Resource extraction projects and health: evidence from cross-national and national data sources

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Summary

Background: Implementation of resource extraction projects often triggers a series of complex environmental and social-ecological changes. These changes may include alterations in land use (i.e., from forestry and vegetation to infrastructure and mining), an increase in construction activities (new buildings such as houses, schools and hospitals), population increase (more people, more road traffic), urbanization, movement and installation of heavy machinery, increases in employment and business opportunities and household resettlements. These changes can positively or negatively affect health of the population living within mining areas and beyond. For instance, one common and most visible contribution of resource extraction projects is the impact on income generation. This has been widely studied in the economic literature, showing both positive and negative effects between natural resources activities and income generation. Positively, governments can benefit from the generated resource rents and royalties. Individually, people can earn income from employment and business opportunities. The revenue generated can help governments to re-invest in other sectors, including health, education and infrastructure. Negatively, the sharp increase in economic development in one sector can hamper growth in other sectors causing what is known as the Dutch disease. The presence of resource-income dependency can as well fuel local conflicts, political instability, weak institutions and corruption, and ultimately result in a slow development process causing the resource curse.

One major aspect of resource extraction projects which is often under-represented is its implication on health. Health is influenced both directly and indirectly through activities involved in resource extraction projects. Evidence suggests that resource extraction projects can positively or negatively affect health and well-being of the population therein. This directly relates to the Sustainable Development Goal (SDG) number 3 (SDG3) of the SDGs 2030 agenda. SDG3 aims to ensure healthy lives and promote well-being for all at all ages. Health has a central place in SDG3, and it is also central to the three dimensions of sustainable development: environment, society and economy. Resource extract projects can act on determinants of health and ultimately contribute to improve lives and well-being. An increase in income can promote access to better care, construction of health care post and hospitals can contribute to improving healthcare delivery, constructions of water points can improve the availability of clean water, and lastly but not least, the provision of health education can contribute to knowledge and disease prevention. On the other hand, resource extraction projects

can cause environmental disruption linked to air, water and land pollution. This can further result in disease outcomes. Combustion activities associated with the extraction process can result in the presence of small particulate matter (PM2.5) in the atmosphere and further lead to respiratory and cardiovascular diseases. Toxic substances often used in the extraction process can leak into the environment and result in cancer diseases.

The presence of both positive and negative health outcomes in resource extraction areas present an opportunity to systematically study the contribution of resource extraction projects to health outcomes. This PhD thesis embarked on this particular opportunity and studied the association between resource extraction projects and population health indicators in three layered perspectives: global, national and subnational.

Objectives: The overarching objective of this PhD thesis was to assess the relationship between natural resource extraction projects and population health from the global, national and subnational perspectives. This was achieved by pursuing the following three specific research objectives: (1) to assess the short- and long-term association of country's resource rents and changes in life expectancy; (2) to assess the relationship between council's type of commodity extraction and incidence of diseases; and (3) to study differences in mortality patterns of miners and non-miners living in close proximity to two major gold mines in Tanzania.

Methodology: The first objective was addressed by exploring the World Development Indicators (WDI) of the World Bank dataset on the global relationship between changes in life expectancy and natural resource rents over the period 1970 – 2017. We employed Ordinary Least Square (OLS) and Conditional Convergence Framework to investigate the long-term association, and Instrumental variable regression framework to assess the causal relationship between short-term changes in natural resources rents and changes in life expectancy. For the second objective, this PhD looked at the country-specific analysis by assessing the relationship between the presence of different types of commodity extraction projects (metal, gemstone or construction materials) and the incidence of diseases at council-level in Tanzania mainland. For the last objective, this PhD thesis further narrowed down to local communities for investigating mortality outcomes of miners and non-miners living in close proximity to two major gold mines in Tanzania, as well as to compare mortality patterns found in the mining communities against subnational and national estimates.

Results: At the global level, country's increase in resource rents were significantly associated with increases in life expectancy. Increase in resource rents were also significantly associated with increase in government revenue which could possibly explain the increase governments' ability to support public health and development programs that can potentially contribute to improved population health. At the national level, councils with presence of metal extraction projects were significantly associated with low incidence of chronic diseases, diarrhoea diseases, undernutrition, parasitic diseases, sexually transmitted diseases and mental health in Tanzania. On the other hand, councils with presence of construction materials extraction were associated with an almost fifty percent increase in chronic diseases. At the local level, we found that miners had twice the risk of dying compared to non-miners in two large gold mining setting in Tanzania. The risk of dying from HIV/AIDS among male miners was about three times higher compared non-miners. In addition, miners in mining communities had over ten times the risk of dying from Road Traffic Injuries (RTIs) and injuries unrelated to RTIs compared to non-miners. Overall, mining communities were observed with high rates of RTIs compared to subnational estimates with non-mining communities and national estimates from Global Burden of Diseases (GBD) study.

Conclusion and Significance: The various positive association of resource extraction projects and different health outcomes and determinants observed in this PhD thesis underline the potential of resource extraction projects to potentially contribute towards improving health at the local, national and global level. This can ultimately contribute to SDG3: to ensure healthy lives and wellbeing for all at all ages, and 2030 Agenda for Sustainable Development overall. But since also negative health effects associated with mining activities were observed in this PhD thesis, there is a need for systematic approaches, such as health impact assessment, to identify and prevent negative impacts of resources extraction projects on social and environmental health determinants and associated health outcome indicators. This can be complemented with the increased use of promising new secondary data sources, such as DHIS2, and data collection methods, such as verbal autopsies, to enable the assessment, monitoring and evaluation of positive and negative health effects resulting from the construction and operation of extractive industry projects. Indeed, this PhD thesis showed that there is an opportunity to integrate routine Health Management Information Systems (HMIS) data and Civil Registration and Vital Statistics (CRVS) data for impact evaluation studies of existing resource extraction activities. Last but not least, this PhD thesis continues to emphasize the importance of including public health considerations in the design, construction and operation of large-scale

infrastructure projects since health is a beneficiary of, and contributor to, development and well-being, and hence, central to the three dimensions of sustainable development: environment, society and economy.

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Isaac Lyatuu

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List of Abbreviations

2SLS	Two Stage Least Squares
AIDS	Acquired Immuno Deficiency Syndrome
BGM	Bulyanhulu Gold Mine
CHE	Current Health Expenditure
CHW	Community Healthcare Worker
CI	Confidence Interval
CISM	Manhiça Health Research Centre
CoD	Cause of Death
CRVS	Civil Registration and Vital Statistics
CRVS-VA	Civil Registration Vital Statistics and Verbal Autopsy
CSR	Corporate Social Responsibility
DALY	Disability Adjusted Life Years
DC	District Council
DHIS2	District Health Information System (version 2)
DSS	Demographic Surveillance Sites
EHA	Environmental Health Areas
EIA	Environmental Impact Assessment
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GGM	Geita Gold Mine
GIS	Geographical Information System
GoT	Government of Tanzania
GST	Geological Survey of Tanzania
HIA	Health Impact Assessments
HIA4SD	Health Impact Assessment for Sustainable Development
HISP	Health Information System Programme
HIV	Human Immunodeficiency Virus
HMIS	Health Management Information System
HTC	Counseling and Testing
ICMM	International Council on Mining and Metals
IFC	International Finance Corporation

IHI	Ifakara Health Institute
IHME	Institute of Health Metrics Evaluation
IQ	Institutional Quality
IRR	Incident Rate Ratio
IRSS	Research Institute of Health Sciences
IV	Instrumental Variable
LATE	Local Average Treatment Effect
LE	Life Expectancy
LGA	Local Government Authority
LMIC	Low and Middle Income Countries
M&E	Monitoring and Evaluation
MICE	Multiple Imputation Chained Equation
MoHCDGEC	Ministry of Health, Community Development, Gender, Elderly and Children
mRDT	Malaria Rapid Diagnostic Test
NADEL	Center for Development and Corporation
NIMR	National Institute for Medical Research
ODK	Open Data Kit
OLS	Ordinary Least Squares
OPD	Outpatient Department
OSHA	Occupational Safety and Health Authority
PM	Particulate Matter
RD	Risk Difference
RR	Risk Ratio
RTI	Road Traffic Injurie
SDC	Swiss Agency for Development and Cooperation
SDG	Sustainable Development Goal
SNSF	Swiss National Science Foundation
SSA	Sub-Saharan Africa
SwissTPH	Swiss Tropical and Public Health Insitute
TC	Town Council
UHAS	University of Health and Allied Sciences
UN	United Nations
VA	Verbal Autopsy

WDI	World Development Indicators
WHO	World Health Organization

1. Introduction

1.1. Natural resource extraction

1.1.1. Global perspective

Natural resource extraction involves the act of withdrawing materials from the natural environment for purpose of energy consumption or economic benefits. This include the removal of raw materials such as minerals, timber, oil, gas and vegetation. The amount and type of resource availability depends on the geographical location and past geological processes [1]. Consequently, natural resources are unevenly distributed across continents, with some countries being more endowed than others. For example, the United States holds the biggest coal reserve, accounting to about 27% of the world's total, China is the largest gold producer with 14% share of the world's production, Russia, Congo and Botswana has 80% of the world's diamond, the Middle East account for the world's largest production of crude oil; and African is endowed with large deposit of different natural resources including diamond, gold, cobalt, uranium, bauxite and cocoa, [2]. Figure 1-1 shows different natural resources distribution around the world.

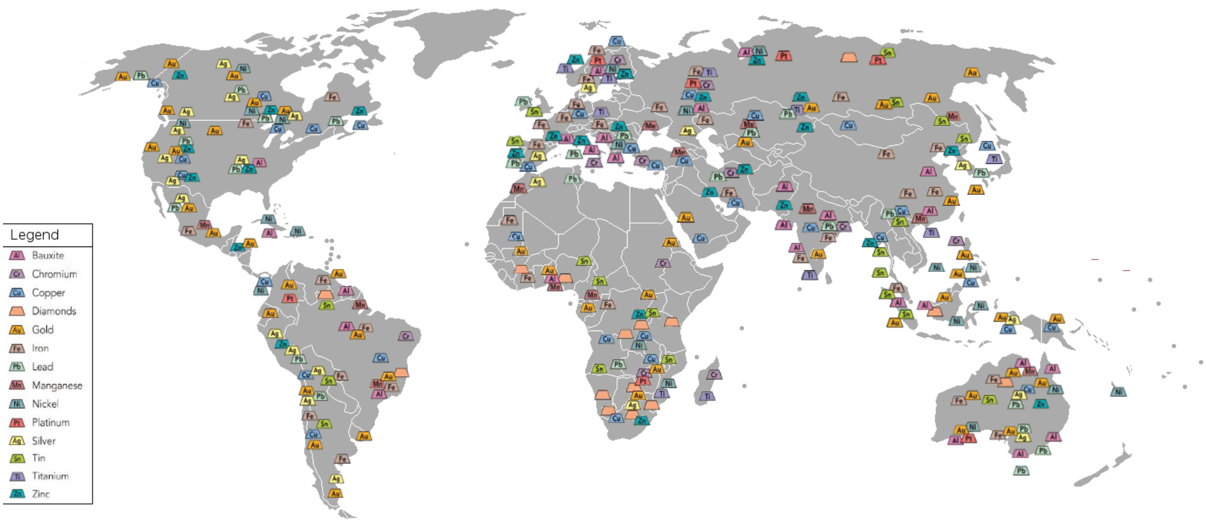

Figure 1-1: Global mineral distribution

(Source: https://commons.wikimedia.org/wiki/File:Simplified_world_mining_map_2.png)

1.1.2. Resource wealth on the African continent

Africa has received particular attention in the discussion of natural resources and endowment [3]. The continent is the home of to one third of the world's mineral reserve, 8 percent of the world's natural gas, 12 percent of the world's oil reserve, and 40 percent of the world's gold and up to 90 percent of the world's chromium and platinum [4, 5]. The continent has more than half of the word's cobalt [6], and a third of its bauxite [7]. In the late 19th and early 20th century, the continent started to experience the so-called *commodities super cycle* [8]. This was due to global industrialization and urbanization. This substantially increased export of the region's abundant natural resources and investment in natural resource extraction by foreign and domestic companies.

Currently, more than half of the countries on the African continent regard natural resource extraction as an important economic activity [9, 10]. In a low carbon future, the mining industry might play an even more important role in African countries. Indeed, wind, solar, hydrogen and electricity systems are significantly more material-intensive in their composition than current traditional fossil-fuel-based energy supply systems, resulting in a rapidly increasing demand in relevant metals [11, 12]. According to a recent study from the World Bank, the African continent, with its large reserves in platinum, manganese, bauxite, and chromium, holds large potential for covering future mineral demands [13].

1.1.3. Natural resource wealth: opportunity or curse?

Resource extraction projects can potential contribute to sustainable development at the local and national level [14, 15]. The underlying promise is that the development and operation of extractive industry projects can trigger improvements in socio-economic status and public infrastructure at the local level, along with generating tax and royalty incomes at the national and sub-nationals' levels [16]. Hence, the extractive sector can be an important player in many low- and middle-income countries (LMICs), including those on the African continent.

The economic contribution of resource extraction projects has been widely discussed in literature [3]. The general hypothesis is that implementations of resource extraction projects trigger a series of environmental, social and economic changes to the producer region [17, 18]. When applying an economic angle, resource extraction projects can bring revenue to central and local governments through tax and royalties, provide business and employment opportunities to local communities [19]. The economic value generated through resource extraction activities can potentially be applied to strengthen the health systems. But little research is available to date on this aspect [20].

A number of economic literatures visited this hypothesis, and among the earlier observation from this domain suggested that there exist a global negative association between country's resource endowment and economic development. One of the first work to be published at the time come from Richard Auty [21] who coined the word "*resource curse*". Using a cross-country regression model, Auty argued that country's rich in natural resources have experienced less economic development compared to countries with fewer resources. Several studies have demonstrated negative effects of the extractive sector on the governance of producing countries, and thus confirmed the *resource curse* [22-24]. This may also partly explain why several of the African countries abundant in natural resources have not being able to transform the presence of the natural resources into their economic development [21, 25, 26]. Indeed, despite the on-going profits from the extractive sector and growing exports, the resource boom has been less successful in improving people's welfare and Africa is still the country with the highest burden of disease (GBD) globally [27].

1.2. Sustainable development, NREPs and health

1.2.1. Health in the 2030 Agenda for Sustainable Development

The WHO defines health as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity [28]. Health is both a beneficiary of and contributor to development and well-being, and hence, central to three dimensions of sustainable development: environment, society and economy [29]. This is also reflected in the United Nation's 17 Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development, in which health is featured as a cross cutting issues [30, 31]. With the objective to *"ensure healthy lives and promote well-being for all at all ages",* SDG3 specifies ambitious targets to reduce maternal mortality ratio to less than 70 per 100,000 live births and end preventable deaths of new-born and children under 5 years of age [32]. Additionally, SDG1 (no poverty), SDG2 (zero hunger), SDG4 (quality education), SDG6 (clean water and sanitation), SDG8 (employment and economic growth), SDG11 (sustainable cities and communities), SDG16 (peace, justice and strong institutions) all focus on key determinant of health [33]. SDG5 (gender equity) and SDG10 (reduce inequalities) directly link to health equity. Together, the SDGs embrace 29 health-related targets and number of specified measurable indicators [34, 35].

1.2.2. *Resource extraction and the SDGs*

For achieving the 2030 Agenda for Sustainable Development, a significant contribution is expected from the private sector, particularly in LMICs [36-38]. Besides financial contributions, extractive projects have the potential to positively act on the SDG 2030 Agenda linked to health in producer regions. For example, extractive projects can support the upgrading of public infrastructure, including health facilities and water resources, and thus foster good health and well-being (SDG3) and improved access to clean water and sanitation (SDG6) [39, 40]. The creation of employment and income can reduce poverty (SDG1) and malnutrition rates (SDG2) [41, 42]. Tax revenues and royalties paid by resource extraction projects are essential for local and national governments to work towards all SDGs [43].

On the other hand, potential positive effects of the extractive sector are opposed by potential adverse impacts. In-migration caused by project developments may put strains on local health systems (SDG3, SDG10 and SDG11), food security (SDG2), and sanitation and water systems (SDG6) [44, 45]. More specifically, the implementation of natural resource extraction projects can trigger a series of complex environmental and social-ecological changes [16]. The changes may include physical, demographic and social disruption similar to infrastructure modification, migration and emerging of different social structures such as workers, brokers, and businessman. These types of disruptions have shown to cause negative [46] or positive outcomes [47]. Changes in the environment can influence prevalence of pathogens and other disease-causing vectors and potentially increase diseases of the respiratory system [48, 49], sexually transmitted infections including HIV/AIDS [50], malnutrition [51], vector-related diseases [52-54], mental health [55, 56] and cancer diseases [57]. Resource extraction projects can also promote the influx of young male workers and economic gain, and potentially increase rates of alcohol/drug consumptions, social interactions and sexually transmitted diseases [58].

While a growing body of evidence shows that natural resource extraction projects can result in a broad set of potential positive and negative effects on health determinants and outcomes in affected communities, these case studies fail in describing overarching effects of natural resource extraction projects on regional and national health systems, and thus have limited power in influencing governance and decision-making at the national level. Therefore, studies are needed that investigate associations between natural resource extraction projects and public health at the country and regional level. Such studies are not only important for influencing decision-makers in the elaboration of legal frameworks that embrace the 2030 Agenda for

Sustainable Development, but they can also influence impact assessment practice of large infrastructure developments.

1.3. Engaging resource extraction projects in sustainable development

Health is largely determined by environment, social, behavioral and institutional factors that are themselves influenced by policies and activities outside the health sector [59, 60]. Considerable health and development gains would accrue from increased action to address the root causes of diseases associated environmental factors. A more systematic targeting of low-cost public health intervention to address environmental causes of diseases such as to ensure adequate and safe drinking water and sanitation, to ensure good air quality, to prevent exposure to hazardous chemicals and waste, could prevent an estimated 13 million deaths per year [61]. Resource extraction projects can positively contribute to population health through improved labour market opportunities and corporate social responsibility (CSR) activities that support local health systems or contribute to general health and education programs [47, 62-64]. Ideally, CSR activities and impact mitigation strategies in areas where extractive industry projects are constructed and operated are informed by *ex-ante* impact assessments, which are considered an important methodological approach for engaging large infrastructure projects in sustainable development [65].

1.3.1. Impact assessments

Impact assessments entail a systematic process that has the objective to minimize potential negative effects of a policy, program or project on the natural environment, society and public health, while promoting potential beneficial impacts [66, 67]. Environmental impact assessment (EIA) – the oldest discipline of impact assessment – has been institutionalized in countries worldwide through the establishment of a legal requirement that requires EIA prior to implementation of a large development project [68]. The United Nations (UN) member states also signed an international legal requirement that refers to EIA implementation across countries [69]. At the country level, EIAs are endorsed by specific laws and regulations. Those laws and regulations often established the scope of public participation and consultations [69], which further makes EIA a policy tool that does not only grant the responsible authority the right to request an EIA, but in most countries, also empowers the government to prosecute environmental offences in the law courts.

1.3.2. Health impact assessment (HIA)

The WHO defines Health Impact Assessment (HIA) as "a combination of procedures, methods and tools used to evaluate potential health effects of a policy, program or project on the health of a population" [70]. HIA uses qualitative, quantitative and participatory techniques and aims to produce recommendation that help decision-makers and other stake holders make choices about alternatives and improvements to prevent disease/injury and to actively promote health [71]. The intended outcome of HIA is to bring a wide range of public health concerns into the decision-making process to reduce impact and promote healthy communities [72].

In contrast to EIA, only few countries have established legal requirements for HIA, which have, at least partially, arisen through discontent with EIA practice [73-75]. This holds particularly true for Africa where not a single country is actively promoting HIA though a policy, regulation or another means of endorsement [72]. As a consequence, EIA is often, and incorrectly, perceived as an instrument of environmental preservation, sometimes referred to as an Environment Impact Statement [76]. Moreover, with regards to health, the legal text on EIA generally has a strong focus on environmental determinants of health but does not generally include health outcome indicators [77]. Hence, in order to tap the full potential of impact assessment as a policy tool for coupling natural resource extraction projects with sustainable development, there is a need to work towards integrated impact assessment that are grounded in inter-sectoral collaboration and backed by policies and methodological guidelines that embrace the SDG 2030 agenda [78-80]. But for fuelling the policy dialogue needed for promoting a more comprehensive inclusion of health in impact assessment – be it through more rigorous integration of health in EIA or stand-alone HIA – a solid evidence-base on local and national level health effects of natural resource extraction projects that goes beyond occasional case studies is needed.

1.4. Research gaps

A substantial body of literature exists that describes associations between natural resource extraction projects and disease patterns [81]. But past research on resource extraction and health has several important shortcomings [81]. First, most of the studies conducted in resource extraction contexts are oriented towards occupational health. Thus, community level health impacts, which may be more important from a public health initiative when considering the generally relatively small number of the workforce compared to the total population affected, are less well understood. Secondly, most papers focus on high income and upper-middle income countries. When considering the complex social-ecological system dynamics that are commonly found in producer regions in the global south, this is problematic. Thirdly, the large majority of studies describing positive and negative effects on health determinants and outcomes in communities affected by extractive activities present case studies from a variety of geographical contexts and types of commodities being extracted. Therefore, it is not well understood whether different types of commodity extraction projects exert similar influences on morbidity and mortality patterns in producer regions. Moreover, the long-term health effects of extractive industry activities are not well understood because very few mortality studies have been conducted in, for instance, mining areas. In summary, existing scientific evidence on the effects of natural resource extraction projects has severe limitations in describing overarching effects of natural resource extraction projects on affected populations, as well as on regional and national health systems. This is a critical constraint for the much-needed policy dialogue at the national and international level on whether or not current regulatory approaches to impact assessment of natural resource extraction projects in Africa promote sustainable development.

1.4.1. The case of Tanzania

Systematically and routinely collected data on country level offer special opportunities to study trends and progress towards many health-related indicators including SDG indicators. This has been extensively missed in the past in most developing countries. Such data have recently become available. For example, the collection of national HMIS data through District Health Information System version 2 (DHIS2, http://www.dhis2.org), Civil Registration and Vital Statistics Verbal Autopsies (CRVS-VA) and demographic surveillance systems (DSS). In addition, many African countries have conducted periodical demographic and population health surveys over the past decades through their national statistical office and in collaborations with international organizations such as WDI and World Health Organization (WHO) World Health Statistics. These data resources provide an invaluable opportunity to study changes in health outcome indicators in given time period.

1.4.2. District Health Information System version 2 (DHIS2) data

By 2011, the Ministry of Health Community Development, Gender Elderly and Children (MoHCDGEC) in Tanzania had scaled out the use of DHIS2 to all 169 councils in the Tanzania mainland [82, 83]. This was after a pilot implementation in the Pwani region over five years back [84]. To date, the Tanzania DHIS2 data repository has over ten years worthy of continuous data which spans across all districts and councils. Although there are notable data quality issues, the quality of DHIS2 data has improved over time [85-87].

The Tanzania DHIS2 data have been frequently used for Monitoring and Evaluation (M&E) activities at the ministry of health departments [88]. The Health Information Systems Programme (HISP) in Tanzania have also supported capacity building, data quality improvements and data use initiates [89]. Several programs such as Pay for Performance [90], Malaria Indicator Survey [91], HIV/AIDS Surveys [92] have used DHIS2 data in peer reviewed literatures. However, no prior evidence for the application of DHIS2 in HIA studies. This PhD has taken the first initiative to use DHIS2 data to inform HIA processes.

1.4.3. Civil Registration Vital Statistics (CRVS)-Verbal Autopsy (VA) data

Tanzania has about 26% coverage in death registration [93], only 8% of all death are assigned a cause of death that is good, usable quality for vital statistics [94]. The 8% referenced here is obtained from routine HMIS, and it is only captured when death occurs within a health facility or the deceased is taken to a health facility after death. In reaction to this gap, the Government of Tanzania (GoT) made several initiatives in order to strengthen the Tanzania CRVS system with the cause of death information. In 2016, the MoHCDGEC integrated verbal autopsies (VA) in the CRVS system in the ten wards along the coastal region, then followed by an expansion to 106 wards of the Iringa region in November 2017 [95]. To date, despite very low data, the CRVS-VA program is continuing to run in both the 10 wards and the Iringa region.

VA is an alternative method to medical certified cause of death often applied in places with incomplete CRVS system [96]. The VA method uses verbal interviews with relative or family member who took care of the deceased prior to death. Cause of Death (CoD) information is then applied to the VA document through a panel exchange of trained physician [97] or automated cause of death algorithms [98, 99].

With only 8% good and usable causes of death information, and all of it comes from health facility records, deaths which occurs in gold mining areas are likely not to have cause of death information. This is a significant gap which may prevent the government from making informed decision on health investments and policies.

1.5. Aim and objectives of the PhD project

The overarching aim of this PhD thesis is to contribute to the understanding how resource extraction projects affect health outcome indicators relevant to SDG3 "Good Health and Well-being" internationally and in Tanzania.

Against the identified research gaps, three distinct objectives were pursued within this PhD project:

- Objective 1: To assess the global (cross-country) associations between resources extraction project's activities and life expectancy
- Objective 2: To assess the national council (district) - level associations between different types of resource extraction project and morbidities in Tanzania
- Objective 3: To assess CoD patterns in communities which lives in close proximity to two gold mines in Tanzania

1.6. Research methodology: A three level perspective

This PhD thesis presents results of assessing the relationship between resource extraction projects and health using a three-stage approach (see Figure 1-2). In Chapter 2, we looked at the global picture by assessing the relationship between changes in country's resource rents and life expectancy. Chapter 3 zoom in to national level, (i.e., Tanzania), to assess council (district) level association between commodity extraction and diseases, and in Chapter 4 this PhD goes further to assess the subnational level association in CoD comparing miners and non-miners in communities neighbouring large scale mining sites, and in additional compared CoD in mining communities versus CoD in Iringa region and national estimates using GBD data. A summary of each of the perspective is provided in the following sub-chapters.

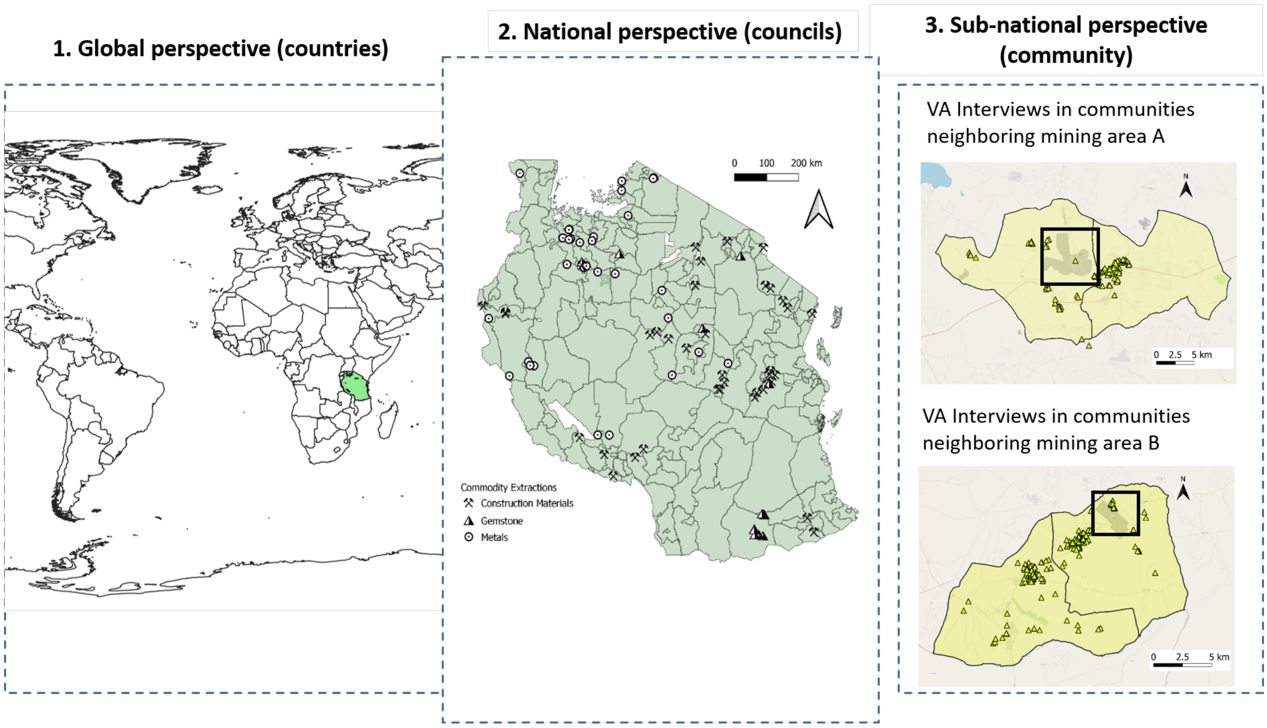

Figure 1-2: Resource extraction projects and health: Global, National and Sub-national perspectives

1.6.1.1. Global perspective: Country-level association

Using a global dataset from the WDI, this PhD assessed the short- and long-term association between country's resource rents and changes in life expectancy in the period 1970 to 2017 using regression analysis with instrumental variable framework approach. The short-term analysis covered repeated 5 years intervals from 1970 to 2017. The long interval covered the period from 1970 to 2017. The dataset covers a total of 199 countries or territories as defined the UN. The short interval association results are presented in Chapter 2 through a peer reviewed manuscript. Both short- and long-term analysis results are discussed in the discussion chapter.

1.6.1.2. National perspectives: Council (District) level association

In the second stage, this PhD zoomed in into Tanzania and assessed district-level association between presence of commodity extraction and incidence of diseases reported in the routine HMIS. This chapter capitalizes on the extended availability of routine HMIS in digital format (over 5 years worthy of continuous data). Recent technological and software advancement have contributed to the evolution of DHIS2. DHIS2 has enabled countries particularly in resource constrained settings to transform paper-based HMIS into an equivalent electronic version. This revolutionized how HMIS data is currently being collected in many LMIC. Tanzania is among the beneficiary of such revolution. Since 2011, Tanzania has been implementing DHIS2 as a central data repository for HMIS data.

This chapter assess the link between the council-level presence of commodity extraction and incidence of diseases reported routine HMIS. The data was extracted from DHIS2. The data covered the period of five years, from 2015 to 2019.

1.6.1.3. Subnational perspectives: Community (population) level association

In the third stage, this PhD further zoomed in to communities living in close proximity to two industrial gold mining in Tanzania and set a prospective surveillance system which captured and conducted verbal autopsy interviews to all death occurred between February 2019 and February 2020. This work was done in collaboration with MOHCDGEC and the Tanzanian Local Government Authority (LGA). Through this PhD, five Community Healthcare Workers (CHW) were trained to conduct verbal autopsy using a standardized electronic version of the WHO VA tool.

Prior to study implementation, sensitization meetings were conducted to important stakeholders at both national and subnational levels. The national level stakeholders included representatives from Ministry of Health, National Environmental Management Council, Ifakara Health Institute, and University of Dar-es-Salaam Geology Department. Subnational representatives came from Regional, District, Ward, and Village administration offices. In Chapter 5, this PhD presents results of the verbal autopsy study as a peer reviewed literature submitted to Environmental Health Perspectives, May 2021.

1.7. Framing project

This PhD thesis is embedded within a large research project titled “Health Impact Assessment” for engaging natural resource extraction projects in sustainable in producer region” (short title: Health Impact Assessment for Sustainable Development (HIA4SD)). The HIA4SD project is a 6-year multi-country research project funded under the Swiss Program for Research on Global issues for Development (r4d Programme; www.r4d.ch). The project consortium consists of 6 partner institutions, including four research institutes from the implementing countries in Africa: (1) Swiss Tropical and Public Health Institute (SwissTPH), Switzerland;(2) Ifakara

Health Institute (IHI), Tanzania; (3) University of Health and Allied Sciences (UHAS), Ghana; (4) Research Institute of Health Sciences (IRSS), Burkina Faso; (5) Manhica Health Research Center (CISM), Mozambique; and (6) Center for Development and Corporation (NADEL), Switzerland.

The HIA4SD project intends to analyse the conditions under which impact assessments are an effective regulatory mechanism to engage natural resources extraction projects in working towards the health-related targets of the SDG 2030 agenda in the four sub-Saharan countries named above [65]. In total, six PhD candidates pursued their research in the frame of the HIA4SD project, each focusing on a different thematic focus that complement each other. This approach allowed to triangulate the findings from the different PhD theses (e.g., comparison of the findings from the quantitative research approaches studying the effects of resource extraction projects on morbidity indicators and the findings from qualitative research on perceived health impacts of affected communities in mining areas). It also needs to be emphasized that the mixed-methods research approach pursued by the research team involved that the six PhD students worked closely together for the data collection in the different countries, as well as for the interpretation of the research findings. Consequently, there several additional publications to which this PhD project contributed (Table 1-1Table 1-1: List of publications resulting from the PhD project) in addition to the three main papers of this PhD thesis.

1.8. Publication summary

Table 1-1 presents a complete list of publications, for which the PhD candidate has been either the leading author or co-author.

Table 1-1: List of publications resulting from the PhD project

Title	Chapter	Journal	Year	Role	Status
Short-term effects of national-level natural resource rents on life expectancy: A cross-country panel data analysis	Chapter 1	PLOS ONE	2021	First author	Submitted, under review
Associations between natural resource extraction and incidence of acute and chronic health conditions: Evidence from Tanzania	Chapter 2	Environmental Research and Public Health	2021	First author	Submitted, under review
How safe are Gold Mines? Evidence from verbal autopsy data collected around gold mines in Tanzania	Chapter 3	Environmental Health Perspectives	2021	First author	Submitted, under review
Investigating Health Impacts of Natural Resource Extraction Projects in Burkina Faso, Ghana, Mozambique, and Tanzania: Protocol for a Mixed Methods Study		JMIR Research Protocols	2020	Co-author	Published
Health impacts of industrial mining on surrounding communities: Local perspectives from three sub-Saharan African countries		PLOS One	2020	Co-author	Accepted
Gendered health impacts of industrial gold mining in northwestern Tanzania:		Impact Assessment and Project Appraisal	2020	Co-author	In press

Perceptions of local communities					
Water and health in mining settings in sub-Saharan Africa: A mixed methods geospatial visualization		Geospatial Health		Co-author	In press
"It is like we are living in a different world": Health inequity in communities surrounding industrial mining sites in Burkina Faso, Mozambique and Tanzania		Frontiers in Public Health		Co-author	Under review
Increased HIV prevalence in mining areas: evidence from Demographic and Health Survey data from 17 countries in sub-Saharan Africa					Under development
Environmental Impact Assessments of Tanzania's Mineral Sector: Strengthening the inclusion of health (Policy brief)		Policy briefs, IHI Publications		Co-author	Published
Health impacts of large natural resource extraction projects in Tanzania Integrating the mineral sector into the holistic view of Sustainable Development (Policy brief)		Policy briefs, IHI Publications		Co-author	Under development

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2. Paper 1 - Short-term effects of national-level natural resource rents on life expectancy: A cross-country panel data analysis

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2.1. Abstract

While a substantial amount of literature addresses the relationship between natural resources and economic growth, relatively little is known regarding the relationship between natural resource endowment and health at the population level. We construct a 5-year cross-country panel to assess the impact of natural resource rents on changes in life expectancy (LE) at birth as a proxy indicator for population health during the period 1970-2015. To estimate the causal effects of interest, we use global commodity prices as instrumental variables for natural resource rent incomes in two-stage-least squares regressions. Controlling for country and year fixed effects, we show that each standard deviation increases in resource rents results in LE increase of 6.72% (CI: 2.01%, 11.44%). This corresponds to approximately one additional year of LE gained over five years. We find a larger positive effect of rents on LE in sub-Saharan Africa (SSA) compared to other world regions. We do not find short-term effects of rents on economic growth, but show that increases in resource rents result in sizeable increases in government revenues in the short run, which likely translate into increased spending across government sectors. This suggests that natural resources can help governments finance health and other development-oriented programs needed to improve population health.

2.2. Introduction

The extraction of natural resources such as minerals, oil and gas have the potential to drive growth, reduce poverty and promote sustainable development [1, 2]. This is particularly relevant for low- and middle-income countries in Africa and Latin America, where the mining industry might play an even more important role in a low carbon future [3-5]. Renewable energy sources and energy storage batteries are significantly more material-intensive in their composition than traditional fossil-fuel-based energy supply systems, which might result in a rapidly increasing demand in relevant metals [5-7].

A large body of literature has highlighted the negative association between natural resource endowment and economic development, often referred to as the "*resource curse*" [8-14]. The principal mechanisms underlying the resource curse outlined in the literature are i) declines in manufacturing and agriculture sectors due to exchange rate appreciation ("Dutch disease"), ii) weakened institutions due to increased rent-seeking and corruption, iii) debt overhang resulting from excess government borrowing against natural resources, and iv) reduced enrolment into higher education due to increasing availability of mining jobs [15-18]. Despite these plausible causal pathways, empirical evidence on the resource curse remains remarkably inconsistent. A recent meta-analysis shows that approximately 40% of empirical papers find negative associations between resource endowments and economic growth, 40% find no associations, and 20% find positive links [19]. In general, the negative relationship between natural resources and economic growth seen in cross-sectional models in Sachs and Warner [13] seem to disappear when country fixed effects are introduced in empirical models [20] and when measurement error concerns are appropriately addressed [21].

One key factor likely to critically shape the nonlinear relationship between resource endowment and economic growth is institutional quality [22-25]. Countries with weak institutions may be heavily affected by natural resource-related rent-seeking behaviour and corruption [26], and may provide owners of natural resources and other elites easy access to political power [27-29]. With strong institutions, natural resources can be converted into productive assets and human capital and contribute to economic development [15].

Most of the literature on natural resource endowments has focused on economic growth. Much less is known regarding the relationship between natural resources endowment and population health. Population health is influenced both directly and indirectly through activities associated with resource extraction [30]. Even though health effects of extractive industries on population health are rarely measured [31-33], both positive and negative effects on health outcomes such as the prevalence of malnutrition, vector-related diseases, sexual transmitted infections including HIV/AIDS and mental health seem plausible [34-37]. The potential interlinkages between population health and natural resource extraction are of particular concern for Africa: the continent with the highest burden of diseases [38], the lowest LE at birth [39] and the highest concentration of natural resources such as oil, copper, diamonds, bauxite, lithium and gold [40]. Hence, Africa's wealth in natural resources presents both a risk and an opportunity for public health in producer regions [41].

While extractive industries may contribute to improved health outcomes locally through improved infrastructure, employment and business opportunities, these effects are likely too small to be reflected in national estimates due to the relatively small populations directly exposed to such projects. Transitory income shocks have been used to assess the impact of GDP per capita on a range of outcomes including conflicts, democracy, population growth and civil wars [42-45]. Brückner et al. [44] show that exogenous increases in international oil prices can affect countries' population growth as well as economic development. In the present paper, we add to the existing literature on the links between a broader range of natural resource endowments and countries' development by assessing the causal relationship between natural resource endowment and LE at birth as the most commonly used proxy for overall population health. Given the importance of mining for SAA, we separately present results for this region versus the rest of the developing world, and also show population health and mining trajectories for selected countries with large natural resource endowments in the subcontinent.

2.3. Data and Methods

2.3.1. Data

We downloaded and combined data from two data sources: (1) World Development Indicators (WDI) – The World Bank [46]; and (2) Pink Sheet Data – The World Bank [47]. The WDI databank provides annual data on different series of development indicators, covering the period from 1960 to 2019. We used STATA/IC 15.0 [48] to download and analyse the data. Using the STATA plugin WBOpendata [49], we downloaded annual and country-specific indicators on Gross Domestic Product (GDP), LE and natural resources rents, and converted these data into a five-year panel data set. Our panel data comprises 1990 country-year observations covering 199 territories and ten 5-year intervals between 1970 to 2015. The 199 territories included the 193 United Nations member states [50], China Macao, China Hong Kong, Greenland and Kosovo, as well as West Bank and Gaza as special administrative regions. Data availability for the period before 1970 was extremely limited in the WDI database. The same was also true for recent years and therefore limited our analysis to 1970-2015, with a total of 186 territories contributing to the core analysis.

2.3.2. Additional calculated indicators

We derived the country's institutional quality (IQ) from the mean value of the three IQ indicators (rule of law, government effectiveness and control for corruption). We obtained country average IQ and country average current health expenditure (CHE) by averaging non-missing values for a given country using a full study sample. We then assigned countries to either low or high IQ and either low or high CHE based on these average values.

2.3.3. Exposure variable

Our independent variable of interest is country's total natural resource rents. We follow most of the literature in using the percent share of GDP as our primary measure for total natural resources rents. The main exception from this approach are papers by Sachs & Warner [11, 51], who measured resource abundance as the share of primary-product export over GDP. The main problem with this measure is that it does not account for non-renewable products such as gold and diamonds, which account for a significant proportion of exports in resource rich countries [22]; it is also heavily affected by the overall composition of each country's export sector [23]. Total natural resource rents are the sum of oil, natural gas, coal, mineral, and forest rents. Individual rents are calculated by taking the difference between the price and the production cost of each commodity and multiplying this margin by the total quantity of the specific commodity extracted [46]. Additional covariates are (1) HIV prevalence, (2) percentage of urban population, (3) secondary school enrolment, (4) tertiary school enrolment, (5) total government revenue, (6) rule of law, governance effectiveness and control for corruption, (7) CHE and (8) foreign direct investment. Definitions of these variables can be found in supplementary Appendix 1.

2.3.4. Global price series data

Data on global price series were extracted from World Bank Commodity Price Data ("The Pink Sheet") in nominal, as well as in real 2010 USD. The Pink Sheet contains commodity price indices on major commodities grouped as energy (crude oil, natural gas, coal), non-energy (cocoa, coffee, tea), agricultural, fertilizers, metals and minerals (aluminium, copper and iron), and precious metals (gold and silver). Further details on these indices are provided at the World Bank website [47].

2.3.5. Missing data and imputation

To address missing data in the WDI database, we used Multiple Imputation Chained Equation (MICE) with Predictive Mean Matching, ten nearest neighbours and fifty iterations on the additional set of variables.

2.4. Statistical methods

2.4.1. Empirical strategy

To overcome both confounding and measurement error concerns in cross-national analysis, we use exogenous variations in global commodity prices as instrument to estimate local average treatment effects (LATE) in an instrumental variable (IV) regression model. We calculate country's predicted rents by multiplying 5-years averages of country's total rents and the five energy indices. In order to illustrate the relationship between natural resource rents and LE at the country level, we also plot the relationship between predicted rents and 5-year changes in LE for the four countries in SSA with the highest natural resource rents in the sample period: Angola, Congo Republic, Equatorial Guinea and Gabon.

2.4.2. Estimation approach

To estimate empirical results on the relationship between change in LE and natural resource rents, we use a conditional convergence framework [52, 53] using 5-year intervals between 1970 and 2015. The empirical model can be described as follows:

$$\ln(\Delta LE_{it,it-5}) = \alpha\ln\,(LE_{it-5}) + \beta\ln(GDP/cap_{it-5}) + \gamma\ln(Rents_{it-5}) + \theta X_{it} + \ a_i + b_i + \ \varepsilon_{it} \quad (1)$$

where γ is the main coefficient of interest on $Rents$, and ΔLE is the 5-year change in LE in country i between time t and t-5. LE_{it-5} and GDP/cap_{it-5} are initial (beginning of the 5-year period) levels of LE and income, respectively. X_{it} is a k-dimension vector of time-varying control variables, including prevalence of HIV, percentage of births attended by skilled labour, urban population share, secondary school enrolment for females, tertiary school enrolment, total government revenue, government effectiveness, rule of law and control for corruption. a_i and b_i are the fixed effects for country and year, respectively. ε_{it} is the error term.

In our 2SLS model, we use the energy price index to instrument for rents. Globally, commodity price tends to precede changes in general price level [54] and disproportionally affect countries heavily dependent on natural resource exports. Similar to previous work of [25, 55, 56], we control for country and year fixed effects in our estimation and explore country-year level changes in rents that result from the interaction between a country's average resource rents and global commodity prices. The main identifying assumption is that the price index is not correlated with any other factor driving changes in population health. The main logic of our model is that price shocks will affect all countries, but will disproportionally affect the rents of those countries that have the largest average natural resource endowments [43, 44, 55]. Given that most of the previous literature highlights IQ as a key moderator of natural resource effects, we also estimated separate models restricted to countries with high and low institutional quality; we also estimate separate models for SSA where political systems have been the most fragile over the past fifty years.

2.5. Results

2.5.1. Descriptive statistics

Table 2-1 presents unweighted summary statistics of data points across 186 countries over 5-year interval periods from 1970 to 2015. Mean LE across all countries and all years was 65 years, with range values varying from 24 (Cambodia 1975) to 84 (Hong Kong SAR China 2015). The mean rent share in our sample was 7.88%, with a maximum value of 84.24% (Equatorial Guinea in 2000). The mean GDP per capita (measured in constant 2010 USD) over the sample period was USD 10,790.73 with a minimum of 137.60 (Mozambique 1985) and a maximum of 189,464.60 (Monaco 2015). The cross-sectional relationship between resource rents and LE shows that LE is negatively associated with an increase in resource rents (Appendix 2).

Table 2-1: Descriptive statistics of the underlying indicators

Variable	Obs	Coverage	Mean	Median	Std. Dev	Min	Max
LE	1,842	1970 □ 2015	64.78	67.72	10.81	23.60	84.28
GDP/Capita	1,555	1970 □ 2015	10,791	3,458	16,351	138	141,200
* Total rents	1,592	1970 □ 2015	7.88	2.61	12.10	-	84.24
Population (in million)	1,860	1970 □ 2015	29.4m	5.93m	113m	21,266	1,370m
% of urban population	1,845	1970 □ 2015	49.66	49.04	24.13	2.85	100.00
Prevalence of HIV	816	1970 □ 2015	1.87	0.30	4.23	0.10	28.30
School enrolment (sec. female)	1,044	1970 □ 2015	65.43	74.59	36.11	0.16	174.67
School enrolment (tertiary)	1,054	1970 □ 2015	23.45	16.71	22.94	-	119.69
Rule of law	730	1996 □ 2015	(0.09)	(0.27)	1.00	(2.41)	2.06
Government effectiveness	726	1996 □ 2015	(0.05)	(0.22)	1.00	(2.23)	2.24
Control for corruption	730	1996 □ 2015	(0.06)	(0.33)	1.01	(1.77)	2.44
* Government revenue	777	1970 □ 2015	25.64	24.47	11.31	1.32	120.49
Foreign direct investment	1,394	1970 □ 2015	3.23	1.54	7.04	(25.78)	103.34
* Current health expenditure	692	2000 □ 2015	6.09	5.72	2.56	1.34	20.41

Notes: Data from World Bank Development Indicators (WDI). Data sampled from 186 countries. Data coverage varies across countries and across indicators. * is measured in % GDP, m indicates that the figure is in millions. Parenthenses denote a negative number.

2.6. First stage regression and instrumental variable estimation

Table 2-2 presents the results from the first stage regressions for the five price indices considered. Overall, the energy index has strong prediction power of annual variation in total natural resource rents, with an F-statistic of 13.43.

Table 2-2: First stage regression: Predicting rents with global price indices

VARIABLES	Log (total rents, % GDP)				
	(1)	(2)	(3)	(4)	(5)
Log (Pred. rents using *energy index*)	0.144*** (0.039)				
Log (Pred. rents using *non-energy index*)		-0.104 (0.075)			
Log (Pred. rents using minerals index)			0.148** (0.058)		
Log (Pred. rents using metals index)				0.121** (0.059)	
Log (Pred. rents using precious metals index)					0.081** (0.037)
Foreign Direct Investment, net inflows (% of GDP)	-0.000 (0.005)	-0.001 (0.005)	-0.001 (0.005)	-0.001 (0.005)	-0.001 (0.005)
Urban population (% of total population)	0.006 (0.007)	0.008 (0.007)	0.008 (0.007)	0.008 (0.007)	0.007 (0.007)
Prevalence of HIV (% of population age 15-49)	-0.022 (0.021)	-0.020 (0.021)	-0.022 (0.021)	-0.021 (0.021)	-0.021 (0.021)
School enrollment, secondary. female (% Gross)	-0.007** (0.003)	-0.006* (0.003)	-0.007** (0.003)	-0.007** (0.003)	-0.007** (0.003)
School enrollment, tertiary (% Gross)	-0.010*** (0.004)	-0.013*** (0.004)	-0.012*** (0.004)	-0.012*** (0.004)	-0.012*** (0.004)
Constant	-0.787*** (0.241)	-0.858*** (0.243)	-0.866*** (0.241)	-0.875*** (0.241)	-0.836*** (0.241)
Observations	1,836	1,836	1,836	1,836	1,836
Number of countries	186	186	186	186	186
F-stats (instrument)	13.45	1.94	6.50	4.15	4.66
Prop > F	0.0003	0.1638	0.0108	0.0416	0.0310

Notes: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Notes: All models include country and year fixed effects. Coefficients displayed are linear regression coefficients with cluster-robust standard errors in parentheses

Figure 2-1 shows the correlation between global energy indexes and the global average resource rents over the full 1970-2015 sample period. The correlation between average rents and the global energy index is 0.67, appearing to be stronger in the second half of the sample (post 1990).

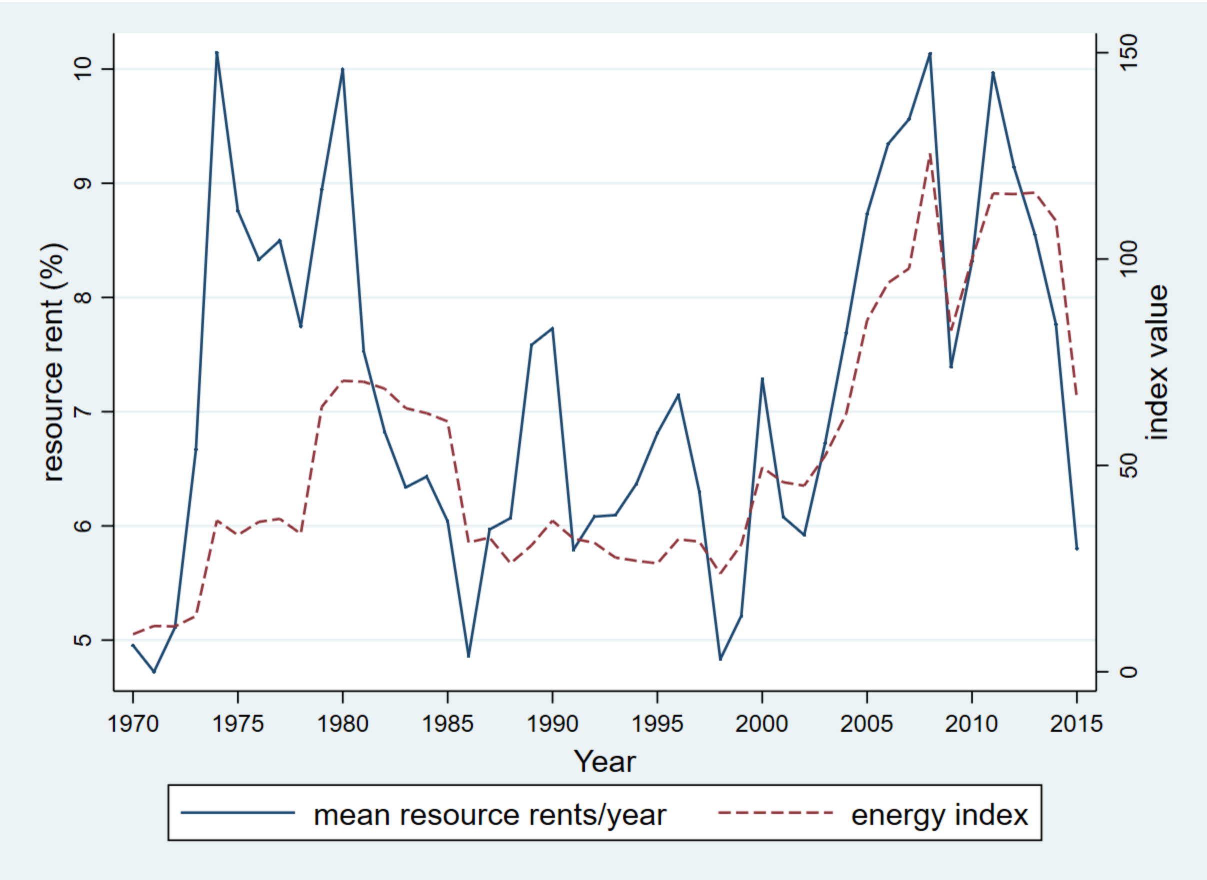

Figure 2-1: Relationship between energy index and resource rents

Table 2-3Table 2-3: Causal impact of rents on changes in LE shows the main ordinary least squares (OLS) and IV estimation results. Our preferred IV specification (Column 3) suggests that a 100% increase in resource rents results in a 2.7% increase in LE (CI: 1%, 4.4%). These results change only marginally when we add additional covariates in column 4. In terms of the covariates included, prevalence of HIV appears to be the only variable that consistently (and unsurprisingly) predicts subsequent changes in LE.

Table 2-4 shows the results of the stratification by region and IQ. As shown in column 1 & 2, the treatment effects appear to be larger for SSA than for other regions. Impacts seem to be similar for countries with high and low IQ.

Table 2-3: Causal impact of rents on changes in LE

VARIABLES	[Log (Change in LE)]$_{t,t-5}$			
	OLS		IV	
	(1)	(2)	(3)	(4)
[Log (total rents)]$_{t-5}$	0.001 (0.001)	0.001 (0.001)	0.027*** (0.009)	0.028*** (0.010)
Log (LE)$_{t-5}$	-0.218*** (0.036)	-0.247*** (0.045)	-0.240*** (0.040)	-0.255*** (0.049)
Log (GDP/Cap)$_{t-5}$	-0.012*** (0.005)	-0.009* (0.005)	-0.003 (0.006)	-0.001 (0.007)
[Foreign Direct Investment, net inflows (% of GDP)]$_t$		0.000 (0.000)		0.000 (0.000)
[Urban population (% of total population)]$_t$		0.001* (0.000)		0.000 (0.000)
[Prevalence of HIV (% of population ages 15-49)]$_t$		-0.003** (0.002)		-0.003* (0.002)
[School enrolment, sec. female (% Gross)]$_t$		-0.000 (0.000)		-0.000 (0.000)
[School enrolment, tertiary (% Gross)]$_t$		-0.000 (0.000)		-0.000 (0.000)
Constant	0.960*** (0.141)	1.041*** (0.163)	1.006*** (0.151)	1.048*** (0.174)
Observations	1,656	1,656	1,656	1,656
Number of country	186	186	186	186

Notes: All models include country and year fixed effects.
Cluster-robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Table 2-4: Impact of rents by region, institutional quality and current health expenditure

VARIABLES	Log (Change in LE)$_{t,t-5}$					
	Excluding SSA	SSA	Low Institutional Quality	High Institutional Quality	Low Current Health Expenditure	High Current Health Expenditure
Log(total rents)$_{t-5}$	0.003 (0.006)	0.062 (14.477)	0.043* (0.025)	0.013 (0.012)	0.010 (0.009)	0.058* (0.032)
Log(LE)$_{t-5}$	-0.234*** (0.068)	-0.288 (0.966)	-0.257*** (0.063)	-0.245*** (0.059)	-0.168*** (0.028)	-0.319*** (0.077)
Log(GDP/Cap)$_{t-5}$	-0.004 (0.006)	-0.012 (0.343)	-0.010 (0.009)	0.007 (0.008)	-0.005 (0.005)	0.019 (0.028)
[Foreign Direct Investment, net inflows (% of GDP)]$_t$	0.000 (0.000)	0.000 (0.014)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
[Urban population (% of total population)]$_t$	0.001 (0.001)	-0.000 (0.217)	0.001 (0.001)	0.000 (0.000)	0.000 (0.000)	0.001 (0.001)
[Prevalence of HIV (% of population ages 15-49)]$_t$	-0.000 (0.004)	-0.002 (0.705)	-0.003 (0.002)	-0.002** (0.001)	-0.001 (0.002)	-0.004* (0.002)
[School enrolment, sec. female (% Gross)]$_t$	-0.000 (0.000)	-0.000 (0.109)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
[School enrolment, tertiary (% Gross)]$_t$	-0.000 (0.000)	0.001 (0.078)	-0.000 (0.001)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
Constant	0.965*** (0.242)	1.060 (30.384)	1.120*** (0.219)	1.074*** (0.256)	0.744***(0.119)	1.178*** (0.273)
Observations	1,226	430	1,026	630	880	776
Number of countries	138	48	115	71	98	88

Cluster-robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

2.6.1. Country case studies

Figure 2-2 shows average income growth as well as rents over the study period for the four countries with the largest natural resource rents (Fig 2). On average, in each of the four countries, total natural resource rents contributed over 20% of the national GDP, with Equatorial Guinea having the highest average of 30.44% (Figure 2). Global natural resource and energy prices were highest in the 1970 and 1980s and lowest in the 1990s and early 2000s. Angola and Equatorial Guinea experienced positive changes in LE throughout the period, with the largest improvements reported in Angola in 2005 and 2010. Overall, the patterns seen in Angola, Republic of Congo and Gabon seem well aligned with the main results presented in the previous section: relatively steady improvements in the 1970s and 1980s as well as post 2005, when resource prices were high, and much weaker (or negative) improvements in the 1990s when resource prices were low. Even though the weaker performance during the 1990s was at least partially due to HIV [57], none of the countries shown here was hit particularly hard by HIV, with HIV prevalence rates below 5% throughout the sample period [58]. The most noticeable outlier is Equatorial Guinea: even though the country very heavily depends on its oil exports, it seems to have succeeded in maintaining steady increases in LE.

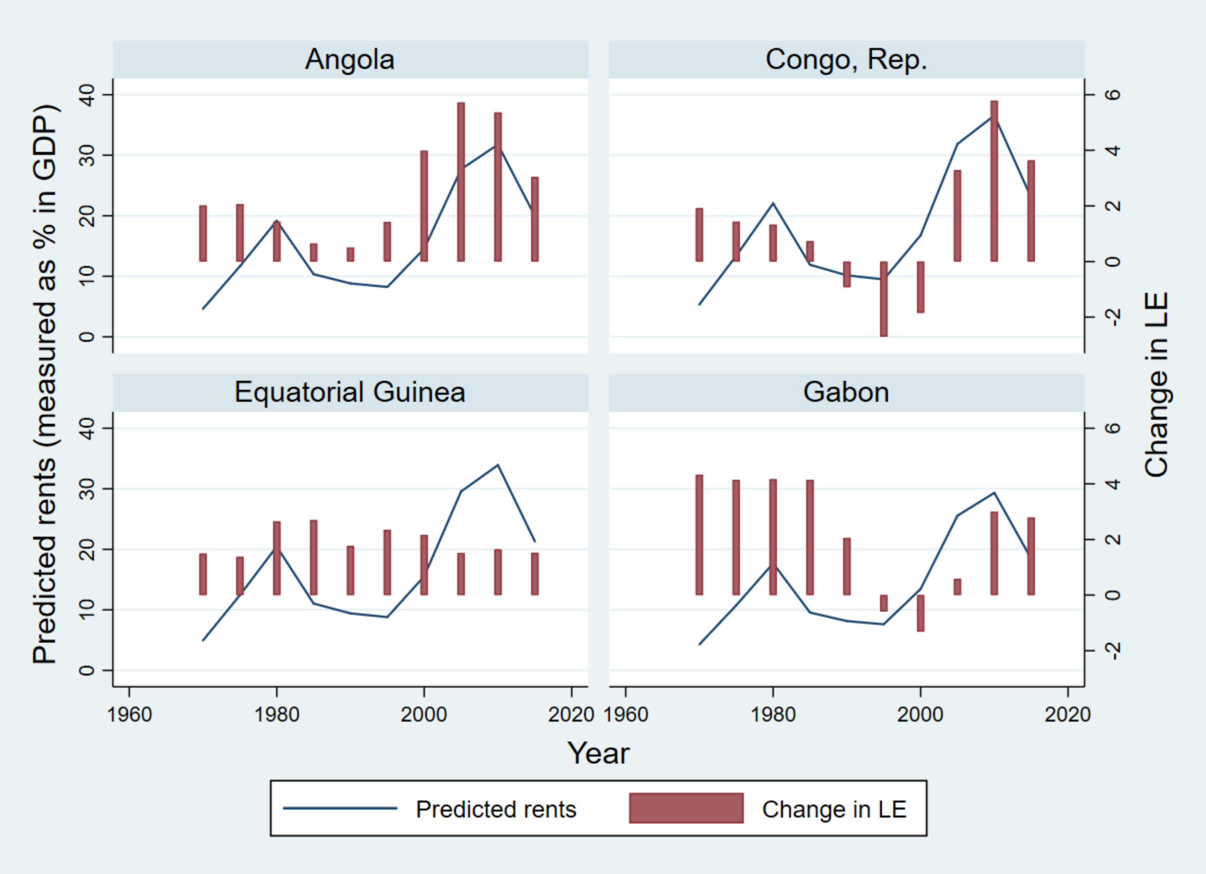

Figure 2-2: Relationship between predicted rents and change in LE in five-year intervals

2.7. Discussion

In this study, we use a large cross-country panel dataset to assess the causal effects of natural resource rents on changes in population health during the period 1970 to 2015 using instrumental variable regression. In a first step, we show that global variations in commodity prices strongly predict the magnitude of natural resource rents earned by countries conditional on country and year fixed effects. Using the observed variation in rents created by global prices in our models, we then show that each standard deviation increases in resource rents results in about one additional year of LE over a five-year period.

While we find no evidence of short-term changes in economic growth, we find that fluctuations in global commodity prices do result in substantial changes in government revenue (Table 2-5: Relationship between resource rents and government revenue and health expenditure). These results are similar to Deaton and Miller [59] and Collier et al. [60] who use vector autoregressive models to test the effects of commodity prices on short-term incomes. It seems plausible that changes in government revenue increase governments' ability to support public health and development programs that can potentially contribute to improved population health. While our data does not allow us to directly identify the causal mechanisms driving these differences, one possible explanation for the larger effects of rents observed in SSA is that governments in stable settings (i.e., with strong institutions and fiscal management) may be better able to smooth incomes over time either by building up reserves (e.g., Norway) [61], through increased borrowing in periods when commodity prices are low, or by hedging resource prices in global markets [62]. This will, however, be difficult in countries with limited fiscal discipline and weak institutions, which will therefore be more exposed to cyclical revenue streams as well as cyclical changes in LE, as shown in our subsample analysis. When we stratify our sample by major geographical regions and average institutional quality, we find large positive effects in the SSA sample, even though the differences across subgroups are not statistically significant. We also observe on average larger resource effects on countries with lower institutional quality; however, estimates on countries with lower institutional quality are relatively imprecise so that subgroup confidence intervals overlap.

A recent scoping review on health in the context of resource extraction suggests that most studies on the relationship between natural resources and health focus on occupational health risks and exposures to toxic substances related to mining activities [31]. The few studies available to date investigating community-level health impacts mostly focus on specific health conditions, highlighting negative effects of mining on malnutrition, malaria, HIV and mental health in specific settings [34, 35, 37]. The results presented in this study are conceptually different from these previous studies because we focus on average country-level health outcomes rather than health outcomes directly observed in contexts where resources are extracted. Even though extractive industries may contribute to improved health outcomes locally through improved public infrastructures, employment and business opportunities, these effects are likely to be too small to be reflected in national estimates due to the relatively small populations directly exposed to such projects. From a central government perspective, natural resources are primarily of interest as a source of additional income, allowing governments to promote access to and improve quality of health services, along with socio-economic development more broadly [63, 64] that can contribute to improved health outcomes [41, 64, 65]. Our results suggest that booms in global commodity prices do indeed create windfall revenue gains for governments in the short run. This does not imply, however, that natural resources are necessarily positive for health or development in the long run: increased revenues during booms also imply negative revenue shocks during global commodity market contractions, with likely immediate negative repercussions on government funding to social and health programs unless these shocks can be offset by fiscal reserves or external financing [66].

Table 2-5: Relationship between resource rents and government revenue and health expenditure

VARIABLES	Log (Revenue)	Log(Current Health Expenditure)	Log(GDP/Cap)
Log(total rents)	0.165* (0.096)	-0.052 (0.073)	-0.087 (0.104)
Log(LE)	0.400* (0.209)	0.176 (0.157)	0.307 (0.234)
Log(GDP/Cap)	0.082 (0.056)	-0.080 (0.055)	
Foreign Direct Investment, net inflows (% of GDP)	0.001 (0.001)	-0.001 (0.001)	0.000 (0.002)
Urban population (% of total population)	0.003 (0.003)	-0.008** (0.004)	0.009* (0.005)
Prevalence of HIV (% of population ages 15-49)	0.008 (0.009)	-0.004 (0.008)	0.005 (0.010)
School enrollment, Sec. Female (% Gross)	0.002 (0.001)	0.000 (0.001)	0.004** (0.001)
School enrollment, tertiary (% Gross)	0.002 (0.002)	0.001 (0.001)	0.008*** (0.002)
Constant	0.195 (0.806)	2.104*** (0.675)	4.531*** (0.896)
Observations	1,842	1,842	1,842
Number of countries	186	186	186

Cluster-robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

2.8. Strengths and limitations

This study is, to our knowledge, the most comprehensive analysis of the empirical relationship between natural resources and improvements in LE using cross-country data to date. Despite the large data set compiled for this study, several limitations are worth highlighting. First, and as already mentioned, missing data is quite common in the WDI database. This was addressed by limiting data extraction to: (1) a specific set of indicators relating to population, health and resource endowment; (2) restricting to data between 1970 and 2017; and (3) by using a multiple imputation algorithm. A second limitation of all cross-country analyses is that variables capturing complex aspects of social, political and health systems are largely lacking. These factors are likely important for understanding some of the changes in LE observed and may help explain the empirical relationships seen in our analysis. Our analysis also focuses on variation in rents that are driven by energy prices – fluctuations in other rents may affect countries in different ways not captured in our analysis. Finally, we did not adjust for geopolitical or global events such as wars and disease epidemics. While these events should not be correlated with the price series conditional on country and year fixed effects, we cannot fully rule out residual confounding concerns.

2.9. Conclusion

The results presented in this paper suggest that natural resources can help governments in low- and middle-income countries to improve population health. On average, we find that LE in countries with large natural resource endowments improves more rapidly than LE of countries with small endowments during the peirod with high commodity prices. However, this also implies that global contractions in commodity prices can slow down progress in population health. To avoid these negative repercussions during commodity price contractions, countries with large resource endowments should put mechanisms in place that allow smoothing of commodity-related incomes over time, and ensure sustainable and continued financing for public services, including health care. More research is needed to identify the best mechanisms for countries to reach this goal.

2.10. Acknowledgements

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3. Paper 2 - Associations between natural resource extraction and incidence of acute and chronic health conditions: Evidence from Tanzania

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3.1. Abstract

Natural resource extraction projects are often accompanied by complex environmental and social-ecological changes. In this paper, we evaluate the association between commodity extraction and the incidence of diseases. We retrieved council (district)-level outpatient data from all public and private health facilities from the District Health Information System (DHIS2). We combined this information with population data from the 2012 national population census and a geocoded list of resource extraction projects from the Geological Survey of Tanzania (GST). We used Poisson regression with random effects and cluster-robust standard errors to estimate the district-level associations between the presence of three types of commodity extraction (metals, gemstone and construction materials) and the total number of patients in each disease category in each year. Metal extraction was associated with reduced incidence of several diseases, including chronic diseases (IRR=0.61, CI: 0.47-0.80), mental health disorders (IRR=0.66, CI: 0.47-0.92) and undernutrition (IRR=0.69, CI: 0.55-0.88). Extraction of construction materials was associated with an increased incidence of chronic diseases (IRR=1.47, CI: 1.15-1.87). This study finds that the presence of natural resources commodity extraction is significantly associated with changes in disease-specific patient volumes reported in Tanzania’s DHIS2. These associations differed substantially between commodities, with most protective effects shown from metal extraction

Keywords: DHIS2; health facility disease diagnoses; health impact assessment; natural resources extraction; routine health management information system

3.2. Introduction

Implementation of natural resource extraction projects often triggers a series of complex environmental and social-ecological changes [1-4]. These changes include increased population growth and urbanization, infrastructure improvements, movement and installation of heavy machinery, changes in land use, increased business and economic opportunities, and household resettlement [5-7]. Such changes can positively or negatively affect the health status of communities in proximity of resource extraction activities [8-12]. Studies have linked activities of the resource extraction with increased incidence of respiratory diseases [13,14], sexually transmitted infections, including HIV/AIDS [15], malnutrition [16], vector-related diseases [17-19], mental health [20,21] and cancer diseases [9]. On the other hand, resource extraction projects can positively contribute to population health through improved labor market opportunities and corporate social responsibility (CSR) activities that support local health systems or contribute to general health and education programs [22-25].

Even though a growing literature has highlighted the importance of comprehensive health impact assessments (HIA) of mining projects [26-28], evidence on the impact of large-scale mining projects on population health remains limited. One of the key challenges for such projects is the lack of reliable data sources for local population health [4,29,30]. Due to major international efforts, such population level health data is increasingly becoming available at the health facility level in low- and middle-income countries, often supported by new digital systems. DHIS2 (District Health Information Systems) is one such web-based software application that can be integrated into the national health management information system (HMIS) to facilitate data collection, data use, data management and archiving of routine data [31]. DHIS2 has been installed in over 73 countries worldwide [32], allowing researchers and policy makers to collect and aggregate data across the health system [33-35].

In this study, we use data from Tanzania's DHIS2 to evaluate the association between the presence of different types of natural resource extraction projects and disease incidence at the district level.

3.3. Materials and Methods

3.3.1. Study setting

Tanzania has an estimated total population of 57 million people [36] and ranks 163 out of 189 countries and territories with a human development index value of 0.529 [37]. Tanzania has a decentralized health system with administrative units in the mainland area extending to 26 regions, 184 districts and municipal councils, and 8,941 health facilities (including both private and public health facilities). According to the Institute of Health Metrics Evaluation (IHME) Global Burden of Diseases estimates, the top three Disability Adjusted Life Years (DALYs) per 100,000 population in Tanzania between 2015 and 2019 have been consistently shown as (1) Neonatal disorders, (2) lower respiratory infections, and (3) HIV/AIDS [38].

Tanzania has a long history of resource extraction activities [39] and was one of the earliest DHIS2 implementers after the platform was developed in 2007 [40,41].

3.3.2. Study design

This is a multi-year cross-sectional study that aims to assess the associations between presence of district-level commodity extraction and disease diagnoses reported in Tanzania's DHIS2.

3.3.3. Data

Disease diagnoses data comes from the DHIS2 outpatient department (OPD) dataset indicators and one additional indicator (i.e., total clients tested and found positive for HIV) from the HIV testing and counselling dataset. As part of national HMIS, disease diagnoses made during health facility visits are captured and summarized in HMIS books and summary information is entered into the DHIS2. We extracted annual aggregated data at the district-level covering the period 2015 to 2019. The data contain counts of disease diagnoses from health facility visits (both public and private). We excluded laboratories, maternity homes and all facilities that do not provide general OPD services. We excluded the region of Dar-es-Salaam (with 5 administrative districts) due to the high density of population and health facilities, and the absence of large scale resource extraction projects. We merged data from the Ifakara Town district and Kilombero District District to accommodate available shape files in the Geographical Information System (GIS), whereby Ifakara Town District was formally part of Kilombero District District until 2016. Our final data set contained a total of 178 districts.

Data on natural resource extraction activities was accessed via the mineral occurrence map of Tanzania [42], which is based on the Geological Survey of Tanzania (GST) conducted in 2015 [43]. The GST lists a total of 480 resource extraction projects with location coordinates and commodity types. In this list, 42% of the projects are marked prospective, 20% active and 38% inactive. We restricted our analysis to natural resource extraction projects that were classified as active in the GST as of 2015 (at the beginning of our sample period).

3.4. Variables

3.4.1. Exposure variables

The primary exposure variable of interest was the presence of a given commodity extraction in the district. We considered three types of commodity extraction: (1) construction materials; (2) gemstone; and (3) metals. As shown in Figure 3-1, most districts contain only one type of extraction project; multiple types of extraction projects were found only in seven districts. Given that coal was identified in only one district and hydrocarbons are mostly located offshore, these two groups were excluded from our analysis. A complete list of the specific commodities extracted is available in Appendix A (Table 3-6).

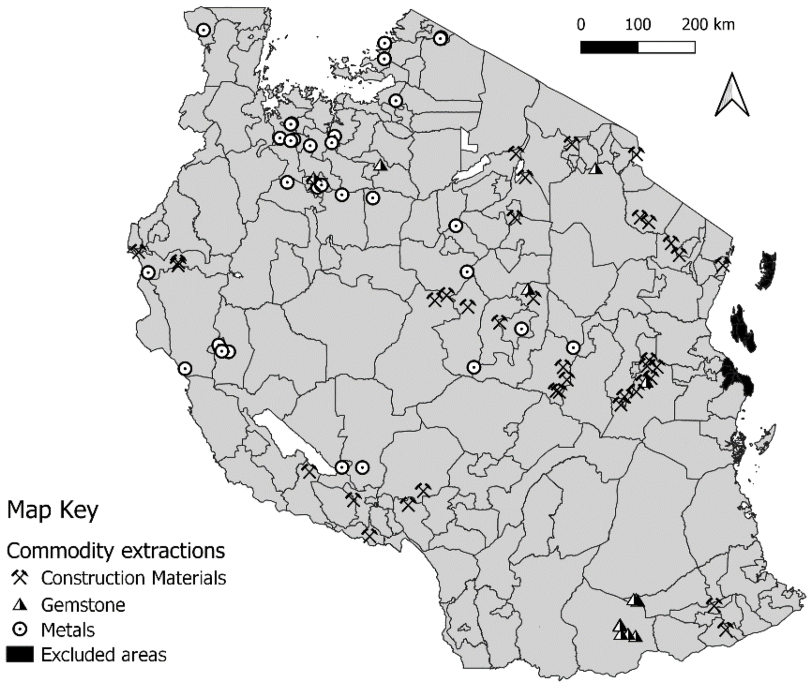

Figure 3-1: Location of selected commodity extraction projects in Tanzania

3.4.2. Outcome variables

We selected and grouped disease indicators based on the environmental health areas (EHA) framework defined in the HIA guidelines developed by the International Finance Corporation (IFC) [44]. The EHA framework provides a conceptual linkage between resource extraction activities and potential community-level impacts, incorporating a variety of biomedical and key social determinants of health [45]. For this study, we divided all reported health programs in the DHIS2 into disease groups based on the EHA framework – these groups as well as the OPD indicators falling into each group are summarized in Table 3-1: List of disease groups and included outpatient department (OPD) indicators from DHIS2Table 3-1.

Table 3-1: List of disease groups and included outpatient department (OPD) indicators from DHIS2

Disease groups	OPD Indicator(s) included in disease group
Chronic diseases	Neoplasms/cancer, hypertension, other cardiovascular diseases, diabetes mellitus, bronchial asthma
Diarrhea	Diarrhea with no dehydration, diarrhea with severe dehydration, diarrhea with some dehydration, dysentery
Sexual transmitted diseases	HIV positive[1], genital discharge syndrome, genital ulcer syndrome, pelvic inflammation, sexual transmitted infections
Malaria	Malaria blood smear positive, Malaria mRDT positive, clinical malaria
Mental health disorders	Psychoses, neuroses
Parasitic infections	Intestinal worms, schistosomiasis
Respiratory health	Pneumonia, non-Severe, pneumonia, severe upper respiratory infections
Road traffic injuries	Road traffic accidents
Tuberculosis	Tuberculosis
Undernutrition	Kwashiorkor, marasmic kwashiorkor, marasmus, moderate malnutrition

[1] This indicator is obtained from HIV Counseling and Testing (HTC) unit. Notes: HIV stands for Human Immunodeficiency Virus, mRDT stands for Malaria Rapid Diagnostic Test.

3.4.3. Statistical Analysis

To assess the association between the presence of commodity extraction projects and disease incidence, we used Poisson regression models controlling for period (in years), population, region fixed effects and number of health facilities by time in the district. We assumed all commodity extraction projects to remain active over the full sample period. We employed cluster-robust standard errors to correct for residual correlation at the district level over time as well as over dispersion. We report incidence rate ratios (IRR) and corresponding 95% confidence intervals (CI) from the final models. All analysis was implemented using the STATA 15.0 statistical software package [46].

3.4.4. *Ethical considerations*

This study obtained ethical approval from Ifakara Health Institute Review Board and the National Institute for Medical Research (NIMR) in Tanzania, the Ethics Committee of Northwestern and Central Switzerland (Ethikkommission Nordwest- und Zentralschweiz, EKNZ) and the institutional review board of the Swiss Tropical and Public Health Institute (Swiss TPH) in Switzerland.

3.5. 3. Results

3.5.1. *Participants: Overall characteristics*

A summary overview of the number and type of health facilities and commodity extraction projects in districts in Tanzania is shown in Table 3-2. On average, a district contained one hospital, five health centres, 36 dispensaries and one health clinic. Two districts were exposed to all three types of commodity extraction, five districts were exposed to two types of commodity extraction and 38 districts exposed to only one type of commodity extraction.

Extraction of construction materials occurred in 14% (N=25) of all districts, metals in 12% (N=22) and gemstone in 4% (N=7). A total of 1% (N=2) of the districts had all of the three types of commodity extraction and 4% (N=7) had at least two types of commodity extractions. 45 districts (25%) were exposed to at least one type of commodity extraction.

Table 3-3 summarizes the average number of patients recorded at the district level in each year. Out of the main disease categories analyzed, the most common were respiratory infections and malaria, with an average of 52,704 and 33,981 cases across the five years, respectively. The least commonly diagnosed health problems were cancer and tuberculosis, with an average of 127 and 266 cases per year, respectively.

Table 3-2: Overview of the number and type of health facilities and commodity extraction projects per district in Tanzania

Facility type	Average count	Median count	Minimum	Maximum
Hospital (N=264)	1.5	1	0	11
Health Center (N=816)	54.6	4	1	16
Dispensaries (N=6,423)	36.0	35	5	83
Health Clinics (N=166)	0.9	0	0	23

Commodity extracted	N	% exposed
Construction materials	38	14%
Gemstone	13	4%
Metals	32	12%

Table 3-3: Number of disease diagnoses per 100,000 population by year

Disease group indicator	Year of observation					Average
	2015	2016	2017	2018	2019	(2015/2019)
Cancer	110	119	123	130	151	127
Cardiovascular	2,643	3,068	3,649	4,661	5,840	3,972
Diabetes	1,020	1,173	1,392	1,637	1,970	1,438
Diarrhea	11,245	11,249	11,684	12,927	13,313	12,084
HIV/AIDS (+ve test results)	1,025	1,231	1,320	1,401	1,593	1,314
Malaria	39,875	31,125	29,315	33,182	36,409	33,981
Mental health	434	439	500	582	662	524
Parasites	6,748	6,570	6,727	7,772	8,033	7,170
Respiratory infection	37,431	42,361	49,854	65,460	68,413	52,704
Road Traffic Accidents	811	828	785	773	795	798
Sexual Transmitted Infections	4,720	4,760	4,973	6,314	7,410	5,636
Tuberculosis	266	265	252	279	267	266
Undernutrition	476	425	342	371	350	393
Other diagnoses[1]	51,109	53,944	58,692	71,227	83,777	63,750

[1] Includes all other diagnoses which are not featured in any of the disease groups used for this study.

Table 3-4 shows the association between type of commodity extraction and disease groups. In the fully adjusted models, we find that the presence of construction material extraction is associated with an increased incidence of chronic diseases (IRR=1.47, 95% CI=1.15 - 1.87). The presence of metals extraction was associated with a reduced incidence of chronic diseases (0.61, 0.47 - 0.80), mental health disorders (0.66, 0.47 - 0.92), undernutrition (0.69, 0.55 – 0.88), parasitic infections (0.84, 0.72 – 0.98), sexual transmitted diseases (0.85, 0.74 – 0.97) and diarrhea diseases (0.88, 0.77 – 0.10). No association was found between gemstone extraction and any of the main disease categories. The outputs of the crude model are available in Table 3-7 in the appendix.

Table 3-5 shows the results for disaggregated disease categories. Extraction of construction materials was associated with an increased incidence of hypertension (IRR=1.49, CI: 1.11 – 2.01), neoplasms/cancer diseases (IRR=1.46, CI: 1.07 – 1.99), bronchitis asthma (1.38, 1.14 – 1.66) and other cardiovascular diseases (1.72, 1.27 – 2.32). Gemstone extraction was associated with a significant increase in the incidence of malaria (blood slide microscopy method) (2.08, CI: 1.06 – 4.07), non-severe pneumonia (1.40, 1.04 – 1.87), diarrhea with some dehydration (IRR: 1.38, 1.11 – 1.73) and severe pneumonia (1.25, 1.01 – 1.54). Protective effects were found for metal extraction projects in the majority of disease-specific indicators.

Table 3-4: Relationship (adjusted model) between disease groups and type of commodity extraction

	Type of Commodity Extraction

Disease groups	Construction materials		Gemstone		Metals	
	IRR	CI	IRR	CI	IRR	CI
Chronic diseases	1.47***	1.15 - 1.87	1.00	0.69 - 1.47	0.61***	0.47 - 0.80
Respiratory infections	1.02	0.90 - 1.16	1.10	0.90 - 1.34	0.90*	0.80 - 1.01
Tuberculosis	1.14	0.85 - 1.54	1.28	0.78 - 2.10	0.76*	0.56 - 1.03
Diarrhea	0.97	0.84 - 1.12	1.25*	0.99 - 1.59	0.88**	0.77 - 0.99
Undernutrition	0.90	0.67 - 1.20	1.06	0.67 - 1.68	0.69***	0.55 - 0.88
Malaria	0.96	0.66 - 1.39	1.23	0.84 - 1.79	1.08	0.85 - 1.38
Parasitic diseases	1.08	0.93 - 1.26	1.10	0.83 - 1.47	0.84**	0.72 - 0.98
Sexual transmitted diseases	1.13	0.94 - 1.37	1.10	0.83 - 1.46	0.85**	0.74 - 0.97
Road traffic accidents	1.13	0.90 - 1.43	1.24	0.85 - 1.80	0.90	0.72 - 1.11
Mental health	1.08	0.79 - 1.49	1.34	0.70 - 2.59	0.66**	0.47 - 0.92

Note: Estimates are adjusted for cluster robust; *** p<0.01, ** p<0.05, * p<0.1

Table 3-5: Relationship (adjusted model) between disease specific indicators and type of commodity extraction

Disease groups	Type of Commodity Extraction					
	Construction materials		Gemstone		Metals	
	IRR	CI	IRR	CI	IRR	CI
Chronic diseases						
Neoplasms/cancer	1.46**	1.07 - 1.99	0.86	0.48 - 1.54	0.93	0.65 - 1.33
Hypertension	1.49***	1.11 - 2.01	1.08	0.66 - 1.78	0.56***	0.41 - 0.77
Other cardiovascular diseases	1.72***	1.27 - 2.32	0.74	0.43 - 1.27	0.62***	0.44 - 0.88
Diabetes mellitus	1.41*	1.00 - 2.00	0.91	0.53 - 1.56	0.42***	0.29 - 0.62
Bronchitis asthma	1.38***	1.14 - 1.66	1.06	0.84 - 1.34	0.82**	0.67 - 0.99
Respiratory infections						
Pneumonia non-severe	1.01	0.86 - 1.20	1.25**	1.01 - 1.54	0.90	0.78 - 1.02
Pneumonia severe	1.04	0.87 - 1.24	1.40**	1.04 - 1.87	0.82**	0.67 - 0.99
Upper respiratory infections	1.02	0.89 - 1.17	1.051	0.85 - 1.30	0.91	0.80 - 1.04
Tuberculosis						
Tuberculosis	1.14	0.85 - 1.54	1.279	0.78 - 2.10	0.76*	0.56 - 1.03
Diarrhea						
Diarrhea with no dehydration	0.98	0.84 - 1.15	1.190	0.93 - 1.53	0.89*	0.77 - 1.02
Diarrhea with severe dehydration	0.86	0.69 - 1.08	1.49	0.93 - 2.4	0.91	0.74 - 1.12
Diarrhea with some dehydration	1.01	0.85 - 1.20	1.38***	1.11 - 1.73	0.91	0.78 - 1.07
Dysentery	0.85	0.61 - 1.18	1.46*	0.99 - 2.14	0.76*	0.57 - 1.01
Undernutrition						
Kwashiorkor	0.91	0.68 - 1.21	1.11	0.57 - 2.15	0.64***	0.48 - 0.86
Kwashiorkor marasmus	1.06	0.75 - 1.50	0.88	0.56 - 1.38	0.68***	0.52 - 0.90
Malnutrition moderate	0.94	0.67 - 1.31	0.93	0.57 - 1.50	0.72**	0.56 - 0.93
Malaria						
Blood slide microscopy	1.11	0.70 - 1.73	2.08**	1.06 - 4.07	0.49***	0.37 - 0.66
Clinical	1.17	0.82 - 1.69	1.11	0.73 - 1.70	0.88	0.69 - 1.12
MRDT	0.82	0.54 - 1.24	1.28	0.84 - 1.95	1.21	0.93 - 1.58
Parasite diseases						

Intestinal worms	1.08	0.92 - 1.27	1.06	0.79 - 1.44	0.82**	0.70 - 0.97
Schistosomiasis	1.09	0.90 - 1.32	1.28	0.93 - 1.76	0.94	0.77 - 1.14
Sexual transmitted diseases						
HIV/AIDS +ve test results	1.11	0.88 - 1.39	1.20	0.76 - 1.90	0.91	0.73 - 1.13
Genital discharge syndrome	1.07	0.86 - 1.33	0.96	0.73 - 1.28	0.84	0.69 - 1.03
Genital ulcer syndrome	1.21	0.96 - 1.52	1.03	0.80 - 1.34	0.83**	0.71 - 0.98
Pelvic inflammation	0.89	0.71 - 1.11	1.19	0.76 - 1.86	0.86	0.70 - 1.05
Sexual transmitted infections	1.12	0.94 - 1.34	1.36	0.93 - 1.99	0.81***	0.69 - 0.95
Road traffic accidents						
Road traffic accidents	1.13	0.90 - 1.43	1.24	0.85 - 1.80	0.90	0.72 - 1.11
Mental health						
Psychoses	1.03	0.70 - 1.50	1.65	0.75 - 3.65	0.54***	0.35 - 0.84
Neuroses	1.23	0.92 - 1.64	1.23	0.70 - 2.16	0.74**	0.57 - 0.96

Note: Estimates are adjusted for cluster robust; *** $p<0.01$, ** $p<0.05$, * $p<0.1$; mRDT stands for malaria rapid diagnostic test, HIV stands for human immunodeficiency virus.

3.6. Discussion

In this paper, we evaluated the relationship between the district-level presence of natural resource extraction activities and the disease-specific patient volumes reported across all health facilities in Tanzania in a given district and year.

Our results show that the presence of commodity extraction projects are associated with significant changes in incidence of diseases reported in the routine national HMIS of Tanzania. The changes in disease incidence appear to differ substantially by the type of commodity extracted: in districts where metal resources are extracted (most typically Gold in Tanzania), we observed a significant decrease in the incidence of chronic diseases (–39%), mental health disorders (–34%), undernutrition (–31%), parasitic infections (–26%), sexually transmitted diseases (–15%) and diarrheal diseases (–13%). On the other hand, the presence of construction material extractions was associated with a significant increase in the incidence of chronic diseases (+47%), including hypertension (+49%), neoplasms/cancer (+46%), bronchitis asthma (+38%) and other cardiovascular diseases (+72%). Gemstone extraction was not associated with any of the aggregated disease categories, but showed positive associations with severe and non-severe pneumonia (+40% and +25%, respectively), as well as diarrhea with dehydration (+38%).

The consistent inverse association between metal extraction industry and disease incidence was rather striking and could be due to several factors. The observed decreased incidence of chronic diseases can partially be explained by in-migration of young and healthy mining workers and other job seekers [47-49], who are at lower risk for chronic diseases such as hypertension and diabetes mellitus [50]. In additional, the majority of large-scale metal industries in Tanzania are led by transnational corporations [51], which are more likely to adhere to international environmental and social standards (e.g. Performance Standards of the International Finance Corporation (IFC) [52]) and recommended industry practices (e.g. International Council on Mining and Metals (ICMM) [53]; Extractive Industries Transparency Initiative (EITI) [54]). Hence, it seems plausible that metal extraction projects on average are more able to support local health systems and community-level interventions [55] or socio-economic development programs [56]. This may also explain why, in contrast to previous studies that reported elevated levels of sexually transmitted diseases in regions where metals are extracted [15,18,57,58], our results show that districts that are exposed to metal extractions activities generally have lower incidences of sexually transmitted diseases, including and HIV/AIDS, even though these differences were not statistically significant.

It is also important to highlight that our study falls in the period 2015-2019, which follows two major national level government interventions. First is the Tanzania Mineral policy 2009 revision which intended to increase the mineral sector contribution to income generation [59]. and second is the re-enacted of the Mining Act 2010 which put a requirement for mining companies to have a plan to increases citizens of Tanzania's participation in mining activities through employment and expatriate succession plans, as well as a plan for procurement of goods and services through available local market in the United Republic of Tanzania [60]. It is likely that these measures had a particular positive effect to districts with presence of metal extractions activities, which are in general larger operations than construction and gemstone commodity extraction projects.

In contrast to metal extraction, increased levels of disease incidence were observed for districts with construction material or gemstone extraction activities. Extraction of construction materials covers commodities such as cement, silicate, carbonate hard rocks, decorative stones (i.e., dolomite and limestone) and industrial minerals (i.e., gypsum, clay, halite, phosphate and mica). The observed increase in the incidence of chronic diseases appears consistent with the risk factors for such projects described by IFC, namely high exposures to dust, vibration, noise and unhealthy lifestyle (related to cigarette smoking and excessive alcohol intake) [61]. Studies have also shown that exposure to particulate matter (PM) from construction dust can significantly influence the appearance of diseases such as cancer, cardiovascular and respiratory diseases [62,63]. Studies from the construction and building materials literature report that there is a growing demand for construction material commodities, and equally draws attention to the environmental and health effects this demand imposes on the livelihood of affected communities [64-66]. In our study sample, 40% of the commodities extraction projects were categorized as construction materials, highlighting the need to further scrutinize this sector in terms of environmental and social responsibility, including the mitigation of potential adverse health impacts.

Strength and Limitations

To our knowledge, this is the first large-scale study of the relationship between mining and disease incidence in Tanzania using the complete national HMIS database. The data set covers – by definition – the entire country and allowed us to analyse a range of different mines at the same time. Having five years of data also allowed us to reduce the risk of specific results being driven by misreporting in a given month or year. The study also has several limitations. First, DHIS2 and routine HMIS data have known data quality issues [67], including concerns regarding to completeness, consistency, coverage and disease coding [68-71]. In our analysis we did not account for potentially different data quality across districts. If such differences in quality exist, they would only bias our results if reporting was systematically correlated with the presence of mines. This is possible in principle if mines directly contribute to health system capacity, and could potentially bias results against mines. We also did not distinguish between missing data and the true zero values in our analysis, which means that the reported case numbers may underestimate the true burden of disease and patient numbers. The OPD diagnoses consist of both clinical and non-clinical indicators. Non-clinical indicators can be influenced by physician’s opinion and are subject to reporting bias. As long as these biases are not correlated with the presence of mines, this should not introduce any systematic bias to our analysis. In addition, we used district boundaries to link mining operations to patient volumes. Even though districts are relatively large, it is possible that some of the mines – particularly when located near district boundaries – also affect patient volumes in neighboring districts. This exposure misclassification will likely result in less precise estimates, but could also lead to an underestimation of the true causal effects if there are systematic spillovers into districts considered unexposed in our analysis. Last, OPD indicators represent counts of people who sought care at health facilities and does not represent actual case numbers in the population.

3.7. Conclusions

The results of this study suggest that the health impact of mining operations may not only depend on the specific health outcome, but also on the types of mines: While metal extraction projects display consistent protective effects against a range of disease indicators, extraction of construction materials and gemstones is associated with increased incidence of chronic and diarrheal diseases, respectively. More research is needed to understand the underlying factors of the differences observed across the types of commodity extracted.

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3.8. Appendix

Table 3-6: List of commodities extracted in Tanzania

Commodity groups	Commodity subgroup	Example
Construction materials	Construction raw materials	Pozzuolana (cement), silicate hard rock, carbonate hard rock
	Decorative stones	Dolomite, limestone, quartzite, travertine
	Industrial minerals	Gypsum, halite, kaoline & kaolin clay, clay minerals, mica, phosphate, sylvinite
Gemstone	Gemstone	Chrysopras, diamond, sapphire, tanzanite
Metals	Precious metals	Gold
	Rate metals	Tin
	Base metals	Copper
Coal[1]	Coal	Coal
Hydrocarbons[1]	Hydrocarbons	Natural gas

[1] excluded in the analysis due to limited exposure

Table 3-7: Crude model of relationship between disease groups and type of commodity extraction.

Disease groups	Type of Commodity Extraction					
	Construction materials		Gemstone		Metals	
	IRR	CI	IRR	CI	IRR	CI
Chronic diseases	1.472**	1.023 - 2.118	0.669*	0.417 - 1.073	0.632**	0.425 - 0.940
Respiratory Infections	1.012	0.891 - 1.148	1.050	0.870 - 1.267	0.898*	0.802 - 1.006
Tuberculosis (TB)	1.075	0.757 - 1.528	0.890	0.532 - 1.491	0.797	0.543 - 1.171
Diarrhea	0.932	0.804 - 1.081	1.180	0.928 - 1.499	0.875**	0.770 - 0.994
Undernutrition	0.860	0.661 - 1.119	0.880	0.547 - 1.415	0.678***	0.529 - 0.869
Malaria	0.927	0.641 - 1.341	1.235	0.872 - 1.750	1.073	0.840 - 1.370
Parasitic Diseases	1.025	0.865 - 1.215	0.961	0.710 - 1.300	0.818**	0.695 - 0.962
Sexual Transmitted Diseases	1.103	0.852 - 1.428	0.850	0.627 - 1.153	0.848	0.697 - 1.032
Road Traffic Accidents	1.112	0.843 - 1.465	0.953	0.608 - 1.494	0.939	0.703 - 1.255
Mental Health	0.927	0.633 - 1.357	1.165	0.486 - 2.789	0.587***	0.404 - 0.852

Note: Estimates are adjusted for cluster robust; *** p<0.01, ** p<0.05, * p<0.1

3.9. Reference

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4. Paper 3 - Estimating the mortality burden of large scale mining projects: Evidence from a prospective mortality surveillance study in Tanzania

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4.1. Abstract

4.1.1. Background

Gold mining is a major source of income in many parts of sub-Saharan Africa. While a growing body of evidence has highlighted the health risks associated with underground work at gold mines, relatively little is known regarding mortality impacts.

Objectives

To assess the cause-specific mortality burden associated with living close to and working in gold mines in Tanzania.

4.1.2. Methods

We selected two of the largest gold mining areas in Tanzania and set up a mortality surveillance system in surrounding areas from February 2019 to February 2020. Community officers and village leaders reported death events. Death circumstances were collected using a standardized verbal autopsy tool, and causes of death assigned using the InSilicoVA algorithm. We compared cause-specific mortality fractions in mining communities with (i) subnational data from the Iringa region and (ii) national estimates from the Global Burden of Disease study. Within mining communities, we estimated mortality risks of mining workers relative to other adults not working at mines.

4.1.3. Results

At the population level, mining communities had higher road-traffic injuries (RTI) (risk difference (RD): 3.1%, Confidence Interval (CI): 0.4%, 5.9%) and non-HIV infectious disease mortality (RD: 5.6%, CI: 0.8%, 10.3%), but a lower burden of HIV mortality (RD: -5.9%, CI: -10.2%, -1.6%). Relative to non-miners living in the same communities, mining workers had over twice the mortality risk (relative risk (RR): 2.09, CI: 1.57, 2.79), with particularly large increases for death due to RTIs (RR:14.26, CI: 4.95, 41.10) and other injuries (RR:10.10, CI: 3.40, 30.02).

4.1.4. Conclusion

Despite major government efforts to ensure the safety in mining communities, our results suggest that gold mines continue to be associated with a large mortality burden. Given that most

of the additional mortality risk appears to be due to RTIs and other injuries unrelated to RTIs, programs targeting these specific risks seem most desirable.

4.1.5. Key messages

- We set up an active mortality surveillance system based on verbal autopsies around two major gold mining areas in Tanzania
- In contrast to previous literature, we find lower incidence of HIV mortality but higher incidence of mortality from other non-HIV infectious diseases in mining communities
- Mining workers have more than double the mortality risk compared to other adults living in the same areas surrounding the mines
- Most of the excess mortality burden appears to be due to road traffic injuries and other non-road traffic injuries
- Health impact assessments and impact mitigation efforts need to be extended to incorporate road safety and accident prevention programs in mining areas

4.1.6. Keywords

Community deaths, environmental health impact, extractive industries, gold mining, mortality, road traffic injuries, verbal autopsy

4.2. Introduction

Extractive industry projects have the potential to trigger improvements in socio-economic status and public infrastructure at the local level, along with generating tax and royalty incomes at the national and sub-national levels [1]. This potential source of development is particularly relevant for the African continent, which is endowed with over 30% of the world's global mineral reserves [2] and features the highest rates of poverty globally [3].

Given the importance of large mining operations for regional economic development, mining also has the potential to improve other indicators targeted by the Sustainable Development Goals (SDGs) – most importantly population health. Recent studies have found positive links between resource rents and life expectancy at the country level [4], and linked resource extraction projects to reduced prevalence of undernutrition and infectious disease [5, 6] as well as to reduced incidence of acute and chronic health conditions [7]. Evidence from Ghana [8, 9], Tanzania [9] and Sub-Saharan Africa (SSA) at large [10] also suggests lower infant mortality in regions with mining projects.

On the other hand, mining has long been identified as a hazardous industry with often substantially increased risk of adverse health outcomes for miners and surrounding communities [11]. Studies have linked mining to increased levels of cancer [12-16], poisoning [17], cardiovascular diseases [18, 19], respiratory diseases [19-22] and adverse pregnancy outcomes [23, 24], as well as injuries [25, 26] and tuberculosis (TB) [21, 27].

Chronic exposures to toxic substances, poor air quality and noise pollution have been highlighted as key mechanisms underlying these adverse health effects. This also applies to gold mining, independent of whether the metal is extracted in industrial mines [28-31] or through artisanal and small-scale gold mining [32, 33]. Given the large health risks documented historically, major efforts have been made in recent years to establish environmental and occupational safety protocols including the establishment of the Occupational Safety and Health Authority (OSHA) in 2001 and the formulation of National Occupational Health and Safety Policy in 2010 [34]. These efforts are generally supported by the large international corporations that run most industrial mines. In this paper, we focus on gold mining, which is the largest mining sector in Tanzania, accounting for 88% of all mineral export and 8% of national income in 2019 [35]. The presence of large-scale international mining companies in

Tanzania presents an opportunity to improve the livelihoods of local communities while ensuring the safety of their workers, but it remains unclear to what degree international safety measures and national level efforts have actually made gold mining safer.

To be able to assess the current safety of gold mining activities in Tanzania and to reconcile the conflicting current evidence on the health impact of mines, we established active mortality surveillance systems based on verbal autopsy in two of the largest gold mining areas in Tanzania in 2019 and closely monitored mortality outcomes over a 12-month period.

4.3. Methods

4.3.1. Study Design

This is a prospective population cohort study designed to monitor mortality outcomes over 12 months in purposively selected communities surrounding two major gold mines in Tanzania.

4.3.2. Study Areas

The study was conducted in two mining areas: (1) the Geita Gold Mine (GGM) in Geita Town Council (TC), Geita Region; and (2) the Bulyanhulu Gold Mine (BGM) in Msalala District Council (DC), Shinyanga Region.

GGM and BGM are both located in the Tanzanian mainland along the Lake Victoria gold belt (Figure 4-1). The Victoria gold belt is located in the northern part of Tanzania and is where most gold extraction takes place in Tanzania. This area hosts Tanzania's major multi-national gold extraction companies, as well as artisanal and small-scale mining activities. Besides mining, the primary economic activities of these areas are crop and livestock agriculture [36].

GGM and BGM are approximately 70 km apart. GGM was opened in 2000 and is located in Geita Town, which constitutes one of six administrative Districts in the Geita Region. BGM was opened in 2001 and is located in Msalala District, which is also one of six districts in the Shinyanga Region. Geita Town and Msalala Districts' estimated populations were 192,707 and 250,727 people, in 2019 respectively [37], which is equivalent to 11% and 16 % of the respective regional population. GGM is an open-pit mine and BGM is an underground mine. At the time of data collection, GGM was operating at full capacity, while BGM was operating at reduced capacity (about 10% production, [38]). In addition to the industrial mining, artisanal activities are common in both study areas.

We used satellite images to identify and select community settlements around the two gold mines. Tanzania is administratively divided into 30 regions and 169 districts or councils, which are further divided into wards [39]. Wards have an average population of around 13,000 people [39]. Our study communities fall within the following administrative wards: (1) Kalangalala, (2) Mtakuja and (3) Mgusu (formally part of Mtakuja) wards in Geita TC; and (4) Bugarama and (5) Bulyanhulu wards in Msalala DC. Kalangalala, Mtakuja, Mgusu and Bulyanhulu Wards are all located next to the industrial mining center. Bugarama Ward is located west of the main mining ward. The ward was chosen because it contains the main access road to Bulyanhulu mine, as well as having a community settlement for miners. The east side of Bulyanhulu gold mine is mostly unoccupied with a limited number of households. Population estimates of the wards are provided in Table 4-1.

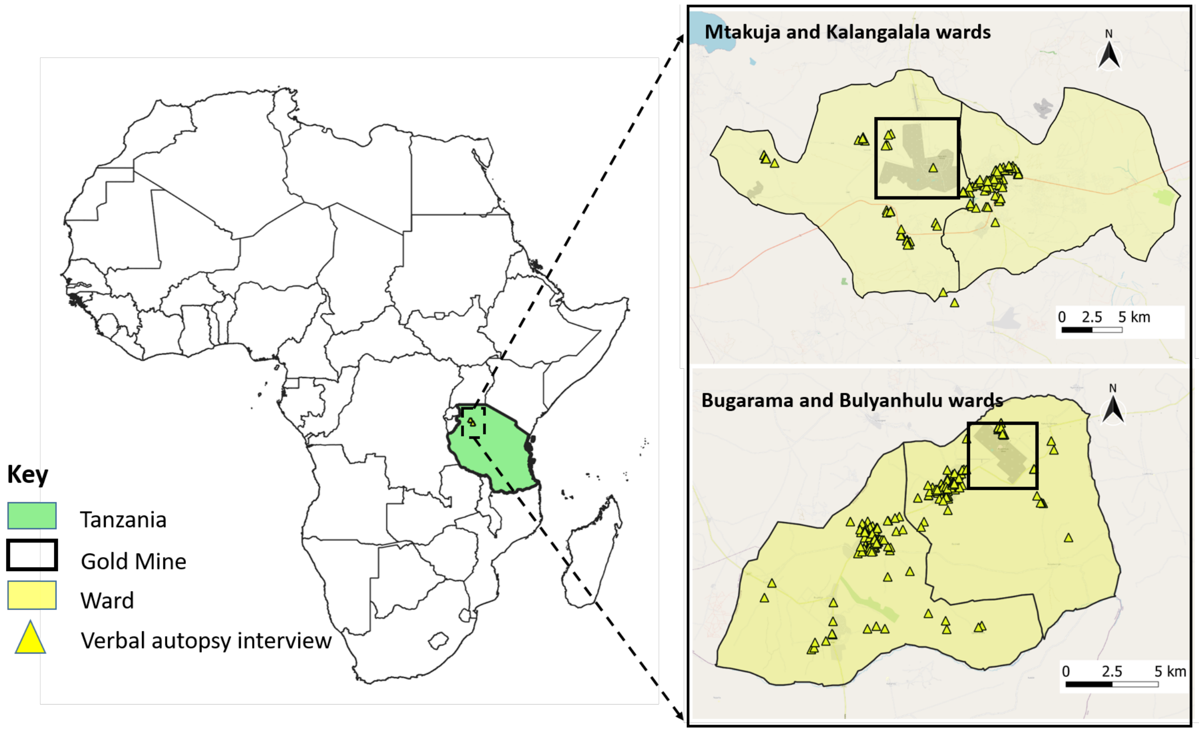

Figure 4-1: Location of mining areas and study sites

4.3.3. Mortality Data

To monitor mortality in the selected wards, we employed one community health care worker (CHW) for each of the selected wards. Each CHW was given a tablet installed with the Open Data Kit (ODK) and verbal autopsy (VA) tool, and trained on the overall objectives of the study as well as on how to conduct verbal autopsy interviews using ODK. For our study, we used the standard VA instrument of the World Health Organization [40] version 1.5.1 adapted to Tanzania administrative structures [41]. The tool has been translated to Swahili (local language) and also applies local Tanzania administrative structures. The tool is designed for all age groups, including maternal and neonatal deaths, as well as deaths caused by injuries.

We conducted community sensitization to describe the project and explain the importance and significance of reporting death events. During the community sensitizations, we recruited community members as death notification officers. The sensitization was followed by active monitoring and notification of death events by community members to CHW in each of the selected wards. Both community and facility deaths were notified. CHW followed and conducted VA interviews on notified death events two weeks after event notification. The VA interview lasted between 45 to 60 minutes. The interview data were transmitted directly from the tablet to the Ministry of Health central server under the Civil Registration and Vital Statistics (CRVS) unit. We provided summary information of collected interviews to CHW and provided supportive supervision at the council level [42]. The VA interviews were conducted on deaths that occurred in a period of one year, from February 2019 to February 2020.

4.3.4. VA Data Processing

We used InSilicoVA version 1.3.0 [43] to obtain the underlying cause of death information for each of the VA questionnaire completed. InSilicoVA employs probabilistic methods [44] to calculate cause-specific mortality fractions against 67 VA target causes (Appendix A1) from VA interviews. We grouped cause of death information from InSilicoVA into seven broad mortality categories defined as (1) Infectious diseases other than HIV, (2) HIV/AIDS-related deaths, (3) Road Traffic Injuries (RTIs), (4) Injuries other than RTIs, (5) Cardiovascular diseases, (6) Cancer/neoplasm and (7) Other.

4.3.5. Variables

The VA tool gathers information on signs, symptoms or conditions that led to the death of an individual with the intent to inform probable underlying causes of death at the population level.

For our study-specific needs, we added an indicator to capture whether the deceased individual worked in the mining sector before death. We captured deaths that occurred at home as well as in health facilities.

4.3.6. Population data

We obtained population data for 2019 from the Tanzania 2012 census projections [37]. We calculated the number of people who work in the mining sector using a percentage of the exposed population from the Maliganya & Paul [36] study. We estimated the total number of people who work in the mining sector by multiplying the percentage of people who work in the mining sector in Geita Region [36] and the 2019 ward population using national census data projections [37].

4.3.7. Other data

We used two additional data sources to compare the overall distribution of causes of deaths: (1) mortality estimates from the Iringa VA demonstration site [45] in Iringa Region, Tanzania, which contains all reported deaths in the region in 2019 and (2) Tanzania's national 2019 mortality estimates from the Global Burden of Disease (GBD) project (https://vizhub.healthdata.org/gbd-compare/). The Iringa Region is located in the southern highlands of Tanzania and is a part of the Tanzania CRVS technical feasibility study for large scale roll-out of the VA methods and CRVS systems integration. The Iringa Region is currently the only region in Tanzania that has a full coverage of VA implementations and thus a natural benchmark for the VA data collected and analysed in this project. Iringa region has a total of 3,238,347 population, 106 Wards and five administrative districts [37]. At the national level, the only available estimates are from GBD.

4.3.8. Statistical Analysis

We limited our analysis to deaths that occurred in 2019. We calculated cause-specific mortality fractions based on the seven broad mortality categories defined for this project and available in all data sets. The seven broad mortality categories are 1) HIV/AIDS related deaths, 2) Road Traffic Injuries (RTIs), 3) Injuries other than RTIs, 4) Cardiovascular diseases, 5) Infectious diseases other than HIV, 6) Cancer and 7) Other. In the first step, we summarized the causes of deaths in the VA data by age group and sex and compared the distribution of causes of death in the surveyed areas to national estimates from the GBD and regional estimates from the Iringa pilot.

In a second step, we focused on deaths occured around the two mines, and compared individuals that directly worked in mines to those in the same communities but were not actively engaged in mining. We estimate overall relative mortality risk as well as relative mortality risk for each category.
For this second analysis, we restricted mortality to the working ages 15-64.

4.3.9. Ethical considerations

This study obtained ethical approval from Ifakara Health Institute Review Board and the National Institute for Medical Research (NIMR) in Tanzania, the Ethics Committee of Northwestern and Central Switzerland (Ethikkommission Nordwest- und Zentralschweiz, EKNZ) and the institutional review board of the Swiss Tropical and Public Health Institute (Swiss TPH) in Switzerland.

4.4. Results

4.4.1. Population Estimates

Table 1 summarizes the estimated age and gender composition of populations living in the five wards under surveillance. The total estimated population in the five wards was 133,639 people. Of the total working-age population, 30% (N=21,080) were estimated to work in the mining sector [36]. 37% of mining workers were female (N=7,852).

Table 4-1: Population under surveillance around Geita Gold Mine and Bulyanhulu Gold Mine

Location	Total Population 2019	Population (15-64 Age Group)		Working at Mines		Not Working at Mines	
		male	female	male	female	male	female
Geita Gold Mine							
Mgusu ward	16,221	4,148	4,493	1,606	953	2,542	3,540
Kalangalala ward	16,660	4,260	4,615	1,649	979	2,611	3,636
Mtakuja ward	52,812	13,505	14,629	5,228	3,103	8,277	11,526
Bulyanhulu Gold Mine							
Bulyanhulu ward	27,854	7,123	7,716	2,757	1,637	4,365	6,079
Bugarama ward	20,092	5,138	5,566	1,989	1,181	3,149	4,385
	133,639	**34,173**	**37,018**	**13,228**	**7,852**	**20,945**	**29,166**

Legend: Table 4-1 shows total population in the five wards under surveillance. Total population in 2019 as well as age 15-64 population estimates are based on 2012 Tanzania census projections [37]. The number of individuals working at mines are computed by multiplying these population estimates by the estimated mining participation rates [36].

Table 4-2 summarizes the total number of deaths. A total of 349 deaths occurred in the study areas in the year 2019 (209 male, 160 female). Sixty-six deceased were under the age of five (Under 5), 20 were between the age of 5 and 14 (children), 186 were of working age (15 to 64), and 77 were 65 years and above. Of the 186 working age deaths, 87 (47%) worked in the mining sector. The mean age of the deceased who worked in the mine was found to be 43 years, with a minimum of 21 years and a maximum of 84 years. Deceased seniors who worked in the mine were 3 females and 10 males.

Table 4-2 also summarizes the main causes of death. Twenty-six percent (N=89) of deaths were due to infectious diseases other than HIV, 17% (N=61) were due to cardiovascular diseases, 11% (N=39) were due to HIV/AIDS-related deaths, 8% (N=29) were due to RTIs, 8%, (N=28) were due to cancer and 7% (N=26) were due to injuries other than RTIs.

Table 4-2: Number of deaths by age group, sex and cause of death

Cause of Death	Under 5		Children (5-14)		Adults (15-64)		Senior (65+)		Grand Total
	Male	Female	Male	Female	Male	Female	Male	Female	
Infectious diseases other than HIV	19	12	5	5	25	7	8	8	89
Cardiovascular diseases	3	1	1	1	20	7	10	18	61
HIV/AIDS related death	0	0	0	0	17	17	4	1	39

Road Traffic Injuries	0	0	0	0	26	2	0	1	29
Cancer	0	0	0	0	5	12	8	3	28
Injuries other than RTI	3	0	0	1	17	4	1	0	26
Other	14	14	0	7	13	14	10	5	77
All Deaths	39	27	6	14	123	63	41	36	349

Figure 4-2 shows cause-specific mortality fractions (CSMF) for mining areas, as well as the GBD estimates and Iringa estimates. In mining sites, the three most common causes of death were infectious disease other than HIV, cardiovascular disease, and HIV/AIDS related deaths. The Iringa ranking was very similar overall, with a switch in the first two categories. Relative to these estimates, the main difference in the GBD ranking was the third place for cancer, which only appeared as the 4th and 5th most common category in the mining and Iringa data.

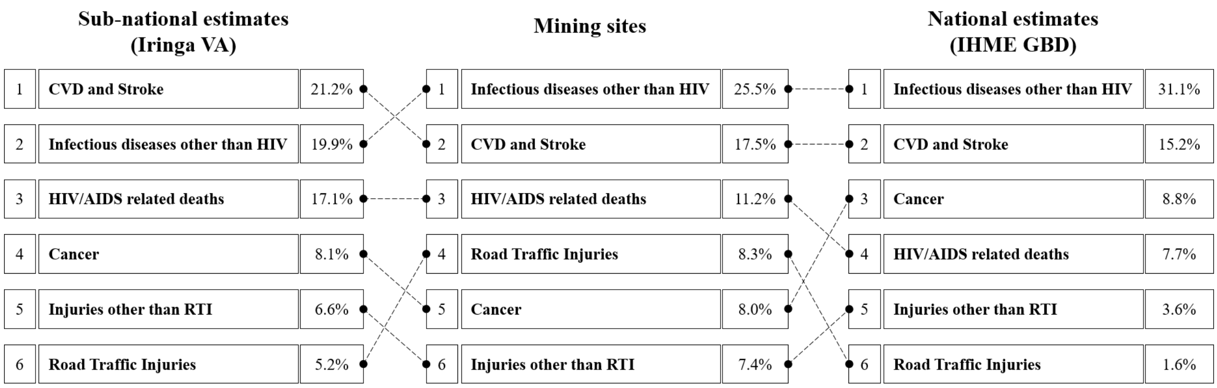

Figure 4-2: Causes of death comparison

Figure 4-3 shows more CSMF differences between mining areas and the Iringa region. Relative to the Iringa region, the share of death due to non-HIV infectious diseases and RTIs was 5.56% (95% confidence interval (CI): 0.01, 0.10) and 3.14% (CIs: 0.004, 0.059) higher in mining sites. The share of HIV/AIDS-related deaths was 5.93% (CIs: - 0.102, - 0.016) lower in mining sites compared to the Iringa region.

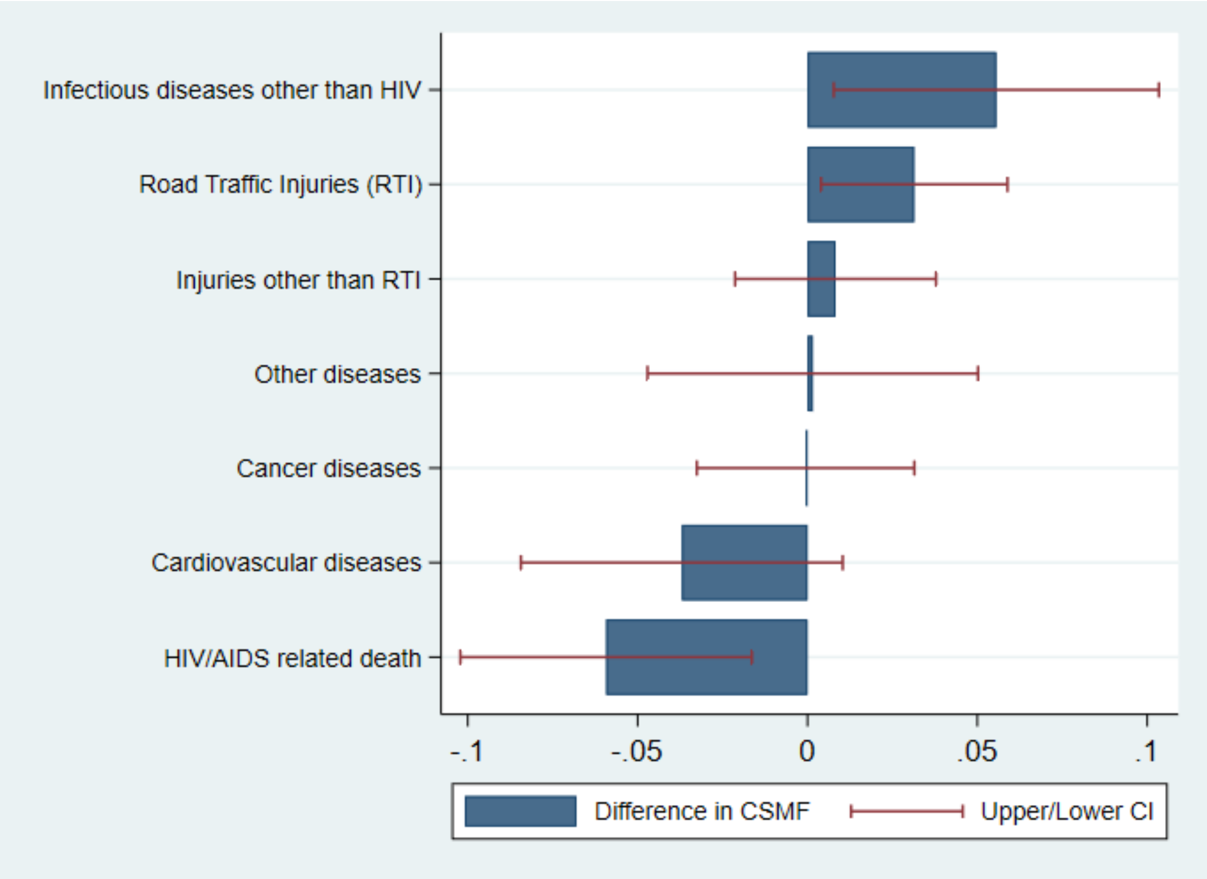

Figure 4-3: Differences in CSMF between mining sites and Iringa region

Table 4-3 shows the number of working age deaths in each category separately for individuals working and not working at mines. Eighty-seven deaths were reported among mining workers, 89% (N=77) were male, 11% (N=10) were female.

Table 4-3: Mortality by mining affiliation

	Working at mines		Not Working at Mines		Total
	Male	**Female**	**Male**	**Female**	
Population	**13,228**	**7,852**	**20,945**	**29,166**	**71,191**
Cause of Death Information					
HIV/AIDS–related	11	3	6	14	34
Road Traffic Injuries	24	0	2	2	28
Injuries other than RTI	16	1	1	3	21
Non-communicable disease	10	1	10	6	27
Inf. diseases other than HIV	8	0	17	7	32
Cancer	4	2	1	10	17
Other	4	3	9	11	27
Total	77	10	46	53	186

Table 4-4 shows relative risk (RR) estimates for mining workers living in the mining area. Compared to working age residents not working at mines, mining workers had twice the overall risk of death (RR=2.09, CI: 1.57, 2.79), with particularly large increases for RTIs and injuries unrelated to RTIs for males. Men working at mines had 2.65 times higher risk of dying compared to non-exposed men (RR=2.65, CI: 1.84, 3.82), while no such associations were found for women (RR: 0.70, CI: 0.36, 1.38). Men working at mines had almost three times the risk of dying from HIV/AIDS-related causes (RR=2.90, CI: 1.07, 7.85), 14 times higher risk of dying from RTIs (RR=14.26, CI: 4.95, 41.10) and 10 times higher risk of dying from other injuries (RR=10.10, CI: 3.40, 30.02).

Table 4-4: Relative risk of cause-specific mortality among mining workers living in the surveillance area

Outcome:	All		Male		Female	
	RR	95% CI	RR	95% CI	RR	95% CI-L
All cause mortality	**2.09**	**(1.57,2.79)**	**2.65**	**(1.84,3.82)**	0.70	(0.36,1.38)
HIV/AIDS-related deaths	1.66	(0.84,3.29)	**2.90**	**(1.07,7.85)**	0.80	(0.23,2.77)
Road Traffic Injuries	**14.26**	**(4.95,41.10)**	**19.00**	**(4.49,80.38)**	*	
Injuries other than RTI	**10.10**	**(3.40,30.02)**	**25.33**	**(3.36,191.01)**	1.24	(0.13,11.9)
Cardiovascular diseases	1.63	(0.76,3.52)	1.58	(0.66,3.8)	0.62	(0.07,5.14)
Inf. diseases other than HIV	0.79	(0.36,1.76)	0.75	(0.32,1.73)	*	
Cancer	1.30	(0.48,3.51)	6.33	(0.71,56.66)	0.74	(0.16,3.39)
Other	0.83	(0.35,1.97)	0.70	(0.22,2.28)	1.01	(0.28,3.63)

Notes: * no cases were observed in the population that worked in the mines. Table 4 is restricted to individuals ages 15-64. Risk ratios with p-value < 0.05 are shown in bold font.

4.5. Discussion

In this study, we prospectively monitored mortality in communities neighboring two major gold mines in Tanzania for a full year to assess the overall impact of mining operations on population health. While the results from the VA data analysis show that overall mortality patterns in the mining communities were relatively similar to the subnational estimates from the Iringa VA implementation study and national estimates using GBD numbers, we found that mining areas had a higher incidence of mortality from RTIs and non-HIV infectious diseases and a lower incidence of HIV mortality compared to other parts of Tanzania, as well as Tanzania overall. In terms of absolute risk, we found that overall mortality was significantly elevated among miners, particularly among male mine workers, who had more than 10 times the mortality risk due to RTIs and other injuries unrelated to RTIs.

Mortality from road traffic injuries is increasingly recognized as central threat to population health in low- and middle-income countries (LMIC). The guide for road safety opportunities and challenges report estimates 93% of RTIs occur in LMIC [46]. In Tanzania, the majority of RTIs appear to be due to motorcycle accidents commonly known as bodaboda [47, 48]. The presence of mining activities can contribute to rapid population growth and urbanization through the boomtown effect [49], as well as by increasing access and affordability of motorcycles and other vehicles due to improvements in socio-economic status in mining areas [50]. Hence, these two factors might partly explain the higher mortalities in relation to RTIs in the mining areas compared to non-mining areas, as well as the ten fold increase in the risk of dying from RTIs in people who worked in gold mining. Men in particular showed a much higher risk of RTI-related death. This may be due to the nature of transport-related activities, which is a male dominated occupation. Our results also show that the risk of dying from other injuries unrelated to RTIs is significantly higher among former miners in the mining communities, particularly in men. This finding is similar to previous literature linking mining activities and increased injury outcomes [51-54]. It is likely that interventions such as community road safety programs that incorporate local community perspectives can contribute to reductions in mortality in mining areas [55].

Our findings contrast with data from previous studies that have documented a significantly higher risk of HIV/AIDS in mining communities [56, 57]. HIV transmission is commonly hypothesized to be elevated in mining areas due to the access to higher income and distance from home among the miners, increasing the likelihood of high risk sexual behaviors [56]. The reason why our findings show comparatively low numbers of HIV/AIDS-related deaths in the mining communities could be due to the contribution of health and education programs often associated with the presence of gold mining industries [5, 58, 59]. We did however find that males who lived in the mining communities and worked in the gold mining sites have about three times the risk of dying of HIV compared to men of similar age not working at mines. The increased overall mortality risk among men working in the mines is not surprising when considering that the mining industry is a male-dominated sector, with women pursuing less dangerous activities [60].

Overall, the leading causes of death observed in the two gold mining communities are (1) infectious diseases other than HIV (including acute respiratory infections, tuberculosis, asthma and chronic obstructive pulmonary diseases); (2) Cardiovascular diseases; and (3) HIV/AIDS related deaths. These shares account for more than half of all deaths in the study population. Respiratory infections as a leading cause of death seem quite plausible overall given that air pollution in gold mining has been linked to the spread of pathogens and potentially toxic elements which can contribute to the increase of respiratory diseases [61, 62]. Our findings are similar to previous literature that found an association between gold mining and increased respiratory diseases [15, 18, 19] and asthma [63]. In addition, a recent qualitative study involving focus group discussions from communities around GGM and BGL published similar concerns with regards to air pollution coming from large-scale mining activities [64]. Given that mining is strongly linked to environmental pollution [18, 22], additional steps such as the application of health impact assessment prior to the development of new mining projects [65, 66] and the incorporation of infectious disease risk assessment and management plans [67] into corporate social responsibility can help to minimize the observed pollution-related disease burden.

4.6. Strength and Limitations

The main strength and novelty of this study is the prospective establishment of a mortality surveillance system in the mining community to monitor mortality in a low income setting where vital registration systems are largely lacking. We managed to build capacities of local CHWs to collect and manage VA data. Despite these efforts, a substantial number of deaths may not have been reported. While the true number of deaths is not known, we estimate that about 50-60% of deaths were reported by applying the current national crude death rates to our population. Factors that influence incomplete reporting include the relatively large size of wards each agent was responsible for and the remoteness of some areas. To minimize these data completeness issues, we conducted supervision of fieldwork activities and encouraged routine sharing of the fieldwork progress to the local administration office. Overall, we believe the data presented here represent the most comprehensive cause-specific mortality estimates available to date.

In addition, it was not possible to distinguish population level exposures of the artisanal and industrial mining. Our study was not large enough to look at specific diseases. The seven groups chosen reflect major disease groups – much larger studies would be needed to look at the incidence of specific diseases such as various types of cancers or poisoning that could be related to mining. Finally, our study was limited by the lack of a directly comparable population. While the data from Iringa are comparable in terms of the data collection tool, socio-economic, climatic and geographic factors are likely different around both mines and thus limit the comparability of the population level estimates.

4.7. Conclusion

The results presented in this paper suggest that mining areas are relatively similar to other areas of Tanzania in terms of the primary causes of death, and do not show higher rates of HIV mortality as suggested by some of the literature. Relative to other adult community members, mining workers – and male mining workers in particular - appeared to have substantially increased mortality risk. Most of this increased mortality risk appears to be due to RTIs and other injuries unrelated to RTIs. Programs targeting these areas may be needed to further improve the overall health impact of major mining operations.

4.8. Acknowledgement

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5. Discussion

The aim of this PhD was to study the associations between natural resources extraction projects and population health using global (cross-country), national (across districts) and subnational (communities) level data. The three manuscripts presented in Chapters 2 - 4 present findings of three different levels on the interactions between resources and health-related indicators. The three manuscripts have been submitted to international peer-reviewed journals (one accepted, two under review). In Chapter 2 of this PhD thesis, we assessed the global level association between countries' resource rents and changes in life expectancy. In Chapter 3 we zoomed in to the national data source and assessed the relationship between council (district) level presence of natural resource extraction activities and reporting of diseases in the routine health system. In Chapter 4, we applied a community level data and estimated the mortality burden associated with living and working in gold mine area.

This discussion chapter reflects on the main chapters in a comprehensive and comparative manner. The first part (Table 5-1) maps the specific contribution of this PhD thesis to the three core pillars of the Swiss Tropical and Public Health Institute (Swiss TPH), i.e., innovation, validation and application. In the subsequent chapters, we present (1) a summary of the main findings of this PhD thesis, (2) a discussion of the findings in relation to the Sustainable Development Goals (SDGs) of the 2030 Agenda, (3) Methodological strength of the three-perspective presentation. We then discuss opportunities and risk associated with our findings. Lastly, we present a summary of conclusions and recommendations, as well as outlook, including opportunities for future research.

5.1. Research objectives and the SwissTPH core pillars

This PhD work was conducted in the Health Impact Assessment (HIA) research group of SwissTPH, which is an associated institute of the University of Basel. Over the course of the development of this PhD thesis, different milestones were met. The milestones contributed to the mandate of SwissTPH, which is to contribute to improving health and wellbeing of populations at the local, national and international levels. This mandate translates into three core pillars of SwissTPH: from innovation to validation and application. Table 5-1 presents a systematic reflection on the contributions of the present PhD thesis to these core pillars of SwissTPH.

Table 5-1: Overview of this PhD contribution to the core pillars of SwissTPH

Milestone	Innovation	Validation	Application
Explain health in the context of the resource curse paradox	Re-evaluation of the resource curse hypothesis by applying a health perspective	The contribution of resource extraction projects on population health indicators	To stimulate additional researches on the interlinkages between natural resources extraction projects and population health, using additional useful indicators identified in this PhD thesis
Understand a country-level picture of the linkages between resource extraction projects and morbidity outcomes	Using routine Health Management Information System (HMIS) and DHIS2 to assess district level effects of large infrastructure projects	The use of routine HMIS and DHIS2 data	Promote the use of local data soruces, in particular, the HMIS/DHIS2 data for research and HIA of projects
Study the local perspectives of the mortality outcomes in relation to living in close proximity to large-scale mining	How to establish cause of death information in resource-limited settings	The use of verbal autopsy data to study the effects of large scale project implementations	Promote the use of verbal autopsy data to assess effects of interventions, as well as policies and programs
Develop a policy brief in order to communicate research findings			To make use of the research findings to facilitate a policy dialogue around the topic of how health can be strengthened in impact assessment regulatory frameworks

5.2. Summary and discussion of the main findings

Over the last three decades, life expectancy at birth has improved in all world regions [1-3]. This is due to several factors, including improvements in social-economic status, access to education, employment, access to health care and changes in the population health behaviours [4-6]. The findings of these studies were confirmed in Chapter 2 of this PhD thesis, in which we tested the hypothesis that resource rents are associated with positive changes in life expectancy at birth. We used cross-country regression analysis involving 199 countries and territories over the period 1970 to 2015. We controlled for initial income, life expectancy and an additional set of covariates. The results showed that the short-term (5-year) increase in countries' resource rents was positively associated with increases in life expectancy in the same countries. In addition, resource rents were positively associated with increased government revenues which could potentially explain the increase in government ability to support development processes such as health and education programs. Support to development processes can act on the determinants of health and ultimately impacts positive changes life expectancy. The observed linkages show that the increase in life expectancy is partly explained by the contribution of the extractive industry, particularly in countries rich in natural resources. The underlying hypothesis to this is that governments obtain more taxes as more commodities are sold, and revenue is more with increases in global commodity prices. Notably, we did not find evidence that resource rents were positively associated with income. We repeated this hypothesis using a long stretch period, 1970 – 2017. Interestingly, the results showed a negative association. Thus, in a long-run, resource rents were negatively associated with life expectancy. The long-run results can further be linked to the paradoxical relationship of the resource curse discussed in a number of scientific papers [7-11], as well as the complex relationship between natural resources and the overall development processes rooted in institutional quality, good governance and location [12-17].

In summary, our research shows that resource extraction projects can certainly contribute to improving population health. However, the potential gain may be confounded by multiple factors, including fluctuations in global commodity prices and the quality of local institutions. In order to avoid negative repercussions during commodity prices contractions, countries with large resource endowments should put mechanisms in place that allow smoothing of commodity-related income over time. In addition, the presence of strong institutions can contribute to translating short gains into long term sustainable benefits [18, 19].

In Chapter 3, this PhD thesis looked at the relationship between types of commodity extraction and the total number of diseases reported at health facilities aggregated to council (district) level. For the analysis, three different secondary data sources were used: (1) national routine HMIS data from the Ministry of Health DHIS2 data repository; (2) national population data projections from the 2012 national census; and (3) the geocoded list of resource extraction projects in Tanzania. The Tanzania DHIS2 data repository provided annual counts of the outpatient-department morbidities at council-level for the period 2015-2019. The coupling of DHIS2 data with census data, and the geocoded list of resources projects in Tanzania, revealed that the presence of commodity extraction activities (either construction materials, gemstone or metals extraction) was significantly associated with incidence of diseases. Metal extraction was associated with low incidence of diseases, but gemstone and construction materials extractions were associated with high incidence of diseases.

Not all mining projects have same the effect at the level of affect communities. The type of the commodity extracted influences methods and materials involved in the extraction process. Since most previous papers that have studied population-level health effects of mining projects were epidemiological studies often oriented towards specific commodities i.e. gold extraction and increased respiratory diseases [20, 21], HIV/AIDS [22], malnutrition [23], coal extraction and mortality/morbidity outcomes [24], cancer diseases [25] and copper extraction with a number of health related indicators [26-28], this paper (presented in chapter 3) is quite unique in a sense that it analyses the effect of resource extraction projects based on the three types of commodity extracted in Tanzania across a range of disease-related indicators. The results from this chapter shows that the presence of construction materials extraction at a council was significant associated with the increase of cancer, asthma, and cardiovascular diseases. Gemstone extraction was significant associated with high incidences of pneumonia, diarrhea with some dehydration and malaria diagnoses from blood slide microscopy. On the other hand, metal extraction was associated with significant low incidences of hypertension, diabetes, asthma, other cardiovascular diseases, severe pneumonia, kwashiorkor, malnutrition, malaria diagnoses from blood slide microscopy, intestinal worms, genital ulcer syndrome, sexually transmitted diseases, psychoses and neuroses. Overall, construction materials and gemstone extractions were associated with high incidence of diseases, while metal extraction was associated with low incidence of diseases.

In Chapter 4, we assessed mortality outcomes in communities living in close proximity to gold mining areas in Tanzania. This included the comparison of causes of death between miners and non-miners who lived in close proximity to the two large-scale mining operation in Tanzania, and comparison of causes of death from the two communities next to the two major gold mines and the sub-national causes of death from the Iringa region (non-mining region) as well as comparison to the national estimates using GBD data. The Iringa region has been implementing VA data collection since 2018 [29]. It is currently the only region in Tanzania that has full coverage of VA implementations. This study adapted VA tools from the Iringa VA implementation. Therefore, the Iringa region offered a natural benchmark for the VA data collected and analysed in this project.

Results from this chapter shows that on average, mining communities have much higher burden of Road Traffic Injuries (RTIs) compared to subnational and national population studied in the same period. Furthermore, miners showed more than two times higher mortality compared to non-miners, with particularly large increases in RTIs. In summary, leading causes of death in the mining communities were (1) Infectious diseases other than HIV, (2) Cardiovascular diseases, (3) HIV/AIDS related deaths and (4) RTIs. One of the important discoveries from this chapter is the significant elevation of RTIs from mining communities compared to subnational and national population. The risk difference was statistically significant, with the relative risk of RTI being 14 times higher for adult individuals who work in the mines.

VA tools provided an alternative mechanism to provide cause of death information to deceased whose such information is not available [30]. An example of such places includes mining areas which are located in low- and middle-income countries and often characterized with none to incomplete vital registration system [31, 32]. Methods applied in this chapter tapped in into the broad initiative of the Ministry of Health initiatives to strengthen nation-wide coverage of Civil Registration Vital Statistics (CRVS) through the use of VA [33].

5.3. Health impacts of the mining projects and the SDGs

One way to improve population health is to act on the determinants of health. The World Health Organization (WHO) refers to three main categories of determinants of health: 1) social and economic environment; 2) the physical environment; and 3) a person's individual characteristics and behaviour [34]. These categories are not mutually exclusive choices. They act in a interconnected web that aims to improve the overall health and wellbeing of populations [35]. Resource extraction projects can potentially affect on each of these categories – positively or negatively – and, thus, may contribute to the achievement of the 2030 Agenda for Sustainable Development or counteract it [36].

Chapter 2 of this thesis provides evidence of the potential contribution of natural resources rents on government revenue, which likely explained the increase in governments ability to support development programs such as the expansion of public infrastructures (e.g. construction of schools, health facilities, water resources and road infrastructure), strengthening of the healthcare systems (e.g. improve access to care, infrastructures) and education programs (e.g. build new schools or employ more teachers). This type of support can act on SDG1-No poverty, SGD4–Quality education, SDG6-Clean water and sanitation, SDG8-Decent work and economic growth, all of which can contribute to overall improvements in life expectancy [37, 38].

Chapter 3 gathered similar evidence from the association between resource extractions and reporting of diseases at local health facilities. Councils with presence of metal extraction activities showed a considerable consistent and significant association with low incidence of Outpatient Department (OPD) disease indicators. This is unlike several other previous studies which have indicated a negative relationship between metal extraction activities and an increase in diseases such as HIV/AIDS [22, 39-41], cancer [42] and respiratory diseases [43]. Our findings indicated that the council-level presence of metal extraction was associated with lower incidence of chronic diseases, diarrhea, undernutrition, parasitic infections and mental health issues. This further demonstrates the potential of the metal extraction industry to act on SDG 3 (Ensure healthy lives and promote wellbeing for all ages) indicator, specifically addressing disease-specific target listed in SDG 3.3 [44].

On the other hand, the negative link between gemstone and construction materials extraction and increase incidence of diseases pauses drawbacks in the generated progress towards good health and wellbeing. A further look into our analysis revealed that 43% of the extraction projects in Tanzania are of the type of construction materials. This include commodities such as construction aggregates, cement, silicate, carbonate hard rocks, limestone and gypsum. While these materials are core resources to supports infrastructural development projects, their potential implications to health effects could be at large. Worldwide, the demand for construction materials continues to grow despite receiving little attention on its potential to contribute to environmental pollution [45, 46]. The increasing demand for construction materials poses a global risk of increasing associated chronic diseases, as evident from this PhD work. Evidence suggest that small particles discharged from extraction of construction materials can be considerably high and may have toxic substances both associated with adverse health effects to human being [47, 48]. The World Bank has recently put Tanzania into the lower-middle income country category [49]. This decision followed the sustained economic growth partly contributed by the expansion in construction activities [50]. With the increased demand of construction materials, extraction of construction materials is likely to continue and increase posing serious risk on potential adverse health effects associated with exposure to construction dust. Without proper mitigation, it is likely that efforts towards reaching SDG3 can be deteriorated.

Beyond disease-specific indicators, resource extraction projects can contribute to social and economic determinants of health. For instance, create local employment and business opportunities in communities where they operate [51]. Comparing our results and that of Leuenberger et. all [52] from Focus Group Discussion (FDG) in the same population, we find similar aspects of both positive and negative association. FDGs reported issues with regards to air and water pollution, loss of fertile land and detrimental housing infrastructure. On the positive side, the FDGs reported an increase in income-generating opportunities, access to health care services as well as access to education. Our findings, and that of a qualitative study [52], shows that resource extraction projects have significant potential to act on SDG3 (contributing to good health and wellbeing) [37, 53].

SDG 3 specific target 3.6 and 3.9 (By 2020, halve the number of global deaths and injuries from road traffic accidents and By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination) respectively are directly relating to environmental factors which could influence health and wellbeing of the population. The extraction of natural resources is as well connected to environmental factors. Results from chapter four indicate that miners had 14 times risk of road traffic injuries (RTI) compared to non-miners. This suggests the risk of RTIs is increased in environmental settings such as mining areas. Furthermore, we note that the absolute risk of dying from RTI among miners was 114 deaths per 100,000 population. This is a clear indication that the risk of RTIs are much higher in mining communities, and therefore slows down the initiative to reach the SDG3 agenda.

5.4. Multi-layered approach

A three-level perspective approach employed in this PhD thesis provided multi-layered benefits for studying associations of resource extraction projects and a range of health indicators. The high-level perspective (global and national levels) allowed us to provide a broad overview of the selected health indicators and their respective association to resource extraction activities. Such a national and international perspective is of particular relevance in the context of the HIA4SD Project, which aims to facilitate a policy dialogue in the four project countries, namely Tanzania, Mozambique, Ghana and Burkina Faso [36].

The local level perspective gives opportunities to reflect on the effects of currently implemented policies. In particular, it assists to make specific and targeted decisions applicable to performance and intervention. Indeed, research has shown an evidence-based decision making is an effective stratergy for addressing population health needs [54, 55]. By zooming in to specific health outcomes, results can be directly linked to implementation procedures.

5.5. Where are the opportunities

This PhD provided an opportunity to compare quantitative and qualitative data. More specifically, the implementation of the HIA4SD Project included a strong qualitative research component, which was conducted in the same mining communities in the northern part of Tanzania. The qualitative results revealed that communities impacted by mining projects perceived both positive and negative impacts on their health status and associated health determinants [52, 56].

Positively, mining projects were associated with perceived improvements in health and wellbeing because of better access to health services, clean water, infrastructural development and income generation [56]. Negatively, mining projects were associated with environmental degradation, water pollution, loss of fertile land, social disruption and an increase in water-borne diseases, skin rashes, birth defects and miscarriages [56]. The compilation and comparison of both quantitative and qualitative findings, which is currently done in the drafting of country-specific policy briefs, conveys a convincing message to inform policy and decision-making processes at the level of ministries, extractive industry companies and civil society. For example, the quantitative research carried out in the frame of this PhD thesis showed that the presence of metal extraction (mostly gold mining) was associated with low incidences of chronic diseases, diarrhea, undernutrition, parasitic infections and mental health illnesses [57]. This association was confirmed in the qualitative study through improved health and wellbeing (SDG3) in the communities studied [56]. The opportunity to present and compare qualitative and quantitative results is similarly a unique choice. While both methods are subjected to design limitations (i.e. the negative aspect from the qualitative study were not detected in the quantitative analysis and the inability of the quantitative method to detect inequalities across different population groups), the ability to present both of them together adds compelling evidence to our results. This evidence gathered can help to inform local decision-making processes, as well as contribute to future researchers.

5.5.1. The usefulness of DHIS2 data for research purposes

This PhD thesis presents an example of using routine HMIS in low- and middle-income countries (LMIC) for assessing the impact of large-scale implementation projects. This was made possible mainly because of the availability of DHIS2. Prior to DHIS2, routine HMIS in LMIC was widely characterised by paper and fragmented registries. Most of the data aggregation across different levels were done manually [58-60]. DHIS2 made electronic data aggregation possible. It allowed data entry forms integration, data archive, data quality and user management functionalities [61]. Despite known data quality challenges [62-65], DHIS2 has evolved and improved over time.

The use of DHIS2 data in Chapter three showed the potential use of routine HMIS for epidemiological studies. It was possible to extract structured data that preserved location (where), period (when) and indicators (what) . The data covered all councils/districts, both public and private health facilities, and annually for the period of five years continuously. The data represented over eighty OPD indicators and over eight thousand reporting health facilities across the entire Tanzania. This is a relatively large dataset that contains continuous reporting of routine HMIS. DHIS2 is a standard software and currently installed in over sixty countries [61]. Methods applied in this paper can be replicated in other countries that has similar DHIS2 setup.

Despite the observed strengths of using DHIS2, there were several limitations worthy noting. First, data completeness varied across different facilities and indicators. It was also not possible to differential zeros and the null values. The null values were assumed as no cases. We assumed the number of facilities stayed the same across the five years. But since our analysis was done using council as the unit of analysis, we believe the aggregated summary would produce the same result.

5.5.2. *The use of verbal autopsy data*

VA are often conducted in places with incomplete vital registration or in communities where most people die at home and are never captured in vital statistics. Tanzania has about 26% coverage in death registration [66], with only 8% of all death having a cause of death assigned with quality that is usable for vital statistics [67]. The 8% referenced here is obtained from routine HMIS, and it is captured if death occurred at a health facility or the body was taken to a health facility after death. Data from this study shows that only 33% of death were taken to health facilities after death. This is similar to the Ministry of Health Sector Strategic Plan (HSSP) IV report, which estimates hospital admission accounts for about 30% of all death [68]. This indicates that about 70% of death in Tanzania occurs in places other than health facilities and their causes of death are not captured.

The VA data analysis from this PhD provided an opportunity to present mortality analysis findings representing both community and health facility deaths. This is likely to be the first study to assess mortality statistics in mining communities incorporating both community and health facility deaths. The methods applied for the VA data collection in this study have also been applied by the Ministry of Health VA implementation strategies in the Iringa region [29]. They have also been recommended by WHO [69]. Future research can apply similar techniques for mortality surveillance, particularly in areas with incomplete vital statistics.

5.6. Conclusion and recommendations

This PhD thesis makes a substantial contribution to the literature describing the interlinkages between resource extraction projects and population health. The results were presented in three levels perspective which covered, (1) a global perspective with a cross-country analysis showing a positive association between country's resource rents and life expectancy, (2) a national level perspective through the incidence of diseases and presence of resource extraction activities at council level and (3) subnational perspective through mortality analysis of the communities living in close proximity to large scale mining projects. The three-level perspective applied here provided a unique opportunity to compare and communicate findings across different geographical scales. Overall, the findings of this PhD thesis shows that resource extraction projects can contribute to improve population health outcomes and, thus, is a potential partner to work towards achieving SDG3 targets. Similarly, resource extract projects can negatively impact population health and wellbeing, and therefore pauses risk to not achieving SDG3 target. Our results also suggest that health effects associated with the extraction industry are beyond occupational health, therefore initiatives to assess the impact of natural resource extraction projects or large-scale implementation projects in general needs to be more broadly incorporating communities as well. The presence of both positive and negative linkages to health outcomes calls for a need to systematically assess health effects associated with the implementations of resource extraction projects in producer regions. HIA is a potential tool, which can be applied to predict potential effects of resource extraction projects and provide necessary information required to help prioritise prevention and control strategies throughout the project cycle. The findings from this PhD can contribute to policy and intervention designs and further help in the reduction of morbidity and mortality burdens associated with the development and operation of resource extraction project.

In light of these findings, the following recommendations arise:

5.6.1. More research on health outcomes and metal extraction projects

This PhD work observed that the presence of metal extraction projects is associated with low incidence of diseases. Hence, there seem to be differences in the level of impact mitigation strategies or health benefits. This could be due to different standards applied in the national or local level regulations for different types of extractive industries. We therefore recommend additional research to investigate potential pathways of positive health benefits associated with metal extractions activities.

5.6.2. The need for strong institutions

Strong institutions can provide a peaceful and inclusive society in sustainable development (SDG 16). Lack of strong institutions can result in a resource curse even at a subnational level [70]. In order to capitalise on the potential of HIA, the presence of strong institutions is of utmost importance. With no strong institutions, there is a risk of having HIA on paper but not in practice [71]

5.6.3. Capacity building

HIA follows a systematic methodology to identify potential risk and benefits associated with the implementation of large-scale extraction projects. Thereafter, HIA provides ways and recommendations to maximize on benefits while minimizing negative effects associated with the extraction projects. In order to deliver an effective HIA, prior knowledge and experience are among key factors needed. This goes hand in hand with the need to build local capacity for HIA implementations. This PhD provides one example. Through the HIA4SD project implementation, four PhD opportunities were awarded to sub-Saharan Africa, specifically to Tanzania, Burkina Faso, Ghana and Mozambique. The participants of the HIA4SD project went through practical training on different aspects of HIA, and acquire different types of capacities. This knowledge has potential to support the promotion and implementation of HIA in the respective countries and can contribute to increasing local capacities.

In addition, this PhD contributed to raise awareness of the HIA approaches. This generated new demands to scale HIA capacity more broadly to include practitioners of the Environmental Impact Assessments (EIAs) at the respective ministries and institutions as well as Monitoring and Evaluation programs at the ministry of health. This new demand can be responded by integrating HIA training courses in local curricula across different universities. In light of the advancement in technologies and Covid19 global pandemic, virtual online courses can as well be created and shared across countries/continents.

5.6.4. The Use routine HMIS to inform health impacts of large implementation projects

The use of DHIS2 to manage routine HMIS data has enabled a new dimension to collect, archive and retrieve nation-wide routine health data. The continuous use of DHIS2 made it possible to collect and store routine health data in a longitudinal fashion across different periods and units of data aggregation, and as well different health indicators. This data becomes available for health practitioners as well as researchers. The data can be used to monitor and evaluate the delivery of healthcare services and programs and as well inform progress and effects of different health interventions.

Prior studies documented different data quality concerns with regards to the use of DHIS2 and routine HMIS [64, 65, 72]. But the continuous use and multi-collaboration support to DHIS2 has allowed new features and functionalities to be added to the DHIS2. The new features address prior challenges [63, 73]. A recent literature review report seven technical strengths and eleven operational challenges for the use of DHIS2 [74]. The strengths are distributed towards improving data qualities.

DHIS2 presents an invaluable opportunity to inform studies on health impacts of large-scale implementation projects. The continuous reporting of health indicators over time is a great opportunity to assess effects associated with exposure-outcome relationships. DHIS2 data can be extracted, and additional layers of data quality and dimension can be appended without affecting original data. This PhD finds that DHIS2 data has significant potential to contribute to research that informs health effects of resource extraction projects.

5.7. Outlook for further research needs

The increase of country-level data at different international organization, particularly through the Extractive Industry Transparency Initiative (EITI) [75] creates several opportunities for additional research to best understand the relationship between resource extraction projects and health indicators. This can also motivate countries to report additional health related indicators which are current missing in the traditional data repositories such as World Development Indicators (WDI). The generated evidence from research can help to inform progress towards SDG 2030 agenda as well as inform future policies.

Locally, Tanzania is endowed with large amounts of natural resources. The country invites local and foreign companies to invest and continue to invest on resource extraction projects. The Tanzania development vision 2025 wishes for the extractive industry to contribute 10% of the national GDP by 2025 [76]. With such aspirations, the extractive industry sector is likely to continue growing. In order to tap into the full potential of resource extraction projects and sustainable development, the inclusion of health in resource extraction projects cannot be overlooked. This creates the need to increase future research on health-related indicators (not withholding socioeconomic and environmental indicators) and resource extraction projects. Furthermore, new researches can capitalize on the existence of DHIS2 for a wide selection of health indicators as well as research methods such as the use of VA to identify causes of death in resource-constrained environment.

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6. Appendix: The WHO VA target list of causes of death list

Cause of death list for VA with corresponding ICD-10 codes.

Column 1 contains the code for the VA entity. Column 2 lists the related titles. Column 3 lists the ICD-10 codes that would be used if the condition labelled by column 2 were coded to ICD-10. The third column lists the ICD-10 codes that relate to the text label of the cause of death category in Column 2.

Verbal autopsy code	Verbal autopsy title	ICD-10 codes (from ICD - 2016)
VAs-01 Infectious and parasitic diseases		
VAs-01.01	Sepsis	A40-A41
VAs-01.02	Acute respiratory infection, including pneumonia	J00-J22; J85
VAs-01.03	HIV/AIDS related death	B20-B24
VAs-01.04	Diarrheal diseases	A00-A09
VAs-01.05	Malaria	B50-B54
VAs-01.06	Measles	B05
VAs-01.07	Meningitis and encephalitis	A39; G00- G05
VAs-01.08	Tetanus[1]	A33-A35

VAs-01.09	Pulmonary tuberculosis	A15-A16
VAs-01.10	Pertussis	A37
VAs-01.11	Haemorrhagic fever[2] Ex	A92-A96, A98-A99
VAs-01.12	Dengue fever	A97
VAs-01.13	Coronavirus disease (COVID-19)	U07.1; U07.2
VAs-01.99	Unspecified infectious disease	A17-A19; A20-A32; A36; A38; A42A89; B00-B04; B06-B19; B25-B49; B55-B99

7. Non-communicable diseases

VAs-98	Other and unspecified non- communicable disease **Note:** **This group covers all non-communicable conditions that could not be assigned to another category in this section. There is a separate category for cases where the cause of death is unknown.**	D65-D89; E00-E07; E15E35; E50-E90; F00-F99; G06-G09; G10-G37; G50G99; H00-H95; J30-J39; J47-J84; J86-J99; K00K31; K35-K38 K40-K69; K77-K93 L00-L99; M00M99; N00-N16; N20-N99;
VAs-02 Neoplasms		
VAs-02.01	Oral neoplasms	C00-C06
VAs-02.02	Digestive neoplasms	C15-C26
VAs-02.03	Respiratory neoplasms	C30-C39
VAs-02.04	Breast neoplasms	C50
VAs-02.05	Female reproductive neoplasms	C51-C58

VAs-02.06	Male reproductive neoplasms	C60-C63
VAs02.99	Other and unspecified neoplasms	C07-C14; C40-C49; C64-D48; C91-C95

VAs-03 Nutritional and endocrine disorders		
VAs-03.01	Severe anaemia	D50-D64
VAs-03.02	Severe malnutrition	E40-E46
VAs-03.03	Diabetes mellitus	E10-E14
VAs-04 Diseases of the circulatory system		
VAs-04.01	Acute cardiac disease[3]	I11.0; I20-I26; I46.1; I46.9; I50.1
VAs-04.02	Stroke	I60-I69

VAs-04.03	Sickle cell with crisis	D57
VAs04.99	Other and unspecified cardiac disease	I00-I10; I11.9-I15; I27-I46.0; I47-I50.0; I50.9-I52; I70-I99
VAs-05 Respiratory disorders		
VAs-05.01	Chronic obstructive pulmonary disease (COPD)	J40-J44
VAs-05.02	Asthma	J45-J46
VAs-06 Gastrointestinal disorders		
VAs-06.01	Acute abdomen	R10
VAs-06.02	Liver cirrhosis[4]	K70.2; K70.3; K71.7; K74
VAs-07 Renal disorders		
VAs-07.01	Renal failure	N17-N19

VAs-08 Mental and nervous system disorders		
VAs-08.01	Epilepsy	G40-G41

VAs-09 Pregnancy-, childbirth and puerperium-related disorders		
VAs-09.01	Ectopic pregnancy	O00
VAs-09.02	Abortion-related death	O03-O08
VAs09.03	Pregnancy-induced hypertension	O10-O16
VAs09.04	Obstetric haemorrhage	O46; O67; O72
VAs-09.05	Obstructed labour	O63-O66
VAs09.06	Pregnancy-related sepsis	O75.3; O85
VAs-09.07	Anaemia of pregnancy	O99.0

VAs-09.08	Ruptured uterus	O71.0-O71.1
VAs09.99	Other and unspecified maternal cause	O01-O02; O20-O45; O47-O62; O68-O70; O71.3-O71.9; O73-O84; O86-O99
VAs-10 Neonatal causes of death		
VAs-10.01	Prematurity or low birth weight	P05; P07
VAs-10.02	Birth asphyxia[5]	P20-P22
VAs-10.03	Neonatal pneumonia	P23-P24
VAs-10.04	Neonatal sepsis	P36
VAs-10.05	Neonatal tetanus	A33
VAs-10.06	Congenital malformation	Q00-Q99
VAs10.99	Other and unspecified perinatal cause of death	P00-P04; P08-P15; P25-P35; P37-P94; P96

VAs-11 Stillbirths		
VAs-11.01	Fresh stillbirth	P95
VAs-11.02	Macerated stillbirth	P95
VAs-12 External causes of death Note: **The list of questions contains sub questions that allow for more specificity for accidents.**		
VAs-12.01	Road traffic accident	[6]
VAs-12.02	Other transport accident	
VAs-12.03	Accidental fall	W00-W19
VAs-12.04	Accidental drowning and submersion	W65-W74
VAs-12.05	Accidental exposure to smoke, fire and flames	X00-X19
VAs-12.06	Contact with venomous animals and plants	X20-X29

VAs12.07	Accidental poisoning and exposure to noxious substance	X40-X49
VAs-12.08	Intentional self-harm	X60-X84; Y87.0
VAs-12.09	Assault	X85-Y09; Y87.1
VAs-12.10	Exposure to force of nature	X30-X39
VAs12.99	Other and unspecified external cause of death	(S00-T99); W20-W64; W75-W99; X10-X19; X50-X59; Y10-Y84; Y86; Y87.2; Y88-Y89;
VAs-99	Cause of death unknown	R95-R99

[1] Excludes: Neonatal tetanus VAs-10.05
[2] Excludes: Dengue VAs-01.12
[3] Includes: Ischaemic heart disease; Pulmonary embolism; Sudden cardiac death; Cardiac arrest, unspecified; Left ventricular failure; and Hypertensive heart disease with heart failure [4] Includes Alcoholic fibrosis/ cirrhosis; Toxic liver cirrhosis; Fibrosis and cirrhosis of liver,
excluding alcoholic and toxic, but including ‘unspecified liver cirrhosis’ [5]
Includes: Hypoxia and respiratory distress

[6] Distinction on the codes between VAs-12.01 and VAs 12.02 is on the basis whether the death was a road traffic accident. V01.1;V02.1;V03.1;V04.1;V05.1;V06.1; V09.2;V09.3; V10.4-V10.9; V11.4-V11.9; V12.4V12.9; V13.4-V13.9; V14.4-V14.9; V15.4-V15.9; V16.4-V16.9; V17.4-V17.9; V18.4-V18.9; V19.4-V19.9;
V20.4-V20.9; V21.4-V21.9; V22.4-V22.9; V23.4-V23.9; V24.4-V24.9; V25.4-V25.9; V26.4-V26.9; V27.4V27.9; V28.4-V28.9; V29.4-V29.9; V30.5-V30.9; V31.5-V31.9; V32.5-V32.9; V33.5-V33.9; V34.5-V34.9;
V35.5-V35.9; V36.5-V36.9; V37.5-V37.9; V38.5-V38.9; V39.4-V39.9; V40.5-V40.9; V41.5-V41.9; V42.5V42.9; V43.5-V43.9; V44.5-V44.9; V45.5-V45.9; V46.5-V46.9; V47.5-V47.9; V48.5-V48.9; V49.4-V49.9;
V50.5-V50.9; V51.5-V51.9; V52.5-V52.9; V53.5-V53.9; V54.5-V54.9; V55.5-V55.9; V56.5-V56.9; V57.5V57.9; V58.5-V58.9; V59.4-V59.9; V60.5-V60.9; V61.5-V61.9; V62.5-V62.9; V63.5-V63.9; V64.5-V64.9;
V65.5-V65.9; V66.5-V66.9; V67.5-V67.9; V68.5-V68.9; V69.4-V69.9; V70.5-V70.9; V71.5-V71.9; V72.5V72.9; V73.5-V73.9; V74.5-V74.9; V75.5-V75.9; V76.5-V76.9; V77.5-V77.9; V78.5-V78.9; V79.4-V79.9;
V80.0-V80.9;V81.1-V81.9; V82.1-V82.9; V83.0-V83.3; V84.0-V84.3; V85.0-V85.3; V86.0-V86.3; V87.0V87.9; V89.2-V89.3; Y85.0; V90-V99; Y85.9

8. Curriculum Vitae

Basic Information

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Post Secondary Education

2017 – 2021: PhD in Epidemiology
Swiss Tropical and Public Health Institute, University of Basel, Basel Switzerland

The PhD thesis is to evaluate population-level health effects associated with large-scale natural resources extraction industries in sub-Saharan Africa. I am part of a large study under research for development (R4D) programs. The study is set up in four African countries (Tanzania therein) with my specific interest in mortality and morbidity health outcomes. I use verbal autopsy techniques to collect primary data and DHIS2 data for secondary data analysis.

2009 – 2011: Master of Science in Mathematics
Tennessee State University, Nashville TN, USA

Defended a Master's thesis on Parameter Variation of Mathematical Modelling of Infectious Diseases, Malaria. Used compartment models and a set of differential equations to study densities of population at a given change in time (Δt). We established disease free equilibrium by calculating basic reproductive $\mathcal{R}_0$ number and monitored the impact of parameter variation on the equilibrium point.

2006 – 2008: Bachelor of Science in Computer Information System
DeVry University, Columbus OH, USA

Coursework included object oriented programming, software development life cycle and project management. Graduated summa cum laude.

2002 – 2006: Associate of Applied Business in Computer Science,
Associate of Applied Science in Network Systems
Hocking College, Nelsonville, OH, USA

Graduated with dual associate degrees (as listed above), and made to National Dean's list and Phi Theta Kappa honorary societies

Other trainings

July 24th – 28th 2017 **Research Data Science Applied Workshop on Bioinformatics**
Participated in the above named workshop as a representative from Tanzania. The workshop was organized by International Centre for Theoretical Physics (ICTP), co-sponsored by International Council for Science – Committee on Data Science and Technology (CODATA), Research Data Alliance (RDA) and The World Academy of Science (TWAS). The training involved examples for processing and visualizing sequence data and finding pathological mutation in the human genome, infer cancer mutation models, and DNA sequence compression.

August 1st – 12th 2016 **Research Data Science summer school**
International Center for Theoretical Physics (ICTP), Trieste Italy
Participated (as a participant and in-class helper) to a dynamic hands-on experience summer school on research data school organized by ICTP in collaboration with CODATA-RDA and Software Carpentry. Core modules included bash shell, programing and visualization in R, SQL, git and GitHub, machine learning and computing infrastructure (Clouds and HPC).

June 2013 - Sept 2013	**Summer school in Biostatistics and Epidemiology** Harvard School of Public Health, Boston, MA Completed four academic courses in Biostatistics and Epidemiology (2 courses each) with focus in statistics and research
Mar 2005	Certificate of completion, Cisco 1 thru 4, Cisco Networking Academy Program
Sept 2004	Occupation Certificate, Networking & Web Design

Scientific Publications, Presentations and Conferences

Isaac Lyatuu, Georg Loss, Andrea Farnham, Mirko Winkler, Günther Fink. Short-term effects of national-level natural resource rents on life expectancy: A cross-country panel data analysis, *PLOS ONE* 2020 (accepted)

Isaac Lyatuu, Georg Loss, Andrea Farnham, Goodluck Lyatuu, Günther Fink and Mirko Winkler. Associations between natural resource extraction and incidence of acute and chronic health conditions: Evidence from Tanzania, *International Journal of Environmental Research and Public Health,* 2020 (under review)

Isaac Lyatuu, Mirko Winkler, Georg Loss, Andrea Farnham, Dominik Dietler and Günther Fink. Estimating the mortality burden from a prospective mortality surveillance study in Tanzania, *Environmental Health Perspectives,* 2020 (under review)

Andrea Leuenberger, Mirko S. Winkler, Olga Cambaco, Herminio Cossa, Fadhila Kihwele, **Isaac Lyatuu**, Hyacinthe R. Zabré, Andrea Farnham, Macete Eusebio, and Khátia Munguambe. Health impacts of industrial mining on surrounding communities: local perspectives from three sub-Saharan African countries. *PLOS Medicine*, 2020 (submitted)

Andrea Leuenberger, Fadhila Kihwele, Isaac Lyatuu, James T. Kengia, Andrea Farnham, Mirko S. Winkler and Sonja Merten. Gendered health impacts of industrial gold mining in northwestern Tanzania: perceptions of local communities. *Gender special issue of impact assessment and project appraisal*, 2020

Ramya Ambikapathi, Imani Irema, **Isaac Lyatuu**, Dominic Mosha, Stella Nyamsangia, Deus Kajuna, Elfrida Kumalija, Lauren Galvin, Bess Caswell, Patrick Kazonda, Germana Leyna, Japhet Killewo, Crystal Patil, Mary Mwanyika Sando, Nilupa Gunaratna, Development and Feasibility of Tablet-based 24-hour Recall for Dietary Intake and Recipe Collection Among Adults and Children in Tanzania (P10-018-19), **Current Developments in Nutrition**, Volume 3, Issue Supplement_1, June 2019, nzz034.P10–018–19, https://doi.org/10.1093/cdn/nzz034.P10-018-19

Trust Nyondo; Gisbert Msigwa; Daniel Cobos; Gregory Kabadi; Tumaniel Macha; Emilian Karugendo; Joyce Mugasa; Geofrey Semu; Francis Levira; Carmen Sant Fruchtman; James Mwanza; **Isaac Lyatuu**; Martin Bratschi; Claud J. Kumalija; Philip Setel; Don de Savigny. Improving quality of medical certification of causes of death in health facilities in Tanzania 2014 - 2019

Gregory Kabadi, Eveline Geubbels, **Isaac Lyatuu**, Paul Smithson, Richard Amaro, Sylvia Meku, Joanna A Schellenberg and Honorati Masanja**.** Data Resource Profile: The sentinel panel of districts: Tanzania's national platform for health impact evaluation. Int. J. Epidemiol. (2015) 44 (1): 79-86 · Oxford Press · DOI:10.1093/ije/dyu223) · 9.176 Impact Factor

S. Sathananthan, **I. Lyatuu**, Michael Knap and L.H. Keel. Robust Passivity and Synthesis of Discrete-Time Stochastic Systems with Multiplicative Noise under Markovian Switching. Communications in Applied Analysis 01/2013; 17(3) · Dynamic Publishers H Index: 10

S. Sathananthan, N. Jameson, I. Lyatuu, L. H. Keel. Hybrid Impulsive Control of Stochastic Systems with Multiplicative Noise Under Markovian Switching, Stochastic Analysis and Applications, Jan 2013. Stochastic Analysis and Applications 09/2013; 31(5) · Taylor & Francis Group Publisher · DOI:10.1080/07362994.2013.817254 · 0.45 Impact Factor

List of workshop/events participated in relation to Verbal Autopsy implementation and Civil Registration and vital statistics

- VA Analysis and Interpretation Workshop, Dec 11 – 14, 2019. Melbourne Australia
- Verbal Autopsy Data Quality Review and CoD Assignment, Nov 6-16, 2018, Columbus Ohio, USA
- OpenVA Pipeline Implementer & Developer Meeting, May 23 – 25, 2018, Singapore
- VA with ODK Regional workshop, (Africa & Latin America), May 28 – June 1st, 2018, Singapore

Key note presentation. **Isaac Lyatuu**. The seven deadly diseases: From mortality statistics to disease identification. Institute of Disease Modeling 2017, Seattle, WA, USA.

Poster Presentation. **Isaac Lyatuu**. Potential use of chicken feathers for mosquito bed nets production at the 65th American Society of Tropical Medicine & Hygiene (ASTMH), Nov 2016, Atlanta Georgia, USA.

Oral Presentation. **Isaac Lyatuu**. Sample Vital Statistics with Verbal Autopsy (SAVVY) – overview, logistics and implementation Workshop: Civil Registration and Vital Statistics (CRVS), Feb 2016, Lilongwe, Malawi

Oral Presentation. **Isaac Lyatuu**. The Experience of Implementing OpenHDS in Ifakara. INDEPTH Scientific Conference (ISC), Nov 2015, Addis Ababa, Ethiopia

Workshop. *Malaria Modeling and Control* sponsored by the National Institute for Mathematical and Biological Synthesis (NIMBios) at the University of Tennessee Knoxville, Knoxville TN, USA. June 15-17, 2011. Additional details can be obtained from the workshop website: http://www.nimbios.org/workshops/WS_malaria_modeling)

Processional Experience

2013 – present — **Technical Consultant, Ministry of Health, Tanzania**
Since 2013, I have been providing technical support to the Ministry of Health in Tanzania through multiple engagement including systems development, participating in technical working groups, capacity building (through DHIS2 user training) and later on to the design of the civil registration and vital statistics verbal autopsy program, (CRVS). I spearheaded development of the verbal autopsy manager (VMAN) which is currently implemented in Tanzania for the management of verbal autopsy program.

March 2017 – present — **Data Systems Manager, African Academy for Public Health, Dar es Salaam, Tanzania**
Provides institutional level guidance on enterprise data architecture for data science innovation including electronic data collection (mobile and desktop application), data management, data archiving and data dissemination. Installed and maintain a server for institutional data services. Developed and enforced data management and data sharing policies within for the organization. Participates to design and implement different data systems architecture for pushing and pulling data to different data sources. Support data science and research activities and also participate in analytical work and proposal writing.

June 2015 – Feb 2017 — **Unit Head: Data Systems, Ifakara Health Institute, Dar es Salaam, Tanzania**
Provided leadership and mentorship aspects of the Data Systems unit of the Ifakara Health Institute, home of the institutional data policies and systems. The unit provided solutions on data management and application development to support research activities. We designed data capture screens, provided data cleaning services and also prepared data for analysis. Data Systems hosted the Health and Demographic Surveillance System (HDSS) in Ifakara and Rufiji areas. The HDSS had over 500 thousands individual records for health and demographic surveillance.

Sept 2013 – June 2015 — **Research Scientist & Project Leader at Ifakara Health Institute (Project SPD)**
Supervised and coordinated data aspects of the Sentinel Panel of Districts (SPD). Primarily worked in data application developments and support. I designed and wrote software applications, supervised junior developers and also support unit data systems. I also worked

as a project leader and coordinate planning, budgeting, deployment of activities, as well as user training and report writing. SPD is an institutional platform. It is a statistical representation of the Tanzanian districts specifically designed to meet timely and accurately availability of data for research and estimation demands. It has 23 districts that are across Tanzania. SPD has two main branches, 1) Facility Based Information System (FBIS) and 2) Community based information system referred as Sample Vital registration with Verbal Autops (SAVVY)

Managed Kernel-Based Virtualization (KVM) machine for SPD that hosts applications and websites, and also software development and testing. KVM is a virtualization infrastructure for the Linux kernel, it is a type of hypervisor that enables full creation of virtual machines on operation systems. This environment is ideal for multiple project hosting and developments.

IHI representative to the Ministry of Health and Social Welfare M&E technical working group sessions for both community and facility based health information system projects. I participate in discussion for health systems improvements. SPD also participate to build district capacity on HMIS data gathering, use and dissemination. Examples of specific projects include District Health Profiles (DHP) and District Health Information System Software, (DHIS2).

Programmed and deployed software tool for administering Service Availability and Readiness Assessment (SARA) activity in Tanzanian health facilities, (paper tool adopted from WHO, USAID). Also participated in the event coordination and report writing. For more details please visit http://spd.ihi.or.tz/sara

Provides DHIS2 technical support and user training within the Institute as well as nationally. I am a member of the DHIS2 national implementer's team, and also DHIS2 national trainer.

Sep 2011 – Sep 2013

Research Scientist, application developer at Ifakara Health Institute (Project SAVVY)
Led project software development, data management and technical user training. Please visit project website: http://spd.ihi.or.tz/savvy for additional details about the SAVVY project

Developed and supported a mobile-based tablet application for baseline census data collection in the SAVVY surveillance sites. Supported an application that uses mobile phones for birth and death events notification

Hosted at team of six undergraduate computer science students from Harvard University on their study abroad program at our institute. Coordinated and assisted on their invitation, accommodation for 28 days, and their departure.

Sep 2009 – Sep 2011

Graduate Research Assistant, Tennessee State University, Dept of Mathematics
Worked at the center of research and sponsored programs as an assistant to reaching staff and research activities. Wrote simulations using MatLab for mathematical models in research and publication work. I also tutored college mathematics 20 hours per week and assisted teaching staff for proctoring exams and class assignments

Spring – Fall 2009

Teaching Assistant, Tennessee State University, Dept of Agricultural Sciences
Taught undergraduate college algebra and Microsoft Office 2007 (class of 26 and 19 students respectively). In these classes, I was responsible for lectures, make and administering tests, and also provide student's progress and the end of the semester.

Apr 2009 – Aug 2009

System Support, DHIS2, University of Dar-es-Salaam, Dept. of Computer Science
Participated in the development and maintenance of District Health Information System – DHIS2 in Tanzania coast region. DHIS supports data collection, validation, analysis and presentation of aggregated health records. DHIS2 it is the current national Health Management Information System software.

Titles and Awards

Sept 2020 – 2023 **Title: Co-Principle Investigator**
Project Title: Health Impact Assessment for Sustainable Development (HIA4SD) – Phase 2
Host Institution: Ifakara Health Institute
Amount: 180,000 CHF

Jan 2020 **Title: Country Coordinator, Machine Leaning (ML) Program**
Project title: DYNAMIC
Host Institution: Ifakara Health Institute

Oct 2019 **Title: Co-Principle Investigator**
Project Title: Care seeking patterns among deceased individuals in Iringa CRVS study
Host Institution: NIMR Tanzania with IHI as primary collaborator
Amount: 34,000 CHF

Sept 2017 – 2020 **Title: Co-Principle Investigator**
Project Title: Health Impact Assessment for Sustainable Development (HIA4SD) – Phase 1
Host Institution: Ifakara Health Institute
Amount: 250,000 CHF

Oct 2014 – 2016 **Title: Principle Investigator, Innovation Challenge, Grand Challenge Canada Round 14**
Project Title: using chicken feathers to produce mosquito bed nets.
Host Institution: Ifakara Health Institute
Grant Amount: 100,000 CAN for a period of 18 months.

Summer 2013 International Clinical, Operational and Health Services Research Training Program (ICOHRTA) funded by NIH/Fogarty – Harvard School of Public Health, Boston MA

2007 – 2008 Delta Epsilon Iota & Dean's list honorary society awards – DeVry University, Columbus OH
2004 – 2006 Dean's List and Phi Theta Kappa honorary society awards - Hocking College, Nelsonville, OH
June 2006 Community College Scholarship to attend BSc program at DeVry University, Columbus OH
2004 – 2005 Received National Dean's List and All-American Collegiate national academic awards, USA