 39*(1), 61-75. https://doi:10.1080/00140139608964434

Xiang, J., Bi, P., Pisaniello, D., & Hansen, A. (2014a). Health impacts of workplace heat exposure: an epidemiological review. *Ind Health, 52*(2), 91-101. https://doi.org/10.2486/indhealth.2012-0145

Xiang, J., Bi, P., Pisaniello, D., & Hansen, A. (2014b). The impact of heatwaves on workers' health and safety in Adelaide, South Australia. *Environmental Research, 133*, 90-95. https://doi.org/10.1016/j.envres.2014.04.042

Xiang, J., Bi, P., Pisaniello, D., Hansen, A., & Sullivan, T. (2014c). Association between high temperature and work-related injuries in Adelaide, South Australia, 2001–2010. *Occupational and Environmental Medicine, 71*(4), 246-252. http://dx.doi.org/10.1136/oemed-2013-101584

Xiang, J., Hansen, A., Pisaniello, D., & Bi, P. (2015a). Extreme heat and occupational heat illnesses in South Australia, 2001–2010. *Occupational and Environmental Medicine*, 72, pp. 580-586 http://dx.doi.org/10.1136/oemed-2014-102706

Xiang, J., Hansen, A., Pisaniello, D., & Bi, P. (2015b). Perceptions of Workplace Heat Exposure and Controls among Occupational Hygienists and Relevant Specialists in Australia. *PloS One, 10*(8), https://doi:10.1371/journal.pone.0135040

Xiang, J., Hansen, A., Pisaniello, D., & Bi, P. (2016). Workers' perceptions of climate change related extreme heat exposure in South Australia: A cross-sectional survey. *BMC Public Health, 16*(1), 549. https://doi:10.1186/s12889-016-3241-4

Xue, L., Weng, L. F., & Yu, H. Z. (2018). Addressing policy challenges in implementing Sustainable Development Goals through an adaptive governance approach: A view from transitional China. *Sustainable Development, 26*(2), pp. 150-158. https://doi.org/10.1002/sd.1726

Yanchar, S. C., & Williams, D. D. (2006). Reconsidering the compatibility thesis and eclecticism: Five proposed guidelines for method use. *Educational Researcher, 35*(9), 3-12.

Yaro, J. A. (2013). The perception of and adaptation to climate variability/change in Ghana by small-scale and commercial farmers. *Regional Environmental Change, 13*(6), 1259-1272. https://doi:10.1007/s10113-013-0443-5

Yates, F. (1934). Contingency tables involving small numbers and the χ 2 test. *Supplement to the Journal of the Royal Statistical Society, 1*(2), pp. 217-235. http://www.jstor.org/citation/info/10.2307/2983604

Zander, K. K., Botzen, W. J., Oppermann, E., Kjellstrom, T., & Garnett, S. T. (2015). Heat stress causes substantial labour productivity loss in Australia. *Nature Climate Change, 5*(7), 647. https://www.nature.com/articles/nclimate2623doi:10.1038/nclimate2623

Zander, K. K., Moss, S. A., & Garnett, S. T. (2017). Drivers of self-reported heat stress in the Australian labour force. *Environ Res, 152*, pp. 272-279. https://doi.org/10.1016/j.envres.2016.10.029

Zinn, J. (2008). *Social theories of risk and uncertainty: an introduction*: Wiley Online Library.

APPENDICES

APPENDIX A: SUPPLEMENTARY MATERIALS

APPENDIX A1: Supplementary data (Tables 1 to 27 and Figures 1 to 8) which is related to the article in chapter two can be found in the online version at: https://doi.org/10.1016/j.scitotenv.2018.06.255

APPENDIX A2: Supplementary data (Tables 1 to 25 and Figures 1 to 11) which is contained in the article in chapter three can be found online at: https://static-content.springer.com/esm/art%3A10.1007%2Fs00484-019-01775-1/MediaObjects/484_2019_1775_MOESM1_ESM.docx

APPENDIX A3: Supplementary data (Tables 1 to 39) associated with this article in chapter five can be found in the online version at https://doi:10.1016/j.envres.2018.11.004

APPENDIX B: ETHICS APPROVAL

HUMAN RESEARCH ETHICS COMMITTEE

For all queries, please contact:
Research Ethics Office
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: 6304 2170
Fax: 6304 5044
Email: research.ethics@ecu.edu.au

OFFICE OF RESEARCH AND INNOVATION
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

21 August 2019

Mr Victor Nunfam
School of Arts and Humanities
JOONDALUP CAMPUS

Dear Victor,

ETHICS APPROVAL

Project Code:	17487 NUNFAM	
Project title:	SOCIAL IMPACTS OF CLIMATE CHANGE AND OCCUPATIONAL HEAT STRESS AND ADAPTATION STRATEGIES OF MINING WORKERS IN GHANA	
Chief investigator	Mr Victor Nunfam	
Supervisors	Dr Kwadwo Adusei-Asante, Prof Jacques Oosthuizen, Dr Eddie van Etten, Dr Kwasi Frimpong	
Approval Dates:	From: 16th August 2016	To: 11th June 2019

This application was reviewed by members of the Human Research Ethics Committee (HREC).

The proposal complied with the provisions contained in the University's policy for the conduct of ethical human research and ethics approval was granted. In granting approval, the HREC determined that the research project met the requirements of the National Statement on Ethical Conduct in Human Research.

All research projects are approved subject to general conditions of approval. Please see the attached document for details of these conditions, which include monitoring requirements, changes to the project and extension of ethics approval.

Yours sincerely

Kim Gifkins

SENIOR RESEARCH ETHICS ADVISOR

Conditions of approval

1. Monitoring of Approved Research Projects

Monitoring is the process of verifying that the conduct of research conforms to the approved ethics application. Compliance with monitoring requirements is a condition of approval.

The *National Statement on Ethical Conduct in Human Research* indicates that institutions are responsible for ensuring that research is reliably monitored. Monitoring of approved projects is to establish that a research project is being, or has been, conducted in the manner approved by the Ethics Committee. Researchers also have a significant responsibility in monitoring, as they are in the best position to observe any adverse events or unexpected outcomes. They should report such events or outcomes promptly to the Ethics Committee and take prompt steps to deal with any unexpected risks.

All projects approved by an ECU Ethics Committee are approved subject to the following conditions of approval:

- If the research project is discontinued before the expected date of completion, researchers should inform the Ethics Committee as soon as possible, giving reasons.
- An annual report (for projects that are longer than one year) and a final report at the completion of the research will be provided to the Ethics Committee. You will also be notified when a report is due. The ethics report form can be found on the ethics website http://intranet.ecu.edu.au/research/research-ethics/human-ethics-applications/managing-your-ethics-approval
- Researchers must also immediately report anything that might warrant review of the ethical approval of the protocol, including:

Any serious or unexpected adverse effects on participants

Any unforeseen events that might affect continued ethical acceptability of the project.

The Ethics Committee retains the right to require a more detailed and/or more frequent report if the research is deemed to be of high risk, and to recommend and/or adopt any additional appropriate mechanism for monitoring including random inspections of research sites, data and signed consent forms, and/or interview, with their prior consent, of research participants.

2. Changes and amendments

Compliance with the approved research protocol is a condition of approval, and any changes to the research design must be reported to the Ethics Committee. Amendments to the research that may affect participants and/or that may have ethical implications must be reviewed and approved by the Ethics Committee before commencement.

Any changes to documents and other material used in recruiting potential research participants, including advertisements, letters of invitation, information sheets and consent forms, should be approved by the Ethics Committee.

In order to request approval for a change, please send an email to the Ethics Office outlining why the change is needed, describing the change (e.g. the new participants or new research procedures), and attach a copy of any amended documents.

3. Extension of ethics approval

All research projects are approved for a specified period of time – from the date of approval until the date of completion provided in the ethics application. If an extension of the approval period is required, a request must be submitted to the Ethics Committee. Please ensure that requests for extension of approval are submitted before the original approval expires.

In order to request an extension of ethics approval, please send an email to the Ethics Office providing a brief reason why the extension is needed and giving the new expected date of completion

APPENDIX C: LETTER OF CONSENT TO CONDUCT RESEARCH WITH MINING COMPANIES IN GHANA

MINERALS COMMISSION

MINERALS COMMISSION GHANA

12 Switchback Road Residential Area, Cantonments
P. O. Box M 248, Accra-Ghana
Tel: (233-302) 772783 / 772786 / 773053 / 771318 Fax : (233-302) 773324
E-mail: mincom@mc.ghanamining.org
Website: www.ghana-mining.org

Our Ref: MC. 10

November 03, 2016

Victor Fannam Nunfam
Edith Cowan University
School of Arts and Humanities
270 Joondalup Drive
Joondalup, WA 6028

Dear Sir,

RE: REQUEST TO CONDUCT RESEARCH

We write in reference to your letter on the above subject dated September 06, 2016.

Please be informed that the Minerals Commission gives its consent to Mr. Victor Fannam Nunfam (a PhD candidate of the Edith Cowan University) to conduct research on the "Impact of Heat Stress on Outdoor Mining Workers in Developing Countries with Emphasis on Ghana".

The Minerals Commission has no intellectual property stake in the research project and agrees for Ghana's mining industry to be a study scope only to support this research and to have access to the aggregate results.

Should the researcher provide details of mine sites to be surveyed and timelines, the Commission will not hesitate to inform local mine management of this upcoming research project, and that mine employee participation is entirely voluntary.

Yours Sincerely

DR.TONI AUBYNN
(CHIEF EXECUTIVE OFFICER)

Cc:
Associate Professor Jacques Oothuizen, Principal Supervisor
Dr. Kwadwo Edusei-Asante, Co-Principal Supervisor
Dr. Eddie Van Etten, Co-Supervisor
Dr. Kwasi Frimpong, Co-Supervisor

APPENDIX D: INFORMATION SHEETS FOR PARTICIPANTS

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX D1: INFORMATION SHEET FOR MINING COMPANIES

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

Invitation to participate in a study

My name is Victor Fannam Nunfam and a PhD candidate at the School of Arts and Humanities, Edith Cowan University in Australia. I am interested in understanding mining workers' thoughts and experiences of the risk and effect of working in hot weather conditions on their health and safety, capacity to work and social life. With your permission, I will like to seek the consent of the mining workers in your company to fill out a survey questionnaire or take part in a focus group to discuss their views and experiences of working in hot conditions. The survey questionnaire will not take more than 25 minutes to complete while the focus group will take not more than 60 minutes to discuss. The information provided will help understand the views of mining workers about the risk and effect of working in hot weather conditions and how to prevent, reduce or adjust to such effects. For this reason, mining companies like you can contribute to the improvement the project is likely to make in reducing mining workers' exposure to hot weather conditions while working. In order to safeguard the privacy of the mining company, its name will be changed when the information is being shared with anyone other than the research team.

Even though all their responses will be kept confidential, the information will only be shared among the research team during the project. After the project is completed, a summary of the findings will be shared with management of the mining company where they work. Should any publication arise from this study measures would be put in place to de-identify the company and the workers.

Please be aware that taking part in the survey is not compulsory. Your company can withdraw from this study at any time without any penalty. Should you have any concerns or queries, you are welcome to contact any member of the research team, local contact persons or the Human Research Ethics Committee of ECU in Australia as listed in Table 1.

Table 1: List of contact persons

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam School of Arts and Humanities, ECU, Australia Email: vnunfam@our.ecu.edu.au Tel: +61 405548063| +233 244793018	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au
Local contact person:	**Human Research Committee:**
Dr Norbert Adja Kwabena Adjei, Senior Research Fellow at the KAAF University College, Ghana; Email: nakaliason@yahoo.com; Tel: +233 244-839 636	Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au; Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX D2: INFORMATION SHEET FOR MINING WORKERS

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

Invitation to participate in a study

My name is Victor Fannam Nunfam and a PhD candidate at the School of Arts and Humanities, Edith Cowan University in Australia. I am interested in understanding your thoughts and experiences of the risk and effect of working in hot conditions on your health, safety, capacity to work and social life. With your permission, I will like you to fill out a survey questionnaire or take part in a focus group to discuss your views and experiences of working in hot weather conditions. The survey questionnaire will take not more than 25 minutes to complete. Please print clearly while filling out the survey. The focus group will take not more than 60 minutes to discuss. Be informed that during the discussion, I will be asking you additional questions in order to understand what you exactly mean. With your permission, I will interview either your partner or older child above 18 years to understand how the hot weather conditions affect your social interaction with them at home. This interview will last not more than 30minutes at a venue and time convenient to them. The information provided will help understand the views and concerns of mining workers and their family members about the risk and effect of working in hot weather conditions and how to prevent, reduce or adjust to such effects. For this reason, mining workers like you can contribute to the improvement the project is likely to make in reducing mining workers' exposure to hot conditions while working.

Because the discussion is being audiotaped, I will need your voice to be loud and clear when responding to my questions. Even though all your responses will be kept confidential, the information will only be shared among the research team during the project. After the project is completed, a summary of the findings will be shared with management of the mining company where you work. Should any publication arise from the study your name or identity will not be mentioned. In order to safeguard your privacy, you and your family member's name will be changed when the information is being shared with anyone other than the research team.

Your responses will be written down and you will be given a copy to confirm whether I have accurately written down what you meant to say. Please be aware that taking part in the survey or focus group is not compulsory. You can respond to all the questions or even refuse to continue with the discussion and withdraw any data already collected at any time you want without any penalty. You are also free and welcome to contact any member of the research team, local contact persons or the Human Research Ethics Committee of ECU in Australia as listed in Table 1.

Table 1: List of contact persons

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam School of Arts and Humanities, ECU, Australia Email: vnunfam@our.ecu.edu.au Tel: +61 405548063| +233 244793018	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au
Local contact person:	**Human Research Committee:**
Dr Norbert Adja Kwabena Adjei, Senior Research Fellow at the KAAF University College, Ghana; Email: nakaliason@yahoo.com; Tel: +233 244 839 636	Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au; Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX D3: INFORMATION SHEET FOR SUPERVISORY PERSONNEL OF MINING COMPANIES

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

Invitation to participate in a study

My name is Victor Fannam Nunfam and a PhD candidate at the School of Arts and Humanities, Edith Cowan University in Australia. I am interested in understanding your thoughts and experiences of the risk and effect of working in hot weather conditions on mining workers' health and safety, capacity to work and social life. With your permission, I will like you to fill out a survey questionnaire. The survey questionnaire will not take more than 25 minutes to complete. Please print clearly while filling out the survey. The information provided will help understand the views of mining workers about the risk and effect of working in hot weather conditions and how to prevent, reduce or adjust to such effects.

Even though all your responses will be kept confidential, the information will only be shared among the research team during the project. After the project is completed, a summary of the findings will be shared with management of the mining company where you work. Should any publication arise from the study your name or identity will not be mentioned. For this reason, mining workers like you can contribute to the improvement the project is likely to make in reducing mining workers' exposure to hot conditions while working. In order to safeguard your privacy, you and your family member's name will be changed when the information is being shared with anyone other than the research team.

Please be aware that taking part in the survey is by will and not force. You can respond to all the questions or even refuse to continue and withdraw any data already collected at any time you want without any problems. You are also free and welcome to contact any member of the research team, local contact persons or the Human Research Ethics Committee of ECU in Australia listed in Table 1 for further information or questions:

Table 2: List of contact persons

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam School of Arts and Humanities, ECU, Australia Email: vnunfam@our.ecu.edu.au Tel: +61 405548063|+233 244793018	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au
Local contact person:	**Human Research Committee:**
Dr Norbert Adja Kwabena Adjei, Senior Research Fellow at the KAAF University College, Ghana; Email: nakaliason@yahoo.com; Tel: +233 244 839 636	Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au; Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX D4: INFORMATION SHEET FOR GCM

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

Invitation to participate in a study

My name is Victor Fannam Nunfam and a PhD candidate at the School of Arts and Humanities, Edith Cowan University in Australia. I am interested in understanding your thoughts and experiences of regulations governing the risk and effect that working in hot weather conditions has on mining workers' health, safety, capacity to work and their social life. With your permission, I will like you to share your views and experiences about the regulations on the risk and effect of working in hot weather conditions on the health and safety, working capacity and social life of mining workers in an interview. The interview session will take not more than 30 minutes. Be informed that during the interview, I will be asking you additional questions in order to understand what you exactly mean. The information provided will help understand the regulations on concerns of mining workers about the risk and effect of working in hot weather conditions and how to prevent, reduce or adjust to such effects. For this reason, officials of the GCM like you can contribute to the improvement the project is likely to make in reducing mining workers' exposure to hot conditions while working by regulation. Because the interview is being audiotaped, I will need your voice to be loud and clear when responding to my questions.

Even though all your responses will be kept confidential, the information will only be shared among the research team during the project. After the project is completed, a summary of the findings will be shared with management of the GCM where you work. Should any publication arise from the study your name or identity will not be mentioned. In order to safeguard your privacy, your name will be changed when the information is being shared with anyone other than the research team.

Your responses will be written down and you will be given a copy to confirm whether I have accurately written down what you meant to say. Please be aware that taking part in the interview is by will and not compulsory. You can respond to all the questions or even refuse to continue with the interview and withdraw any data already collected at any time you want without any penalty. You are also free and welcome to contact any member of the research team, local contact persons or the Human Research Ethics Committee of ECU in Australia as listed in Table 1.

Table 1: List of contact persons

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam School of Arts and Humanities, ECU, Australia Email: vnunfam@our.ecu.edu.au Tel: +61 405548063| +233 244793018	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au
Local contact person:	**Human Research Committee:**
Dr Norbert Adja Kwabena Adjei, Senior Research Fellow at the KAAF University College, Ghana; Email: nakaliason@yahoo.com; Tel: +233 244839 636	Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au; Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX D4: INFORMATION SHEET FOR IDMC

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

Invitation to participate in a study

My name is Victor Fannam Nunfam and a PhD candidate at the School of Arts and Humanities, Edith Cowan University in Australia. I am interested in understanding your thoughts and experiences of regulations governing the risk and effect that working in hot weather conditions has on mining workers' health, safety, capacity to work and social life. With your permission, I will like you to share your views and experiences about the regulations on the risk and effect of working in hot conditions on the health and safety, working capacity and social life of mining workers in an interview. The interview session will take not more than 30 minutes. Be informed that during the interview, I will be asking you additional questions in order to understand what you exactly mean. The information provided will help understand the regulations on concerns of mining workers about the risk and effect of working in hot weather conditions and how to prevent, reduce or adjust to such effects. For this reason, officials of the IDMC like you can contribute to the improvement the project is likely to make in reducing mining workers' exposure to hot conditions while working by regulation. Because the interview is being audiotaped, I will need your voice to be loud and clear when responding to my questions.

Even though all your responses will be kept confidential, the information will only be shared among the research team during the project. After the project is completed, a summary of the findings will be shared with management of the IDMC where you work. Should any publication arise from the study your name or identity will not be mentioned. In order to safeguard your privacy, your name will be changed when the information is being shared with anyone other than the research team.

Your responses will be written down and you will be given a copy to confirm whether I have accurately written down what you meant to say. Please be aware that taking part in the interview is by will and not compulsory. You can respond to all the questions or even refuse to continue with the interview at any time you want without any penalty. You are also free and welcome to contact any member of the research team, local contact persons or the Human Research Ethics Committee of ECU in Australia as listed in Table 1.

Table 1: List of contact persons

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam School of Arts and Humanities, ECU, Australia Email: vnunfam@our.ecu.edu.au Tel: +61 405548063 | +233244793018	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au
Local contact person:	**Human Research Committee:**
Dr Norbert Adja Kwabena Adjei, Senior Research Fellow, KAAF University College, Ghana; Email: nakaliason@yahoo.com; Tel: +233 244 839 636	Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au; Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX D4: INFORMATION SHEET FOR GNASSM

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

Invitation to participate in a study

My name is Victor Fannam Nunfam and a PhD candidate at the School of Arts and Humanities, Edith Cowan University in Australia. I am interested in understanding your thoughts and experiences of regulations governing the risk and effect that working in hot weather conditions has on mining workers' health, safety, capacity to work and their social life. With your permission, I will like you to share your views and experiences about the regulations on the risk and effect of working in hot weather conditions on the health and safety, working capacity and social life of mining workers in an interview. The interview session will take not more than 30 minutes. Be informed that during the interview, I will be asking you additional questions in order to understand what you exactly mean. The information provided will help understand the regulations on concerns of mining workers about the risk and effect of working in hot weather conditions and how to prevent, reduce or adjust to such effects. For this reason, officials of the GNASSM like you can contribute to the improvement the project is likely to make in reducing mining workers' exposure to hot conditions while working by regulation. Because the interview is being audiotaped, I will need your voice to be loud and clear when responding to my questions.

Even though all your responses will be kept confidential, the information will only be shared among the research team during the project. After the project is completed, a summary of the findings will be shared with management of the GNASSM where you work. Should any publication arise from the study your name or identity will not be mentioned. In order to safeguard your privacy, your name will be changed when the information is being shared with anyone other than the research team.

Your responses will be written down and you will be given a copy to confirm whether I have accurately written down what you meant to say. Please be aware that taking part in the interview is by will and not compulsory. You can respond to all the questions or even refuse to continue with the interview and withdraw any data already collected at any time you want without any penalty. You are also free and welcome to contact any member of the research team, local contact persons or the Human Research Ethics Committee of ECU in Australia as listed in Table 1.

Table 1: List of contact persons

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam School of Arts and Humanities, ECU, Australia Email: vnunfam@our.ecu.edu.au Tel: +61 405548063 | +233 244793018	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au
Local contact person:	**Human Research Committee:**
Dr Norbert Adja Kwabena Adjei, Senior Research Fellow at the KAAF University College, Ghana; Email: nakaliason@yahoo.com; Tel: +233 244839 636	Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au; Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

APPENDIX E: INFORMED CONSENT FORMS FOR PARTICIPANTS

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX E1: INFORMED CONSENT FORM FOR MINING COMPANIES

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

By signing this consent form, I declare that the researcher has explained the study to me and I have also read the information sheet. I therefore willingly decided to permit mining workers in this company to fill out a survey questionnaires or take part in a focus group and all their responses will be tape recorded. I understand that the workers will be giving information about the risk and impact of working in hot weather conditions on mine workers' health, safety, productivity, and social well-being, and their strategies of coping or adjusting to such conditions. I understand that the workers will share their views or experiences by either filling out a survey questionnaire that will take not more than 25 minutes or take part in focus group that will take not more than 60 minutes. I understand that all their responses will be kept confidential and only be shared among the research team. I also understand that under no circumstance will the name of the company or the names or identity or the mining workers be mentioned in the final results of the research or in any publication arising from the research. I have been made aware that should the company or workers suffer from any risk of time inconvenience or breach of privacy as a result of sharing information, the company or workers have the right to complain to any of the local contact persons or research team who are readily available. I have the contact details of the research team and independent persons and I am welcome to contact them anytime should I have any questions or concerns about this study. I understand that my participation in this study is not compulsory and I can withdraw my consent anytime I wish without any penalty.

Contact:

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au
School of Arts and Humanities, ECU,	Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au
Australia	Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au
Email: vnunfam@our.ecu.edu.au	Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au
Tel: +61 405548063| +233 244793018	

NOTE: Before signing this consent form, please read a copy of the information sheet attached

Research participant’s signature: …………………………………………… Date: ………..…
Contact number: ……………………………………. Email: ………………………………
Chief investigator’s signature: ……………………………………………… Date: …………

For further concerns, please contact:

Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au; Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX E2: INFORMED CONSENT MINING WORKERS

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

By signing this consent form, I declare that the researcher has explained the study to me and I have also read the information sheet. I therefore willingly decided to fill out a survey questionnaires or be interviewed and all my responses will be tape recorded. I understand that I will be giving information about the risk and impact of working in hot weather conditions on mine workers' health, safety, productivity, and social well-being, and their strategies of coping or adjusting to such conditions. I understand that I will share my views or experiences by either filling out a survey questionnaire that will take not more than 25 minutes or take part in focus group that will take not more than 60 minutes. That the discussion will be audiotaped and I need to speak loudly and clearly. I understand that all my responses will be kept confidential and only be shared among the research team. I also understand that under no circumstance will my name or identity be mentioned in the final results of the research or in any publication arising from the research. I have been made aware that should I suffer from the risk of breach of privacy and time inconvenience as a result of sharing information, I have the right to complain to any of the local contact persons or research team who are readily available for me. I have the contact details of the research team and independent persons and I am welcome to contact them anytime should I have any questions or concerns about this study. I understand that my participation in this study is not by force and I can end the interview anytime I wish without any penalty.

Contact:

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au
School of Arts and Humanities, ECU,	Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au
Australia	Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au
Email: vnunfam@our.ecu.edu.au	Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au
Tel: +61 405548063| +233 244793018	

NOTE: Before signing this consent form, please read a copy of the information sheet attached

Research participant’s signature: …………………………………………… Date: ………..…
Contact number: ……………………………………. Email: ………………………………
Chief investigator’s signature: ……………………………………………… Date: …………

For further concerns, please contact:
Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au;
Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |
Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX E3: INFORMED CONSENT FORM FOR SUPERVISORY PERSONNEL

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

By signing this consent form, I declare that the researcher has explained the study to me and I have also read the information sheet. I therefore willingly decided to fill out a survey questionnaire. I understand that I will be giving information about how I am affected while working in hot weather conditions. I understand that I will share my views or experiences by filling out a questionnaire that will be provided by the researcher. I am aware that it will take not more than 25 minutes to complete the survey questionnaire. I understand that all my responses will be kept confidential and only shared among the research team. I also understand that under no circumstance will my name or family member's (spouse or adult child) name be mentioned in the final results of the research or in any publication arising from the research. I have been made aware that should I suffer from any risk of time inconvenience or breach of privacy as a result of sharing information, I have the right to complain to any of the local contact persons or research team who are readily available for me. I have the contact details of the research team and independent persons and I am welcome to contact them anytime should I have any questions or concerns about this study. I understand that my participation in this study is not compulsory and I can stop completing the questionnaire anytime I wish without any penalty.

Contact:

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au
School of Arts and Humanities, ECU	Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au
Email: vnunfam@our.ecu.edu.au	Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au
Tel: +61 405548063| +233 244793018	Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au

NOTE: Before signing this consent form, please read a copy of the information sheet attached

Research participant's signature: …………………………………………… Date: ………..……
Contact number: ………………………………… Email: ……………………………………
Chief investigator's signature: …………………………………………… Date: ………………..

For further concerns, please contact:

Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au; Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX E4: INFORMED CONSENT FORM FOR GCM

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

By signing this consent form, I declare that the researcher has explained the study to me and I have also read the information sheet. I therefore willingly decided to be interviewed and all my responses will be tape recorded. I understand that I will be giving information about mining regulations on risk and impact of working in hot weather conditions on mine workers' health, safety, productivity, and social well-being, and their strategies of coping or adjusting to such conditions. I understand that I will share my views or experiences in an interview by the researcher that will take not more than 30 minutes. I understand that all my responses will be kept confidential and only be shared among the research team. I also understand that under no circumstance will my name or identity be mentioned in the final results of the research or in any publication arising from the research. I have been made aware that should I suffer from any risk of time inconvenience or breach of privacy as a result of sharing information, I have the right to complain to any of the local contact persons or research team who are readily available for me. I have the contact details of the research team and independent persons and I am welcome to contact them anytime should I have any questions or concerns about this study. I understand that my participation in this study is not compulsory and I can end the interview anytime I wish without any penalty.

Contact:

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au
School of Arts and Humanities, ECU	Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au
Email: vnunfam@our.ecu.edu.au	Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au
Tel: +61 405548063| +233 244793018	Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au

NOTE: Before signing this consent form, please read a copy of the information sheet attached

Research participant's signature: …………………………………………… Date: ………..…

Contact number: …………………………………… Email: ……………………………….

Chief investigator's signature: ……………………………………………… Date: …………

For further concerns, please contact:

Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University,

270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au;

Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX E5: INFORMED CONSENT FORM FOR IDMC

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

By signing this consent form, I declare that the researcher has explained the study to me and I have also read the information sheet. I therefore willingly decided to be interviewed and all my responses will be tape recorded. I understand that I will be giving information about mining regulations on risk and impact of working in hot weather conditions on mine workers' health, safety, productivity, and social well-being, and their strategies of coping or adjusting to such conditions. I understand that I will share my views or experiences in an interview by the researcher that will take not more than 30 minutes. I understand that all my responses will be kept confidential and only be shared among the research team. I also understand that under no circumstance will my name or identity be mentioned in the final results of the research or in any publication arising from the research. I have been made aware that should I suffer from any risk of time inconvenience or breach of privacy as a result of sharing information, I have the right to complain to any of the local contact persons or research team who are readily available for me. I have the contact details of the research team and independent persons and I am welcome to contact them anytime should I have any questions or concerns about this study. I understand that my participation in this study is not compulsory and I can end the interview anytime I wish without any penalty.

Contact:

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au
School of Arts and Humanities, ECU	Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au
Email: vnunfam@our.ecu.edu.au	Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au
Tel: +61 405548063| +233 244793018	Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au

NOTE: Before signing this consent form, please read a copy of the information sheet attached

Research participant's signature: …………………………………………… Date: ………..…

Contact number: …………………………………… Email: ………………………………

Chief investigator’s signature: ……………………………………………… Date: …………

For further concerns, please contact:

Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au;

Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX E6: INFORMED CONSENT FORM FOR GNASSM

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

By signing this consent form, I declare that the researcher has explained the study to me and I have also read the information sheet. I therefore willingly decided to be interviewed and all my responses will be tape recorded. I understand that I will be giving information about mining regulations on risk and impact of working in hot weather conditions on mine workers' health, safety, productivity, and social well-being, and their strategies of coping or adjusting to such conditions. I understand that I will share my views or experiences in an interview by the researcher that will take not more than 30 minutes. I understand that all my responses will be kept confidential and only be shared among the research team. I also understand that under no circumstance will my name or identity be mentioned in the final results of the research or in any publication arising from the research. I have been made aware that should I suffer from any risk of inconvenience or breach of privacy as a result of sharing information, I have the right to complain to any of the local contact persons or research team who are readily available for me. I have the contact details of the research team and independent persons and I am welcome to contact them anytime should I have any questions or concerns about this study. I understand that my participation in this study is not compulsory and I can end the interview anytime I wish without any penalty.

Contact:

Chief Investigator/PhD Candidate:	**Co-investigators/Supervisors:**
Victor Fannam Nunfam	Dr Kwadwo Adusei-Asante; k.adusei@ecu.edu.au
School of Arts and Humanities, ECU,	Prof Jacques Oosthuizen; j.oosthuizen@ecu.edu.au
Australia	Dr Eddie van Etten, Email: e.van_etten@ecu.edu.au
Email: vnunfam@our.ecu.edu.au	Dr Kwasi Frimpong, Email: k.frimpong@ecu.edu.au
Tel: +61 405548063| +233 24793018	

NOTE: Before signing this consent form, please read a copy of the information sheet attached

Research participant's signature: …………………………………………… Date: ………..…

Contact number: ……………………………………. Email: ………………………………

Chief investigator's signature: ……………………………………………… Date: …………

For further concerns, please contact:

Kim Gifkins, Senior Research Ethics Advisor, Office of Research & Innovation, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027; Email: research.ethics@ecu.edu.au;

Tel: +61 08 6304 2170 | Fax: +61 08 6304 5044 |

Your interest and participation is appreciated

APPENDIX F: SURVEY QUESTIONNAIRES FOR PARTICIPANTS

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX F1: SURVEY QUESTIONNAIRE FOR MINING WORKERS

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

General instruction

- This is a survey being conducted by Edith Cowan University to assess the social impact of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana
- The survey is strictly for academic purpose. Respondents are assured of confidentiality. Participation in the survey is voluntary based on informed consent of the respondents
- Please answer each question as honestly as possible to the best of your perception and knowledge of risk associated with occupation heat exposure, social effect and adaptations
- Place a tick (√) in the bracket next to your preferred answer(s) and fill in the spaces where necessary.

Thank you very much for taking time to participate in this survey.

Contact person: Victor Fannam Nunfam; Email: vnunfam@our.ecu.edu.au;

Phone: +61405548063\+233244793018

Section A: Background characteristics of respondents

1. What is your sex?
   1. Male [ ] 2. Female [ ]
2. What is your formal level of education?
   1. No formal education [ ]
   2. Basic education [ ]
   3. Secondary education [ ]
   4. Tertiary education [ ]
   5. Other (specify)……………………...
3. How old are you?……………….years
4. What is your marital status?
   1. Single [ ]
   2. Married [ ]
   3. Divorced [ ]
   4. Separated [ ]
   5. Widowed [ ]
   6. Other (specify)………………………..
5. What is your family size? ……………….
6. How many years of working experience do you have in mining? …………..……
7. What is your main occupation in the mining company? ……………………......
8. How will you describe your workload?
   1. Light [ ]
   2. Moderate [ ]
   3. Heavy [ ]
   4. Very heavy [ ]
9. What time do you start work?...................
10. What time do you end work?....................
11. How many hours do you work per day?....

12. How many breaks do you have per working day and how long are each of these breaks?..
13. Which type of workplace environment do you mostly work?
    1. Completely outdoor [ ]
    2. Mostly outdoor [ ]
    3. Completely indoor [ ]
    4. Mostly indoor [ ]
14. To what extent is your job physically demanding and labour intensive? (e.g. digging or lifting or moving heavy load)
    1. Not at all [ ]
    2. A little [ ]
    3. Moderately [ ]
    4. Very much [ ]
15. Do you work around sources of heat (e.g. under the sunshine, machines, explosives, blasting, mechanical equipment, underground)? 1. Yes [ ] 2. No [ ]
16. If yes to question 15, how often?
    1. Never [ ]
    2. Not often [ ]
    3. Sometimes [ ]
    4. Often [ ]
    5. Always [ ]

Section B: Perceptions and experiences of risk associated with climate change and occupational heat stress and adaptation strategies

17. Are you aware of changes in climate conditions in your areas?
    1. Yes [ ] 2. No [ ]
18. If yes to question 17, what are the signs and effect of the changing patterns of climate conditions?
    1. Increase in temperature and hot environment [ ]
    2. Irregular rainfall and storms [ ]
    3. Frequent floods [ ]
    4. Prolong drought [ ]
    5. Rising sea levels [ ]
    6. Other (specify)……………………
19. To what extent are you concerned about the effect of climate change conditions?
    1. Not at all concerned [ ]
    2. A little concerned [ ]
    3. Moderately concerned [ ]
    4. Very much concerned [ ]
20. Do you consider mining workers at risk of workplace heat exposure due to climate change conditions?
    1. Yes [ ] 2. No [ ]
21. If yes to question 20, which of the following external/environmental factors influence the risk of workplace heat exposure of mining workers?
    1. How hot the air is around the workplace [ ]
    2. The amount of air moisture in the outdoor settings or workplaces [ ]
    3. Air speed\movement around the workplace [ ]
    4. Heat radiation from the sun and other sources around the workplace [ ]
    5. Other (specify) ……………………
22. Which of the following work-related factors influence the risk of mining workers to heat exposure?
    1. Type of physical workload [ ]
    2. The duration of working hours [ ]
    3. Type of protective clothing, e.g., overalls [ ]
    4. Access to cooling system, e.g., air conditions and fans [ ]
    5. Duration of break/rest hours [ ]
    6. Access to shade [ ]

7. Access to drinking water [ ]
8. Type of clothing [ ]
9. Other (specify) ……………………

23. To what extent are you concerned about workplace heat exposure and heat stress (heat-related illness & injuries)?
    1. Not at all concerned [ ]
    2. A little concerned [ ]
    3. Moderately concerned [ ]
    4. Very much concerned [ ]
24. Have you ever experienced any form of heat-related illness as a mining worker?
    1. Yes [ ] 2. No [ ]
25. If yes to question 24, which of the following heat-related illness did you experience?
    1. Excessive sweating [ ]
    2. Headaches [ ]
    3. Heat exhaustion/tiredness [ ]
    4. Heat cramps(pains) [ ]
    5. Heat rash [ ]
    6. Heat syncope (fainting) [ ]
    7. Admitted to hospital due to heat stroke [ ]
    8. Other (specify)……………………
26. Have you ever had any form of heat-related injury as a mining worker?
    1. Yes [ ] 2. No [ ]
27. If yes to question 26, how will you describe the injury?
    1. Minor [ ]
    2. Moderate [ ]
    3. Serious [ ]
    4. Severe [ ]
    5. Critical [ ]
28. If yes to question 26, which of the following injury concerns did you have?
    1. Burns from the sun[ ]
    2. Burns from hot objects/surfaces [ ]
    3. Falls, trips, and slips due to dizziness, fainting and fatigue [ ]
    4. Loss of grip and controls due to sweaty hands [ ]
    5. Being hit by objects [ ]
    6. Hitting objects [ ]
    7. Other (specify)…………………...
29. Have you ever witnessed any form of heat-related injury to another mining worker?
    1. Yes [ ] 2. No [ ]
30. If yes to question 29, which of the following types of injury concerns did you witness?
    1. Burns from the sun [ ]
    2. Burns from hot objects/surfaces [ ]
    3. Falls, trips, and slips due to dizziness, fainting and fatigue [ ]
    4. Loss of grip and controls due to sweaty hands [ ]
    5. Being hit by objects [ ]
    6. Hitting objects [ ]
    7. Other (specify)……………………
31. Are you aware of measures to prevent and control the effect of heat stress and climate change?
    1. Yes [ ]
    2. No [ ]
32. If yes to question 31, which action are you aware of in preventing and controlling heat stress and climate change?
    1. Drinking adequate water [ ]
    2. Using air conditions and fans [ ]
    3. Taking work breaks and resting in shades [ ]
    4. Wearing loose and light-coloured clothing [ ]
    5. Other (specify)……………………...

Section C: Social impact of heat stress on mining workers

33. The following describes the adverse effect of heat stress on occupational health & safety of mining workers. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following statements about how you are affected by heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3**-Undecided (U); **4**-Disagree (D); **5**-Strongly disagree

Physiological health and safety effect of heat stress on mining workers						
	Statement	SA	A	U	D	SD
a	Intensive physical mining work in hot weather conditions results in excessive sweating, headaches, and dizziness					
b	Doing mining work in hot weather conditions increases the risks of tiredness, weakness, and muscles cramps or body pains					
c	Excessive sweating as a result hot weather conditions during intensive mining work enhances the potential for heat rashes					
d	Excessive sweating due to heat exposure increases the risk of extreme thirst					
e	Intensive work in hot weather conditions enhance the risk of injuries such as heat burns from the sun or hot surfaces					
f	Fatigue, confusion and lack of concentration due to heat exposure during heavy mining work leads to heat-related injuries likes skin burns, bruises and cuts					
g	Loss of grip and control of mining equipment due to sweaty hands results in heat-related injuries like skin burns, bruises, and cuts					

h. Which other ways are your health and safety negatively affected by heat stress?

....

34. The following describes the behavioural and psychological adverse effect of heat stress on mining workers. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following statements about how you are affected by heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3**-Undecided (U); **4**-Disagree (D); **5**-Strongly disagree

Behavioural and psychological effect of heat stress on mining workers						
	Statement	SA	A	U	D	SD
a	Tiredness, weakness and muscle cramps due to high temperature slow down the pace of mining workers					
b	Physical fatigue and excessive sweating due to heat exposure affects the attentiveness and judgement of mining workers					
c	Thoughts of risk of accidents and injuries due to heat-related exhaustion reduced alertness and sense of understanding increase the fear and anxiety of mining workers					
d	Fatigue, weakness and lack of concentration due to intensive mining work in hot environment increase the need for work-rest hours for mine workers					
e	Mistakes/errors during work in hot weather conditions are due to lack of training and information on risk of heat exposure					

e. Which other ways are your behaviour, action, and attitude affected by heat stress?

....

35. The following describes the adverse effect of heat stress on economic productivity of mining workers. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following statements about how you are affected by heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3**-Undecided (U); **4**-Disagree (D); **5**-Strongly disagree

Economic productivity effect of heat stress on mining workers						
	Statement	SA	A	U	D	SD
a	Tiredness, weakness and muscle cramps due to intensive mining work in hot environment reduces productive capacity of mining workers					
b	Lack of concentration, confusion and coordination as result of heat exposure leads to loss of productive efficiency of mining workers					
c	Heat-related illness and injuries increase the risk of absenteeism of mining workers					
d	Absenteeism of mining workers due to heat-related illness and injuries result in loss of income and employment opportunities					
e	Work-rest regimes due to excessive heat exposure increase the risk of reducing productivity of mining workers					

f. Which other ways is your productive capacity negatively affected by heat stress?

....

36. The following describes the adverse effect of heat stress the social lives and well-being of mining workers. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following statements about how you are affected by heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3**-Undecided (U); **4**-Disagree (D); **5**-Strongly disagree

Social health effect of heat stress on mining workers						
	Statement	SA	A	U	D	SD
a	Heat-related illness and injuries increases the medical expenses of mining workers and their families					
b	Tiredness and excessive sweating due to intensive mining work in hot environment increase the risk of drinking alcohol and energy drinks as well as substance abuse					
c	Fatigue and weakness of mining workers due to intensive mining work in hot environment disrupts family life due to loss of leisure time					
d	Erosion of income due to increased medical expense as a result of heat-related illness and injuries of mining workers increase the risk of family education, health and cohesion					
e	Increased medical costs due to heat-related illness and injuries affect the social health and cohesion of mining workers and their family					
f	Increase irritation, exhaustion, and lack of concentration of mining workers due to workplace heat exposure increase the risk of poor interpersonal relationship with coworker, family and community					

g	Heat-related illness and loss of productivity due to workplace heat exposure influence the social well-being and cohesion of mining workers, their families, coworkers, and communities					
h	Workplace stress and frustration due to heat-related tiredness and illness influence alcoholism, smoking, substance abuse, and workplace and domestic violence					

g. Which other ways is your social life and well-being negatively affected by heat stress?

....

Section D: Adaptation strategies of workers to occupational heat stress.

37. The following statements describe mining workers' coping and adaptive behaviour in managing the effect of working in hot weather conditions. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following statements describing your coping and adaptive behaviour to heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3**-Undecided (U); **4**-Disagree (D); **5**-Strongly disagree

	Statement	SD	D	U	A	SA
a	Frequently drink lots of cool water before feeling thirsty					
b	Wear loose and light-coloured clothing while working in hot weather conditions					
c	Drink coffee, soft drinks, caffeinated energy drinks, and alcohol when working in hot environment and tired					
d	Take regular breaks away from hot conditions in a cooler or shaded area					
e	Used to working in the heat without any medication to cope with heat stress					
f	Use mechanical equipment to reduce the need for strenuous physical workload					
g	Plan and carry out heavy routine outdoor work during the early morning or evening hours or in shaded areas during hot weather					
h	Participate in training programmes on working safely in the heat					
i	Share unavoidable heavier jobs and rotate jobs on shift schedules					
j	Slow down work at my pace to meet hot weather conditions					
k	Use personal protective equipment like sunglasses, wide-brimmed hats and hand gloves during hot weather conditions					
l	Use cooling systems like air conditions and electric fans during hot weather conditions					
m	Live in a house designed to allow proper air flow and escape of heat through windows and roofs					

n. Which other ways do you cope and adapt to heat stress and climate change impacts?

....

o. Which of the following social protection measures enhance your coping and adaptive capacity to the effect of heat stress and climate change?

1. Work based health insurance scheme [ ]
2. National health insurance scheme [ ]

3. Compensation scheme [ ]
4. Social security and pension scheme [ ]
5. Minimum wage [ ]
6. Membership of labour union [ ]
7. Membership of credit union [ ]
8. Other (specify)…………………………………………………………………………..

Section F: Barriers to effective implementation of adaptation strategies to occupational heat stress

38. The following statements describe barriers to effective implementation of adaptation strategies to the effect of occupational heat stress on mining workers operating in hot conditions. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following barriers or factors that impede the coping and adaptive capacity of mining workers to heat stress and climate change adaptation by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3-**Undecided (U); **4-**Disagree (D); **5-**Strongly disagree

	Statement	SD	D	U	A	SA
a	Inadequate knowledge of coping and adaptive behaviour					
b	Lack of regular training on heat stress risk, work safety, and adaptation measures					
c	Lack of specific heat-related policies and regulation on work health and safety					
d	Poor compliance and implementation of heat stress guidelines, policies and programmes					
e	Inadequate financial resources to support engineering control of heat stress					
f	Lack of management commitment to heat-related health and safety measures					
g	Lack of access to innovative technology and equipment for mining work in hot weather conditions					

h. Which other things do you consider as barriers to adaptation to heat stress and climate change?

....

Section G: Recommendations.

39. What do you suggest can be done to help reduce heat exposure risk and contribute to improving the coping and adaptive capacity of mining workers to heat stress and climate change impacts?

…………………………………………………………………………………………………

Thank you very much for your time and participation

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX F2: SURVEY QUESTIONNAIRE FOR SUPERVISORY PERSONNEL OF MINING WORKERS

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

NOTE: This is a survey being conducted by Edith Cowan University to assess the social impact of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana. The survey is strictly for academic purpose. Respondents are assured of confidentiality. Participation in the survey is voluntary based on informed consent of the respondents. Please answer each question as honestly as possible to the best of your professional perspective of risk and management of occupation heat exposure, social effect and adaptation strategies of mining workers. Place a tick (√) in the bracket next to your preferred answer(s) and fill in the spaces where necessary.

Thank you very much for taking time to participate in this survey.
Contact person: Victor Fannam Nunfam; Email: vnunfam@our.ecu.edu.au;
Phone: +61405548063\+23324793018

Section A: Background characteristics of respondents

2. What is your job position?....................
3. How many years have you been working in this positions?.....................
4. How many years of occupational health and safety work experience do you have?...
5. How old are you?……………….years
6. What is your sex?
   1. Male [ ]   2. Female [ ]
7. What is your highest level of educational qualification?
   1. Diploma certificate [ ]
   2. Undergraduate [ ]
   3. Graduate(masters)[ ]
   4. Postgraduate degree(PhD)[ ]
   5. Other (specify)……………………

Section B: Perceptions and experiences of risk associated with climate change and occupational heat stress and adaptation strategies

8. Are you aware of changes in patterns of climate conditions in your area?
   1. Yes [ ]   2. No [ ]
9. If yes to question 7, what are the signs of the changing patterns of climate conditions?
   7. Increase in temperature and hot environment [ ]
   8. Irregular rainfall and storms [ ]
   9. Frequent floods [ ]
   10. Prolong drought [ ]
   11. Rising sea levels [ ]
   12. Other (specify)……………………
10. Do you consider mining workers at risk of workplace heat exposure due to climate change conditions?

2. Yes [ ] 2. No [ ]

11. If yes to question 9, which of the following external/environmental factors influence the risk of workplace heat exposure of mining workers?
    6. How hot the air is around the workplace [ ]
    7. The amount of air moisture in the outdoor settings or workplaces [ ]
    8. Air speed\movement around the workplace [ ]
    9. Heat radiation from the sun and other sources around the workplace [ ]
    10. Other (specify) ……………………
12. Which of the following work-related factors influence the risk of mining workers to heat exposure?
    10. Type of physical workload [ ]
    11. The duration of working hours [ ]
    12. Type of protective clothing, e.g., overalls [ ]
    13. Access to cooling system, e.g., air conditions and fans [ ]
    14. Length of break/rest hours [ ]
    15. Access to shade [ ]
    16. Access to drinking water [ ]
    17. Type of clothing [ ]
    18. Other (specify) …………………
13. To what extent are you concerned about workplace heat exposure and heat stress (heat-related illness & injuries)?
    5. Not at all concerned [ ]
    6. A little concerned [ ]
    7. Moderately concerned [ ]
    8. Very much concerned [ ]
14. In your working experience, have mining workers expressed concern about heat exposure in your workplace or workplaces you consulted during hot weather conditions?
    1. Yes [ ] 2. No [ ]
15. If yes to question 13, which of the following heat-related illness concerns mining workers?
    9. Excessive sweating [ ]
    10. Headaches [ ]
    11. Heat exhaustion/tiredness [ ]
    12. Heat cramps [ ]
    13. Heat rash [ ]
    14. Heat syncope (fainting) [ ]
    15. Hospital admission due to heat stroke [ ]
    16. Other (specify)……………………
16. Have mining workers ever had any form of heat-related injury in your workplace or workplaces you consulted during hot weather conditions?
    2. Yes [ ] 2. No [ ]
17. If yes to question 15, how will you describe the injury?
    6. Minor [ ]
    7. Moderate [ ]
    8. Serious [ ]
    9. Severe [ ]
    10. Critical [ ]
18. If yes to question 15, which of the following injury concerns do mining workers have?
    8. Burns from the sun [ ]
    9. Burns from hot objects/surfaces [ ]
    10. Falls, trips, and slips due to dizziness, fainting and fatigue [ ]
    11. Loss of grip and controls due to sweaty hands [ ]
    12. Being hit by objects [ ]
    13. Hitting objects [ ]
    14. Other (specify)…………………...
19. Have you ever witnessed any form of heat-related injury to a mining worker?
    2. Yes [ ] 2. No [ ]
20. If yes to question 18, which of the following types of injury concerns did you, witness?
    8. Burns from the sun
    9. Burns from hot objects/surfaces [ ]

10. Falls, trips, and slips due to dizziness, fainting and fatigue [ ]
11. Loss of grip and controls due to sweaty hands [ ]
12. Being hit by objects [ ]
13. Hitting objects [ ]
14. Other (specify)……………………

21. Are you aware of measures to prevent and control the effect of heat stress and climate change in your workplace or workplaces you consulted during hot weather conditions?
    3. Yes [ ]
    4. No [ ]

22. If yes to question 20, which measures are you aware of in preventing and controlling heat stress and climate change at your workplace?
    6. Drinking adequate water [ ]
    7. Using air conditions and fans [ ]
    8. Taking work breaks and resting in shades [ ]
    9. Wearing loose and light-coloured clothing [ ]
    10. Other (specify)……………………

Section C: Social impact of heat stress on mining workers

23. The following describes the adverse effect of heat stress on occupational health & safety of mining workers. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following statements about how mining workers are affected by heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3**-Undecided (U); **4**-Disagree (D); **5**-Strongly disagree

Physiological health and safety effect of heat stress on mining workers						
	Statement	SA	A	U	D	SD
a	Intensive physical mining work in hot weather conditions results in excessive sweating, headaches, and dizziness					
b	Doing mining work in hot weather conditions increases the risks of easy exhaustion, weakness, and muscles cramps or body pains					
c	Excessive sweating as a result of hot weather conditions during intensive mining work increases the risk of heat rashes					
d	Excessive sweating due to heat exposure enhances the risk of extreme thirst					
e	Intensive work in hot weather conditions increase the risk of injuries such as heat burns from the sun or hot surfaces					
f	Fatigue, confusion, and lack of concentration due to heat exposure during heavy mining work leads to heat-related injuries likes skin burns, bruises, and cuts					
g	Loss of grip and control of mining equipment due to sweaty hands results in heat-related injuries like skin burns, bruises, and cuts					

i. Which other ways is the health and safety of mining workers negatively affected by heat stress?

……

24. The following describes the behavioural and psychological adverse effect of heat stress on mining workers. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree

with the following statements about how mining workers are affected by heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3-**Undecided (U); **4-**Disagree (D); **5-**Strongly disagree

Behavioural and psychological effect of heat stress on mining workers						
	Statement	SA	A	U	D	SD
a	Exhaustion, weakness, and muscle cramps due to heat exposure slow down the pace of mining workers					
b	Physical fatigue and excessive sweating due to heat exposure affects the attentiveness and judgement of mining workers					
c	Thoughts of risk of accidents and injuries due to heat-related exhaustion, reduced alertness, and sense of understanding increase the fear and anxiety of mining workers					
d	Fatigue and lack of concentration due to manual work in hot environment increase the need for work-rest hours for mine workers					
e	Mistakes/errors during work in hot weather conditions are due to lack of training and information on risk of heat exposure					

f. Which other ways is the behaviour, action, and attitude of mine workers affected by heat stress?

....

25. The following describes the adverse effect of heat stress on the social lives and well-being of mining workers. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following statements about how mining workers are affected by heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3-**Undecided (U); **4-**Disagree (D); **5-**Strongly disagree

Effect of heat stress on social lives and well-being of mining workers						
	Statement	SA	A	U	D	SD
a	Heat-related illness and injuries increases the medical expenses of mining workers and their families					
b	Exhaustion and excessive sweating due to intensive mining work in hot environment increase the risk of drinking alcohol and energy drinks as well as substance abuse					
c	Fatigue and weakness of mining workers due to intensive mining work in hot environment disrupts family life due to loss of leisure time					
d	Erosion of income due to increased medical expense as a result of heat-related illness and injuries of mining workers increase the risk of family education, health, and cohesion					
e	Increased medical expenses due to heat-related illness and injuries affect the social lives and cohesion of mining workers and their family					

f	Increase irritation, exhaustion, and lack of concentration of mining workers due to workplace heat exposure increase the risk of poor interpersonal relationship with coworkers, family, and community					
g	Heat-related illness and loss of productivity due to workplace heat exposure influence the social lives and cohesion of mining workers, their families, coworkers, and communities					
h	Workplace stress and frustration due to heat-related tiredness and illness influence alcoholism, smoking, substance abuse, and workplace and domestic violence					

i. Which other ways are the social life and well-being mine workers negatively affected by heat stress?

....

26. The following describes the adverse effect of heat stress on economic productivity of mining workers. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following statements about how mining workers are affected by heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3-**Undecided (U); **4-**Disagree (D); **5-**Strongly disagree

Economic productivity effect of heat stress on mining workers						
	Statement	SA	A	U	D	SD
a	Exhaustion, weakness and muscle cramps due intensive mining work in hot environment reduces productive capacity of mining workers					
b	Lack of concentration, confusion and coordination as result of heat exposure leads to loss of productive efficiency of mining workers					
c	Heat-related illness and injuries increase the risk of absenteeism of mining workers					
d	Absenteeism of mining workers due to heat-related illness and injuries result in loss of income and employment opportunities					
e	Work-rest regimes due to excessive heat exposure increase the risk of reducing productivity of mining workers					

j. Which other ways is the productive capacity of mine workers negatively affected by heat stress?

....

Section D: Adaptation strategies of workers to occupational heat stress.

27. The following statements describe measures adopted at the workplace or workplaces you consulted to help mine workers' coping and adaptive behaviour in managing the effect of working in hot weather conditions. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following statements describing adaptation strategies to heat stress by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3-**Undecided (U); **4-**Disagree (D); **5-**Strongly disagree

	Statement	SD	D	U	A	SA
a	Provision of cool drinking water for mining workers at workplace					

b	Supply and ensure the use of personal protective equipment like loose and light-coloured clothing, sunglasses, wide-brimmed hats, and hand gloves during hot weather conditions					
c	Encourage mining workers to avoid drinking coffee, soft drinks, caffeinated energy drinks, and alcohol when working in hot environment and tired					
d	Ensure mining workers take regular breaks away from hot conditions in a cooler or shaded area					
e	Assist mining workers to acclimatise to hot weather conditions without any medication to cope with heat stress					
f	Provide mechanical equipment to reduce the need for strenuous physical workload					
g	Plan and carry out heavy routine outdoor work during the early morning or evening hours or in shaded areas during hot weather					
h	Organise regular training programmes on working safely in the heat					
i	Share unavoidable heavier jobs and rotate jobs on shift schedules					
j	Encourage mining workers to slow down work at their pace while working in hot weather conditions					
k	Use cooling systems like air conditions and electric fans during hot weather conditions					

l. Which other ways do mine workers cope and adapt to heat stress and climate change impacts?

....

m. Which of the following social protection measures are provided at the workplace or the workplaces you consulted to help mine workers' to enhance their coping and adaptive capacity to the effect of heat stress and climate change?

9. Work based health insurance scheme [ ]
10. National health insurance scheme [ ]
11. Compensation scheme [ ]
12. Social security and pension scheme [ ]
13. Minimum wage [ ]
14. Membership of labour union [ ]
15. Membership of credit union [ ]
16. Other (specify)……………………………………………………………………………

Section F: Barriers to effective implementation of adaptation strategies to occupational heat stress

28. The following statements describe barriers to effective implementation of adaptation strategies to the effect of occupational heat stress on mining workers operating in hot conditions. Kindly indicate on a scale of 1-5 the extent to which you agree or disagree with the following barriers or factors that impede the coping and adaptive capacity of mining workers to heat stress and climate change adaptation by ticking (√):

1-Strongly agree (SA); 2-Agree (A); **3**-Undecided (U); **4**-Disagree (D); **5**-Strongly disagree

	Statement	SD	D	U	A	SA
a	Inadequate knowledge of coping and adaptive behaviour					
b	Lack of regular training on heat stress risk, work safety and adaptation measures					
c	Lack of specific heat-related policies and regulation on work health and safety					
d	Poor compliance and implementation of heat stress guidelines, policies and programmes at workplace					
e	Inadequate financial resources to support engineering control of heat stress at workplace					
f	Lack of management commitment to heat-related health and safety measures					
g	Lack of access to innovative technology and equipment for mining work in hot weather conditions					

m. Which other things do you consider as barriers to adaptation to heat stress and climate change?

....

Section G: Recommendations

29. What do you suggest can be done to help reduce heat exposure risk and contribute to improving the coping and adaptive capacity of mining workers to heat stress and climate change impacts?

....

Thank you very much for your participation

APPENDIX G: IN-DEPTH INTERVIEW AND MODERATOR'S FGD GUIDE

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX G1: IN-DEPTH INTERVIEW GUIDE FOR GCM AND GNASSM

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

A. Introduction and consent

Thank you for your time. My name is …………………………………….. and I would be talking to you about your perspectives of mining regulations on occupational health and safety of mining workers in Ghana. Specifically, the interview will focus on mining regulations on risk and impact of heat stress on mine workers' health, safety, productivity, and social well-being, and adaptation strategies.

The interview will last not more than 30 minutes. The information will be used mainly for academic work and to help improve occupational health and safety regulation. The interview session will be recorded by audiotape in order to adequately capture all the very important viewpoints. Your responses and identity will remain confidential. You do not have to respond to every question when you are not comfortable. You are also free to end the interview at any time. Do you have any questions on what I have talked about so far? Are you willing to participate?

Interviewees' name: …………………………………………Contact: ……………

Signature: ……………………………………………. Date: ………………………

B. Perspectives on regulatory standards for occupational health and safety in the mining industry

1. Please give a brief background description of your job position, key responsibilities, qualification(s), and years of working experience?
2. Are you aware of changes in weather conditions over the last 30 years? What are the signs and effects of climate change?
3. To what extent are mining workers at risk of occupational health and safety hazards because of heat exposure at mine sites during hot weather conditions?
4. Describe the type of occupational related illness and injury of mining workers because of extreme heat exposure during hot climatic conditions?

5. What factors or conditions of mining workers contribute to the risk and impact of heat stress (e.g., excessive sweating, headaches, heat exhaustions/tiredness, dizziness, dehydration, heat cramps, heat rashes, heat stroke, etc.) in the mining industry?
6. Are you aware of any incidence of heat-related death to mining workers? Describe what happened?
7. What are the existing mining regulatory standards in Ghana? Please list them.
8. Which of the mining regulatory standards focus on ensuring the occupational health and safety of mining workers? What does it say about protection mining workers from the effect of heat stress on health, safety, productivity, and social well-being at work? (e.g., drinking adequate water, using air conditions/fans, taking work break, resting in shades, wearing loose and light-coloured clothes, etc.)
9. To what extent are the regulatory standards on occupational health and safety enforced in the mining industry in Ghana? How are they implemented to protect workers? Why?
10. What role do you (GCM/GNAASSM) play in enforcing the regulatory standards to protecting your members from the effect of heat stress and improve on adaptation strategies?
11. What factors impede the enforcement of these regulatory standards?

C. Conclusion

12. Base on the things we talked about, which aspect is the most important? If you had a minute with major stakeholders in the mining industry, what would you say?

Thank you very much for your participation

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX G2: IN-DEPTH INTERVIEW GUIDE FOR IDMC

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

A. Introduction and consent

Thank you for your time. My name is …………………………………….. and I would be talking to you about your perspectives of mining regulations on occupational health and safety in Ghana. Specifically, the interview will focus on mining regulations on risk and impact of heat stress on mine workers' health, safety, productivity, and social well-being, and adaptation strategies.

The interview will last not more than 30 minutes. The information will be used mainly for academic work and to help improve occupational health and safety regulation. Even though the interview session will be recorded by audiotape in order not to miss out on very important viewpoints, your responses and identity will remain confidential. You may not necessary have to talk about everything especially when you are not comfortable and you are free to end the interview at any time. Do you have any questions on what I have talked about so far? Are you willing to participate?

Interviewees' name: …………………………………………Contact: ……………

Signature: ……………………………………………. Date: ………………………

B. Perspectives on regulatory standards for occupational health and safety in the mining industry

1. Please give a brief background description of your job position, key responsibilities, highest qualification(s), and years of working experience?
2. Are you aware of changes in weather conditions over the last 30 years? If yes, what are the signs and effects of the changes in weather conditions?
3. To what extent are mining workers at risk of occupational health and safety hazards because of heat exposure at mine sites during hot weather conditions?
4. What type of occupational related illness and injury affects mining workers because of extreme heat exposure during hot weather conditions?

5. What factors or conditions of mining workers contribute to the risk and impact of heat stress (e.g., excessive sweating, headaches, heat exhaustions/tiredness, dizziness, dehydration, heat cramps, heat rashes, heat stroke, etc.) in the mining industry?
6. Are you aware of any incidence of heat-related death to mining workers? Describe what happened?
7. What are the existing mining regulatory standards in Ghana? Please list them.
8. Which of the mining regulatory standards focus on ensuring the occupational health and safety of mining workers? What does it say about protection mining workers from the effect of heat stress on occupational health and safety, productivity and social well-being at work? (e.g., drinking adequate water, using air conditions/fans, taking work break, resting in shades, wearing loose and light-coloured clothes, etc.)
9. To what extent are the regulatory standards on occupational health and safety enforced in the mining industry in Ghana? How are they implemented to protect workers?
10. What factors impede the enforcement of these regulatory standards?

C. Conclusion

11. Base on the things we talked about, what is the most important aspect to you? If you had a minute with key stakeholders in the mining industry, what would you say?

Thank you very much for your participation

JOONDALUP CAMPUS
270 Joondalup Drive, Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: +61 (08) 9300 1257
CRICOS 00279B
ABN 54 361 485 361

APPENDIX G3: MODERATOR'S FOCUSED GROUP DISCUSSION GUIDE FOR MINING WORKERS

Social impacts of climate change and occupational heat stress and adaptation strategies of mining workers in Ghana

---

A. Introduction (2minutes)

- Welcome and thanks for coming. My name is ………and the moderator for this group discussion session. …………is the assistant moderator and is to help in taking notes, handling logistics and monitoring the equipment for recording as well as refreshments.
- The purpose of this meeting is to talk about the impact of hot weather, heat stress, and adaptation strategies of mining workers in Ghana.
- I will be asking about your perceptions and experience of heat stress, social effect of heat stress, coping and adaptation strategies, and things that serve as barriers to coping and adapting to heat stress as mining workers.
- The information is purely for academic work, and your responses and identity will remain anonymous and confidential.

B. Ground rules (2minutes)

- The meeting will last not more than **60 minutes**, and audiotape and written records of the discussions taken. We do not want to forget some of the critical viewpoints in the discussion.
- There are no correct and wrong answers. All your opinions and varying points of views on the subject matter of heat exposure and adaptation is important.
- Everyone is encouraged to talk but in a very clear and loud voice, one at a time. Avoid interrupting or disturbing others when they are talking.
- Please put your phones on silence or vibration to minimise disruptions.
- Is there any question before we start?

C. Background (3minutes)

- Take some few minutes to introduce yourselves to the person seated by you. You will be called to introduce (e.g., name, where they live, hobbies, etc.) the person seated by you to the group. Thank you.

D. Perceptions and experiences of climate change, heat stress and adaptation strategies (15minutes)

1. Are you aware of changes in weather conditions over the last 30 years? What are the signs and effects of climate change? (e.g., increasing temperature, irregular rainfall, occurrence of storms, prolong drought, frequent floods, rising sea levels, etc.).
2. As a mining worker, are you at risk of heat exposure because of increasing hot weather conditions? In your opinion, what environmental factors or conditions increases your risk of heat stress? (e.g., working under the sun, air moisture, air movement/speed, heat radiation from the sun or sources around the workplace, etc.). In your opinion, what factors related to the mining work contribute to heat stress? (Physical workload, duration of work, break-rest hours, type of clothing, access to drinking water, access to cooling systems-shade, fan, air conditions, etc.)

3. Have you or your co-workers ever had any form of heat-related illness? If yes, what type of the disease did you or your co-worker experience? (e.g., excessive sweating, headaches, heat exhaustions/tiredness, dizziness, dehydration, heat cramps, heat rashes, heat stroke, etc.)
4. Have you or your co-workers ever had any form of heat-related injuries? If yes, what type of injury did you or your co-worker experience?
5. Are you aware of any incidence of heat-related death to mining worker? What happened?
6. Are you aware of measures to prevent and control the effect of heat stress and climate change? Which means are you aware of in preventing and controlling heat stress and climate change? (e.g., drinking adequate water, using air conditions/fans, taking a work break, resting in shades, wearing loose and light-coloured clothes, etc.)

E. Social effect of heat stress (15minutes)

7. As a mining worker, is your health and safety affected by workplace heat exposure? If yes, how does heat stress affect your health and safety? If no, why not?
8. As a mining worker, is your behaviour, actions, and attitude affected by heat stress? If yes, how does heat stress change your behaviour, actions, and attitude at work and home? If no, why not?
9. As a mining worker, is your productive capacity negatively affected by heat stress? If yes, how does heat stress affect your productive capacity? If no, why not?
10. As a mining worker, is your social life and well-being negatively affected by heat stress? If yes, how does heat stress affect your social life and well-being? (e.g., family leisure and time, co-workers, etc.) If no, why not?

F. Adaptation strategies (10minutes)

11. Do you often take measures to prevent and manage the effect of heat stress when working during hot weather conditions? If yes, please share with us what steps you take to cope and adapt to the effect of heat stress when working in hot weather environments? If no, why not?
12. Are there specific guidelines for the occupational health and safety policies regulating mining workers in a hot environment? If yes, what does the policy say? If no, why not?

G. Barriers to adaptation (8minutes)

13. Are there any obstacles to your attempts at preventing and managing the effect of heat stress? If so, what factors or things do you consider as barriers to adaptation to heat stress and climate change effects on you as a mining worker?

H. Conclusion (5minutes)

14. Base on the things we talked about, what is the most important thing to you? If you had a minute with your co-workers, employers, or important government official, what would you say?
15. Background characteristic of participants:
    i. What is your sex?………………………..........……………………………….
    ii. What is your educational level?……………...…………………………………
    iii. How old are you? ……………………….……….…………………………….
    iv. What are your job position?......…………………………………….………

Thank you very much for your participation