HEALTH AND INDUSTRIAL DEVELOPMENT IN OMAN: EPIDEMIOLOGICAL ANALYSIS OF THE HEALTH EFFECTS IN A POPULATION LIVING NEAR A MAJOR INDUSTRIAL PARK IN OMAN

A thesis submitted for the degree of Doctor of Philosophy

by

Adil Said Al-Wahaibi

College of Health and Life Sciences

Institute for Environment

Brunel University

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AUTHOR'S DECLARATION

I declare that this thesis has been composed by myself and that the research it describes has been done by me. This thesis has not been accepted in any previous application for a degree. All quotations have been distinguished by quotation marks and the sources of information clearly acknowledged. Longer quotations have been indented in italics and sources similarly acknowledged.

Name: Adil Said Al-Wahaibi

Signed:

Date:

LIST OF ABBREVIATIONS

AC	Auto-Correlation
AGS	Arab Gulf States
AIC	Akaike Information Criterion
ARD	Acute Respiratory Diseases
BHR	Bahrain
CALMET	California Meteorological Model
CALPUFF	California Puff
CI	Confidence Interval
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Diseases
corAR1	AC structure of order 1
CVD	Cardiovascular Diseases
DPSEEA	Driving Force-Pressure-State-Exposure-Effect-Action
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
GAM	Generalised Additive Model
GI	Gastrointestinal Diseases: Diseases of Esophagus, Stomach and Duodenum
GIS	Geographical Information System
GLM	Generalised Linear Model
GP	General Practitioner
GYTS-Oman	Global Youth Tobacco Survey
ICD-10	The International Classification Of Diseases version 10
ID	Identification Number
IHD	Ischemic Heart Diseases

ISAAC	The International Study of Asthma and Allergies in Childhood
MAD	Minimal Accepted Distance
MCM	Major Congenital Malformations
MECA	Ministry of Environment and Climate Affairs
MI	Myocardial Infarction
MM5	High-resolution Metrologic Mesoscale Model
MNE	Ministry of National Economy
MoH	Ministry of Health
MRMWR	Ministry of Regional Municipalities, Environment and Water Resources
MS	All Musculoskeletal Diseases
NB	Negative Binomial
NHL	Non-Hodgkin's Lymphoma
NO_2	Nitric Dioxide
NO_X	Nitric Oxides
O_3	Ozone
OMN	Oman
OR	Odds Ratio
PCBs	Polychlorinated Biphenyl
PM	Particulate Matter
POPs	Persistent Organic Pollutants
PSR	Pressure, State and Response
QAT	Qatar
RR	Risk Ratios
RS	All Respiratory Diseases
SAU	Saudi Arabia
SES	Socio-economic Status
SIE	Sohar Industrial Estate
SIP	Sohar Industrial Port
SIZ	Sohar Industrial Zone
SO_2	Sulphur Dioxide

TRI	Toxic Release Inventory
UAE	United Arab Emirates
US	United States
VOC	Volatile Organic Compounds
WHO	World Health Organisation

CHAPTER (I): INTRODUCTION

The accelerated global industrialisation trends during the past century have raised many concerns about the potential environmental health problems that might be caused by these industrial movements. Industrialisation, with its resulting urbanisation, has been long associated with adverse population health effects through air, water and noise pollution (Shen 1999). As the industrialisation trend moved towards developing countries, 25% of all environment-related mortalities were found in these countries, compared to 17% in developed countries. Children are particularly susceptible; the World Health Organisation (WHO) has estimated that 36% of global child mortalities are due to environmental causes (Prüss-Üstün & Corvalán 2006). This might be due to the presence of rigorous environmental regulations in the developed countries which forced the industries to transfer their entire industrial activities or their waste materials to the less developed countries (Shafik & Bandyopadhyay 1992).

The Sultanate of Oman is an oil-producing country situated on the eastern cost of the Arabian Peninsula (MoI 2012). Oman, as one of the currently fast developing economies, has also initiated a heavy industrialisation movement to supplement its national resources. This industrialisation movement has resulted in the establishment of several major industrial parks in the country that may harness possible public and environmental health effects. These effects might be augmented by the presence of underdeveloped public health policies and environmental standards in the country.

One of the major, fast growing, industrial parks in Oman is the Sohar Industrial Zone (SIZ). SIZ was established in 2006 containing a wide range of petrochemical industries such as: oil refinery, polypropylene, formaldehyde, urea, aromatics plant and a methanol plant. In addition, SIZ has an iron and aluminium smelter (Sohar Port and Freezone 2013). New expansions and developments are expected in the near future, including more heavy industries and an airport. Such industries potentially emit air pollutants and many environmental toxins such as sulphur dioxide (SO_2), nitric oxides (NO_x) and volatile organic compounds (VOC) (Nielsen 2013).

SIZ was built near a densely populated area, consequently raising great health- and financial-related concerns from its surrounding residents (Rejimon 2013). SIZ, with its anticipated expansions in the near future (Sohar Port and Freezone 2013), necessitates a parallel community health assessment of the population of the residential area around it.

Globally, epidemiological studies investigating the effects of industries on the surrounding population are scarce, especially those concerned with children (Pascal et al. 2013). These limited epidemiological evidences show adverse health effects of air pollution, including increases in morbidity and mortality from respiratory and cardiovascular causes (Brunekreef & Holgate 2002; Dockery & Pope 1994; Arbex et al. 2012). Other studies have also shown that there is a link between living near industrial complexes and occurrence of adverse health outcomes (Mudu et al. 2014; Yang et al. 2004; Bentov et al. 2006). In children, evidences have found that living near industrial parks have greater incidence of respiratory and allergic diseases compared to those living away
(Smargiassi et al. 2009; F. A. Wichmann et al. 2009; Yang et al. 1997; Papadimitriou et al. 2012; Ernst et al. 1986; Lewin et al. 2013; Spektor et al. 1991; Wilhelm et al. 2007). The respiratory effects of air pollution range from mild respiratory tract irritation to chronic bronchitis, pneumonia and increase in asthmatic attacks (Laumbach & Kipen 2012). In children, air pollution has also been associated with acute respiratory tract infections (Kampa & Castanas 2008). A recent cohort study suggested that for each monthly 10% increase in the level of outdoor carbon monoxide (CO) and ozone (O_3), the use of respiratory treatment in children increases by 2-3 % in that month (Beatty & Shimshack 2014).

Depending on the duration of the air pollution exposure, the cardiovascular system might also be affected, either acutely or chronically. Acute effects include angina, myocardial infarction and heart failure, whereas the chronic effects include increased susceptibility to ischemic heart disease and increase blood pressure (Franchini & Mannucci 2012; Mills et al. 2008). SO_2 and suspended particles has also been associated with increased incidence of stroke admissions (Low et al. 2006).
Air pollution is also associated with many atopic diseases such as hay fever, allergic conjunctivitis and dermatitis (Morgenstern et al. 2008). Studies have found

higher levels of immunoglobulin E, which increases in response to allergic diseases, among people who have higher levels of particulate matter (PM) exposure (Boezen et al. 1999). A recent study has found that the treatment for atopic dermatitis in children living near busy roads was 40% greater than those living away from traffic (Kim et al. 2013).

Studies have also shown that air pollution is associated with adverse reproductive system effects. For example, the risk of preterm birth was found to be higher in women living near oil refineries (Yang et al. 2004). Furthermore, increased air pollution levels have been associated with an increase in infant deaths (Klonoff-Cohen et al. 2005). Long-term air pollution has also been linked to different types of malignancies. For example, PM and NO_x exposure have been linked to an increased incidence of lung cancer (Curtis et al. 2006). Moreover, air pollution, especially from incinerators, has been linked with laryngeal cancer and non-Hodgkin’s lymphoma (NHL) (Franchini et al. 2004).

The rapid industrial development in Oman might have created several environmental and public health threats to the Omani population. To date, only two studies have assessed the environmental effects of SIZ on its surrounding area, and they suggested adverse environmental conditions (Al-Shuely et al. 2010; Abdul-Wahab & Yaghi 2004). One of these studies was conducted before the start of intensive industrial establishments in the area (Abdul-Wahab & Yaghi 2004). There have been no environmental health studies conducted in Oman to investigate the potential health effects of SIZ on its surrounding population, or the effects of any other new industrial developments. Therefore, the previously discussed health effects of industrialisation and air pollution need to be investigated in Oman. In addition, similar studies elsewhere examining the effects of industries on surrounding populations health have been limited (Pascal et al. 2013). Thus, this study contribution will be also important regionally and globally.

Along with the investigation of the effects of this industrial movement on the population’s health, there is a need to discuss the level of preparedness of the Omani public and environmental health systems for these new challenges. This investigation could be achieved by analysing the situation of environmental health in Oman and its surrounding countries. Such analysis will be helpful in the suggestion of an improved environmental health policy in the country to ensure more sustainable development.

This study was sponsored by the Omani ministry of health (MoH). The aim of this study was to conduct an epidemiological study to explore the acute health effects of living in close proximity to SIZ. Primary, secondary and tertiary healthcare data from the MoH were utilised to model the monthly cases around SIZ, for the period from January 1st, 2006 to December 31st, 2010. The decision to study the acute health effects, rather than the chronic health effects, was based on the fact that SIZ was opened recently, in 2006. This time period is relatively short for chronic effects to have taken place. Exposure classification was determined using a proximity method that defined high, intermediate, and control exposure zones as ≤5, >5-10, and ≥20 km from the SIZ. Dispersion models and wind roses were used, in addition, confirming the proximity method exposure zone definitions. Results were presented as risk ratios (RR) of the studied diseases. The aim of the study was divided into two parts investigating two major age groups in the area:

- A young population of <20 years old.
- An adult population of ≥20 years old.

These effects were further classified according to age sub-categories, gender and socio-economic status (SES).

After exploring the possible health effects in people living near the SIZ, the third aim of this study was to discuss the situation of environmental health in Oman and to suggest an improved environmental health policy in the country. A conceptual analysis of the dynamics that drive environmental health threats globally, and in Oman and its adjacent Arab Gulf States (AGS) is presented. Then, the need for a public health system improvement along with industrial development in Oman is discussed by suggesting the most pertinent practices and solutions to improve environmental health practice in the country.

CHAPTER (II): HEALTH EFFECTS IN A POPULATION LIVING NEAR A MAJOR INDUSTRIAL PARK IN OMAN: TWO EPIDEMIOLOGICAL ANALYSES

II.1.Abstract

Background and Aims: The Sohar Industrial Zone (SIZ), Oman, which started to operate in 2006, contains many industries that possibly affect the health of the local population. This study was carried out to evaluate the health effects in a population living near SIZ.
Methods: Retrospective health care visits for acute respiratory diseases (ARD), asthma, conjunctivitis and dermatitis were collected between 2006 and 2010 for 2 large provinces with geographic proximity to SIZ. Exposure of the surrounding villages was classified using proximity to SIZ. Three exposure zones were defined according to the distances from the SIZ: ≤5, >5-10, ≥20 km representing high, intermediate and control exposure zones respectively. Age and gender-adjusted monthly counts of visits for the selected diseases were modelled using generalised additive models controlling for time trends. The high and intermediate exposure zones were later merged together due to similarity of effects. Exposure effect modification by age, gender and socioeconomic status (SES) was also tested.
Results: Living within 10 km from SIZ showed greater association for ARD (RR: 2.5; 95% CI: 2.3-2.7), asthma (RR: 3.7; 95% CI: 3.1-4.5), conjunctivitis (RR: 3.1; 95% CI: 2.9-3.5) and dermatitis (RR: 2.7; 95% CI: 2.5-3.0) when compared to the control zone, for the population of <20 years. For the population of ≥20 years, these risks were: (RR: 2.0; 95% CI: 1.9-2.2), (RR: 3.6; 95% CI: 3.0-4.4), (RR: 2.8; 95% CI: 2.5-3.2) and (RR: 2.1; 95% CI: 1.9-2.4), respectively. Greater exposure effects were observed amongst ages ≥50 years and lower SES groups in the ≥20 years group. Models showed no differences between the gender groups.
Conclusion: This is the first study conducted in Oman examining the adverse health effects on the population living near SIZ. We hope that these findings will contribute to building up an evidence-based environmental and public health policy in Oman.

II.2.Introduction

The two epidemiological studies aim is to investigate the health effects of the SIZ on its surrounding nearby population. This aim was divided into two main studies investigating the effects in: a young population of <20 years old and an adult population of ≥20 years old. Because similar methodology in both studies was used, one description will be provided for both age groups. However, the analysis, results and discussion will be described according to the two age groups.

II.3.Methodology

Study data include health data, exposure analysis data, meteorological data, and demographic data. The data were obtained from Oman after fulfilling the regular Omani requirements to obtain “official data”. Such requirements included the administration of an “ethical clearance request” to MoH to obtain the health data. In addition, inter-ministerial letters to obtain data from the Ministry of Environment and Climate Affairs (MECA) (for air quality data), the Ministry of National Economy (MNE) (for census 2010 data) and data from the Department of Meteorology (for meteorological data) were required. Ethical approval for the study was obtained from the Omani MoH and Brunel University Ethics Committee (see Appendix 1).

a. Location of the study

Site characteristics

SIZ contains many world-leading industries and companies. It was established in 2006 and consists of two main industrial regions: Sohar Industrial Port (SIP) and Sohar Industrial Estate (SIE). Covering an area of 2,058 hectares, SIP contains a wide range of petrochemical industries and an iron smelter. An oil refinery and a polypropylene plant started in 2006, subsequently followed by two major industries: a power company and a methanol industry in 2007. A formaldehyde plant and a urea industry were established between 2008-09; an iron smelter and an aromatics plant were appended in 2010. New expansions and developments are planned soon, including more heavy industries and an airport (Sohar Port and Freezone 2013). SIE, which was built on 2,100 hectares, is situated five kilometres southwest of SIP. Besides other complementary industries, Sohar Aluminium, which started in 2008, is the most important industry in SIE for its size of investment (Sohar Aluminium 2014). A map of the industries initiated in this area is shown in **Figure II.3 1**. In addition, **Table II.3 1** shows a summary of the most important industries in SIP and the year they began operating.

Table II.3-1: Industries in SIP and SIE and their corresponding first year of operation.

Industry	First year of operation
Sohar Refinery (Orpic 2011)	2006
Polypropylene Plant (Orpic 2011)	2006
Sohar Power Company (Sohar Power Company SAOG 2012)	2007
Oman Methanol Company (OMZEST 2012b)	2007
Oman Formaldehyde Chemical (OMZEST 2012a)	2008
Sohar International Urea & Chemical Industries (Suhail Bahwan Group 2012)	2009
Shadeed Iron & Steel (JSPL 2012)	2010
Aromatics Plant (Orpic 2011)	2010
Sohar Aluminum (Sohar Aluminium 2014)	2008

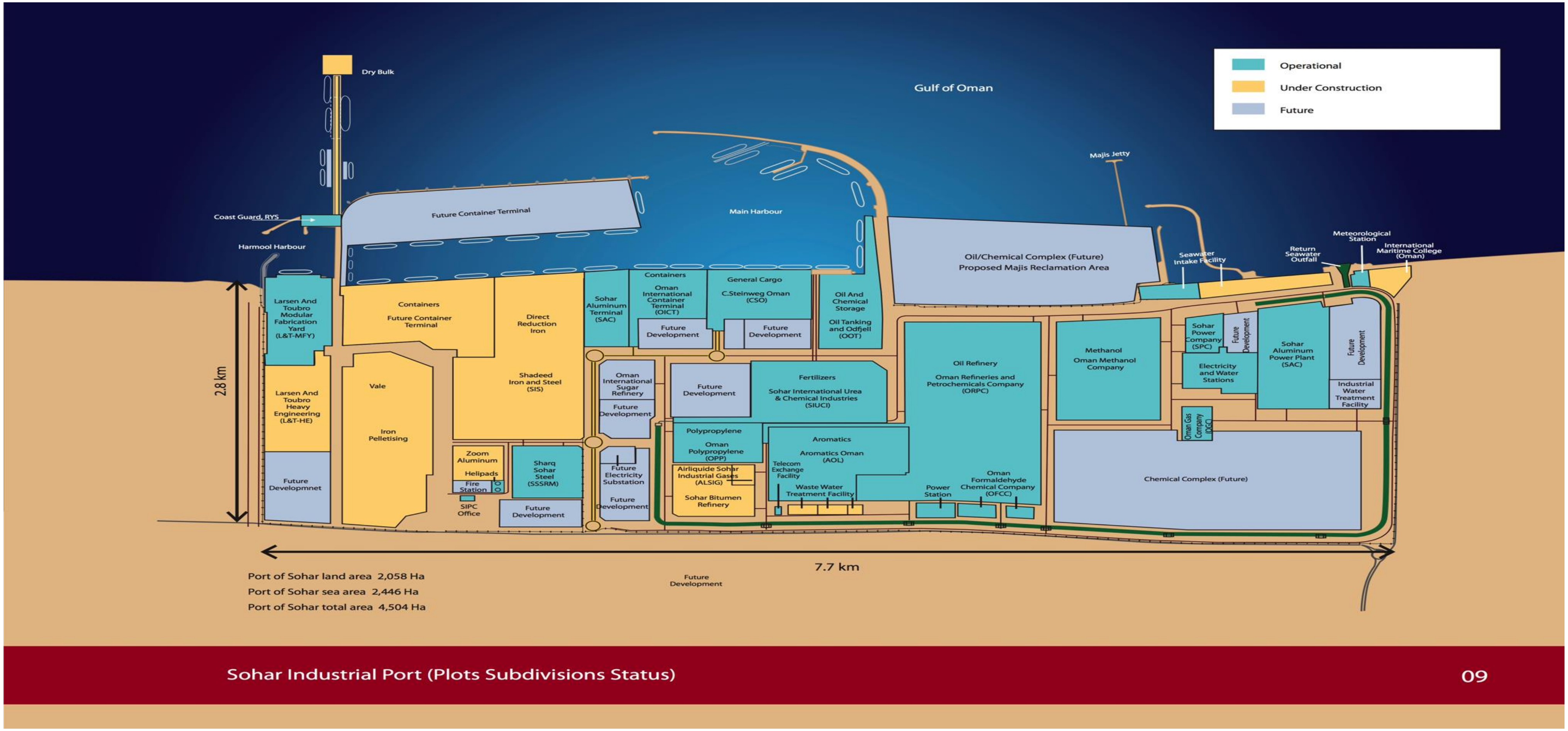

Figure II.3-1: A map showing the distribution and types of industries in SIP. The map is taken from (Sohar Port and Freezone 2013).

Villages localisation

Determining the geographical location of each village was essential to measure its distance from the industrial area. Such distances will be used later to determine exposure classification. The location was approximated using Google Earth software (Google inc 2011), (**Figure II.3 2**). Then, the coordinates, longitude and latitude of each village and the industrial area were calculated using ExpertGps software (TopoGrafix 2011). This software transforms the Google file format (.KML) into an Excel sheet containing each village with its geographical coordinates. The villages with their coordinates were then combined with the main health data set. Finally, the distance of each village from the refinery was calculated using R software. **Table II.3 2** shows a sample of the resulting file. In this study, there were no villages located between 10 and 20 km from the oil refinery.

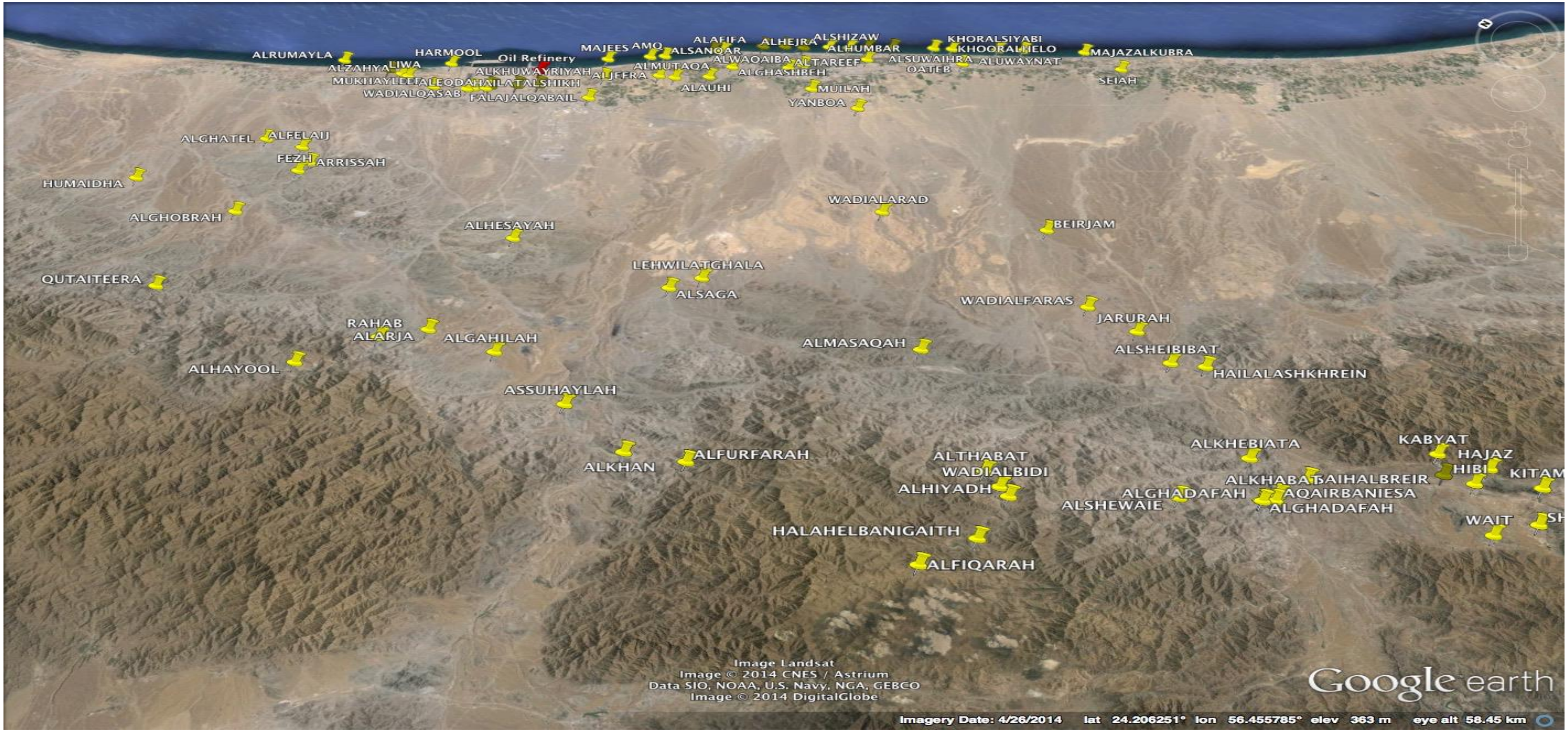

Figure II.3-2: Google earth image illustrating the location of the villages in the study area. The figure is taken from (Google inc 2011).

Table II.3-2: A sample of village locations according to longitude/latitude and distance from Sohar oil refinery.

Village	Latitude	Longitude	Distance from oil refinery (km)
Al-Ghuzayyil	24.48	56.60	2.37
Al-Eqda	24.50	56.59	3.38
Al-Had	24.49	56.59	3.42
Al-Auhi	24.40	56.67	10.80
Al-Afifa (Sohar)	24.41	56.71	11.80
Al-Ghashbeh (Sohar)	24.40	56.69	12.16
Al-Felaij (Sohar)	24.53	56.47	16.12
Al-Hadhira (Sohar)	24.38	56.74	16.90
Al-Ghatel (Sohar)	24.55	56.46	17.42
Al-Hejra (Sohar)	24.36	56.75	18.49
Al-Hesayah	24.37	56.46	20.04
Al-Ghobrah	24.50	56.39	22.88
Al-Arja	24.35	56.37	29.02
Al-Gahilah	24.32	56.38	30.89
Al-Hayool	24.38	56.31	33.15
Al-Fiqarah	24.30	56.36	33.67
Al-Furfarah	24.20	56.36	41.35
Al-Heshma	24.11	56.50	43.38
Al-Ghadafah	23.99	56.49	56.46

Geographical information system (GIS)

For an easier visualisation and presentation of the villages, GIS was used. This was done using ‘Quantum GIS’ software (Quantum GIS Development Team 2012). The shape files for the region were provided by the GfK GeoMarketing website (GFK Geomarketing 2015). The villages with their longitude and latitude were entered into QGIS software along with the shape files. The resulting map was used in the demonstration and presentation of the exposure assessment method.

b. Health effect data

The health data were obtained from the Omani MoH. These data were collected from a health recording system called the Al-Shifa system.

Al-Shifa health system

In 1987, MoH started an electronic healthcare information system known as the ‘Al-Shifa system’. This system serves as an electronic health record for patients’ information and clinical details, allowing better quality in healthcare. It was first started in the tertiary healthcare centres in Muscat, the capital of Oman. Then, in 1997, the system was started in primary healthcare institutions (Elhadi et al. 2008). In this study’s area, which is Liwa and Sohar governorates in the North Albatina region, the ‘Al-Shifa’ system was started in 2006.

Diseases explored in the study

Depending on the availability of data and according to the literature review discussed earlier, the acute health effects of air pollution such as respiratory disease, cardiovascular disease, and allergic diseases of the skin and eyes were studied.

The *International Classification Of Diseases* version *10th* (ICD-10) (WHO 2004) was used for determining the diagnosis of the diseases. The respiratory diseases involved acute respiratory infections covering both upper (ICD-10: J0-J06) and other acute lower respiratory infections (J20-J22) and pneumonia (ICD-10: J12-J18). These diseases were grouped together as acute respiratory diseases (ARD). The other respiratory diseases were chronic obstructive pulmonary diseases (COPD) (ICD-10: J40-J44 and J47) and asthma (J45 and J46).

On the other hand, the cardiovascular diseases include ischemic heart disease (IHD) (ICD-10: I20-I25), myocardial infarction (MI) (ICD-10: I21-I22), dysrhythmias (I46-I49), atrial fibrillation (ICD-10: I 48), chronic heart failure (ICD-10: I50) and stroke (ICD-10: I60-I69).

The allergic diseases explored were disorders of the conjunctiva (ICD-10: H10-H13) and dermatitis and eczema (ICD-10: L20-L30 and L50-L54, respectively).

Finally, diseases that are presumed not to be affected by air pollution, namely musculoskeletal health effects (MS) (ICD-10: M00-M99) and diseases of the oesophagus, stomach and duodenum (GI) (ICD-10: K20-K31), were also collected. Although the age was lacking in this data set, it was used mainly for sensitivity analysis. The *ICD -10 codes* of the studied diseases is summarised in **Table II.3 3.**

Table II.3-3: Diseases explored in the study with their *ICD-10 codes.*

ICD-10 code	**Disease**
Respiratory diseases	
J0-J06	Upper respiratory infections[1]
J20-J22	Lower respiratory infections[1]
J12-J18	Pneumonia[1]
J40-J44 and J47	Chronic obstructive pulmonary diseases (COPD)
J45 and J46	Asthma
Cardiovascular diseases (CVD)	
I20-I25	Ischemic heart disease
I21-I22	Myocardial infarction
I46-I49	Dysrhythmias
I 48	Atrial fibrillation
I50	Chronic heart failure
I60-I69	Stroke
Allergy of the eye	
H10-H13	Disorders of conjunctiva
Allergy of the skin	
L20-L30	Dermatitis
L50-L54	Eczema
Others[2]	
M00-M99	Diseases of the musculoskeletal system and connective tissue
K20-K31	Diseases of esophagus, stomach and duodenum

[1] grouped together as acute respiratory diseases (ARD).
[2] data lacking age of the patient and used for sensitivity analysis.

The collected health data

The health data were a record of daily visits to the primary, secondary, and tertiary health institutions registered by the treating physician. Data were gathered from the national Al-Shifa electronic health recording system from eight state health institutions in these provinces, for the period of January 1st, 2006, to December 31st, 2010. The information given for each visit is shown in **Table II.3 4**. Collectively, these health records reached more than 900,000 entries, and were provided as a CSV text file on a compact disc.

Table II.3-4: Health data variables given for each visit.

Variables	Explanation
Date	The date of the consultation.
Patient Identification Number (ID)	A health registry identification number unique for each patient.
ICD-10	Final diagnosis of the physician recorded as an *International classification of diseases-10*[1].
Village	The village of the patient.
Health institution	The name of the visited health institution.
Date of birth	-
Sex	-

[1] **ICD-10 codes included:** J: respiratory diseases; I: cardiovascular diseases; H: disorders of the conjunctiva; L: dermatitis and eczema; M: all musculoskeletal diseases and K: diseases of esophagus, stomach and duodenum.

Health effects definition: a literature review

In this study, an ‘event’ was defined as any patient ID with its associated ICD-10 diagnosis. This was determined by the attending physician.

To measure the incidence rate, and the subsequent RR between the exposure zones of the studied diseases, there was a need to differentiate between a ‘new event’ and a ‘follow-up’ of an event by the same patient ID. In the next section a literature review of the previous epidemiological studies is presented to decide the best method on the definition of a new event for each disease. A summary of this literature review is shown in **Table II.3 5**.

Respiratory diseases

The respiratory diseases included acute respiratory diseases, asthma and COPD.

Acute respiratory diseases (ARD)

Because of the similarities in their clinical definitions and presentations, one definition of 'new events' and follow-ups will be used for acute respiratory infections, upper and lower, and pneumonia. Clinically, the average duration of any acute respiratory tract infection is around seven days (Elliot & Fleming 2009), whereas a subjective improvement will be expected within five days after treatment with antibiotics (Fein et al. 2006). Epidemiological studies defined the duration of ARD differently. While some studies defined the follow-ups as: the same 'defined case' coming within one week (Ezzati & Kammen 2001; Sharma et al. 1998), others defined the duration as 12 days (Cerqueiro et al. 1990), two weeks (Broor et al. 2001), one month (Hertz-Picciotto et al. 2007) and as far as three months (Campbell et al. 1989). In their epidemiological review of the best methodology for studying acute respiratory diseases, Lanata *et al.* suggested a minimum of two weeks free of symptoms for a case to get a new acute respiratory event (Lanata et al. 2004). Combining all of these definitions, duration of one month for the event will be satisfactory in decreasing the possibility of counting a follow-up respiratory infection as a new event

Asthma

Many epidemiological studies considered the prevalence of asthma attacks as the prevalence of 12 months' attack rates (Brim et al. 2008; Sama et al. 2003; Akinbami et al. 2011). This was also adopted in the questionnaire by The International Study of Asthma and Allergies in Childhood (ISAAC) (Asher et al. 1995). However, a one-day definition was adopted by Loyo et al. (Loyo-Berrios et al. 2007), whereas, Gruchalla et al. defined this period as two weeks (Gruchalla et al. 2005) and Gerald et al. defined it as one month (Gerald 2009). Therefore, and because of the insufficiency of cases to use the one-year definition, the one-month definition for new asthma event was used.

The choice of a one month definition, for both ARD and asthma, would be within the range of the previously discussed studies. In particular, the one month period definition would be between the period chosen by the big study of ISAAC (Asher et al. 1995), which was one year, and the two week period suggested by Lanata et al (Lanata et al. 2004) in their review study. The use of the one month lag between visits to define new cases in our study also ensured sufficient number of events to improve the study efficiency. In addition, a one month definition period is a conservative definition to prevent the overlap between the new events and follow ups.

COPD

COPD or chronic obstructive lung disease consists of chronic bronchitis and emphysema. The disease is progressive and partially reversible (Siafakas 2004). Studies examining the association between COPD and air pollution use COPD exacerbation attacks as a disease activity marker. While some studies examined this exacerbation attacks as hospital admission rates (Schwartz 1994; Burnett et al. 1995; Dominici et al. 2006), others explored it as emergency admission rates (Sunyer et al. 1993; Peel et al. 2005). This study's data are mainly primary health records, while patients with COPD exacerbation are usually managed in tertiary hospitals. Moreover, the definition of this 'exacerbation' is still controversial and evolving (Pauwels et al. 2004; Voekel et al. 2008) which may add more confusion as to whether it is a follow-up case or an exacerbation of COPD. For these reasons, a definition of a yearly 'new event' will be adopted in this study, which will also increase the number of cases for the analysis.

Cardiovascular diseases

The cardiovascular diseases covered in this study included IHD, MI, dysrhythmias, atrial fibrillation, chronic heart failure and stroke. However, for an easier analysis, and to increase the power of the study, MI with IHD was merged and atrial fibrillation with dysrhythmias was merged.

IHD: including MI

Epidemiological studies exploring the effects of environmental exposure to IHD have different explanations for the 'new events'. For example, Metzger *et al.* disregarded any patient as having a 'new MI' if he is coming within a day of his first MI (Metzger et al. 2004). This period was two weeks in a study conducted by Slaughter *et al*. (Slaughter et al. 2005). As a 30-day hospital stay is now considered a metric for care of patients with MI, a follow-up MI is considered if coming within 30 days of the first infarct (J. Wichmann et al. 2012; Juster et al. 2007). Hence, a 30-day approach to distinguish a 'new event' from a follow-up MI will be used.

Dysrhythmias, chronic heart failure and stroke

These conditions are episodic and chronic cardiovascular conditions. When a patient comes with exacerbation of a chronic heart failure, for example, his subsequent visits will be for the same heart failure, especially in a primary health care setting. Similarly in stroke, studies usually examined the life time incidence as it is difficult to distinguish between new and a recurrent stroke (Pascal et al. 2013; Low et al. 2006).

All cardiovascular approach

It is worthwhile mentioning that some studies suggested the use of all-causes cardiovascular diseases as it will add more power to the study (Liang et al. 2009; Dominici et al. 2007; Dockery et al. 1993). Thus, this definition approach was also tested.

Allergic diseases of eye and skin

For allergic diseases, several epidemiological studies extended their definition of a new event from 10 disease-free days (Chang et al. 2012) to up to one year (Solé et al. 2007). Thus, a similar one-month definition for allergic diseases was adopted. This will help increasing the sample size for the analysis.

Musculoskeletal diseases and gastrointestinal diseases

Because these diseases were only used for sensitivity analysis, their monthly follow-ups were compared with the monthly follow-ups of ARD and asthma cases.

Table II.3-5: A summary of environmental epidemiology studies that used different disease-event definition in respiratory diseases, asthma, cardiovascular diseases and allergic diseases.

Study	Disease	Definition of a 'new event'	Outcome recording	Exposure type	Age group
Acute respiratory diseases					
(Wong 2006)	Respiratory tract diseases	First visit/ one event per each ID	Primary consultation in the general practitioner	Measured pollutants levels	All age groups
(Vichit-Vadakan et al. 2001)	Upper respiratory tract infection and lower respiratory tract infection.	One day (but was controlled for in the model with a variable indicating if the patient has previous day symptoms)	Questionnaire-reported symptoms for 3 months	Measured pollutants levels	All age groups
(Campbell et al. 1989)	Acute lower respiratory tract infections	Three months from the previous attack	Questionnaire Reported symptoms	Measured pollutants levels	Children
(Cerqueiro et al. 1990)	Acute lower respiratory tract infections	Onset of acute respiratory infection within 12 days before admission	Hospital admissions	Measured pollutants levels	Children
(Broor et al. 2001)	Acute lower respiratory tract infections	Having symptoms for less than 2 weeks	Hospital admissions	Studying the environmental risk factors of infections.	Children
(Ezzati & Kammen 2001)	Acute lower respiratory tract infections	One week recording of symptoms	Community nurse visit and survey	Measured pollutants levels	All age groups
(Hertz-Picciotto et al. 2007)	Lower respiratory tract illness	One-month from the previous attack	Paternal questionnaire and hospital medical records	Measured pollutants levels	Children

Study	Disease	Definition of a 'new event'	Outcome recording	Exposure type	Age group
(Ostro et al. 1993)	Reported respiratory symptoms	One symptom-free day	Diaries filled by patient	Measured pollutants' levels	Adults
(Sharma et al. 1998)	Acute lower respiratory tract infections	Seven symptom-free days	Survey by doctors and health care workers	Measured pollutants' levels	Infants
(Lanata et al. 2004)	Acute respiratory tract infection	2 weeks symptom-free days.	A Recommendation based on previous developing countries studies		All age groups
(Slaughter et al. 2005)	All respiratory causes, pneumonia, acute upper respiratory tract infections, COPD and Asthma	If readmission within 2 weeks of the first admission, the case was excluded from analysis.	Accident and emergency visits and hospital admission	Measured pollutants levels	All age groups
(Tramuto et al. 2011)	Acute respiratory tract diseases	One-month from the previous attack	Accident and emergency visits and hospital admission	Measured pollutants levels	Adults
(Hajat 2001)	Allergic rhinitis	One symptom-free day	Primary consultation in GP	Measured pollutants levels	All age groups
Asthma					
(Sama et al. 2003)	Asthma	Reactivated/ exacerbation asthma: after one year of inactivity	Health maintenance organization records	Investigating the best methodology of asthma	Adults
(Salmond et al. 1999)	Asthma	One year to reactivation/ exacerbation/attack	Questionnaire Reported symptoms	Environmental /social depravation	Adults
(Brim et al. 2008)	Asthma	One year from the previous attack	National Health Interview Survey	Environmental /social depravation: ethnic	Children

Study	Disease	Definition of a ‘new event’	Outcome recording	Exposure type	Age group
(Asher et al. 1995)	Asthma, conjunctivitis and eczema	One year from the previous attack	ISAAC study		Children
(Loyo-Berrios et al. 2007)	Asthma	One-attack free day	Asthma-related medical visits through health insurance claims	Proximity to pollutant source	Children
(Gruchalla et al. 2005)	Asthma	Two attack-free weeks	Clinical interviews	Exposure to allergens	Children
(Gerald 2009)	Asthma	One –attack free month	Part of a randomised clinical trial study	Environmental tobacco smoke exposure	Children
(Eisner et al. 2005)	Asthma	Monthly cases of asthma	Hospital admissions of asthma	Environmental tobacco smoke exposure	Adults
Allergies					
(Chang et al. 2012)	Conjunctivitis	Repeated visit within 10 days	Outpatient ophthalmologist diagnosis	Measured pollutants levels	All age groups
(Solé et al. 2007)	Asthma, conjunctivitis and eczema	One year from the previous attack	Survey using ISAAC	Measured pollutants levels	Children
(Susitaival et al. 2003)	Eczema	One year from the previous attack	Nordic Occupational Skin Questionnaire	Questionnaire for occupational skin eczema	All age groups.
(Parker et al. 2008)	Allergies (respiratory, food and skin)	One year from the previous attack	National Health Interview Survey / interviews	Measured pollutants levels	Children

Study	Disease	Definition of a 'new event'	Outcome recording	Exposure type	Age group
(Kim et al. 2013)	Eczema	One year from the previous attack	Survey using ISAAC	Proximity to pollutants and air pollution monitoring data	Children
Cardiovascular diseases					
(Metzger et al. 2004)	Cardiovascular morbidities	One-visit free day	Emergency department visits	Measured pollutants levels	Adults
(Slaughter et al. 2005)	Cardiovascular morbidity and mortalities	Two-visits free weeks	Hospital admissions and emergency room visits	Measured pollutants levels	Adults
(J. Wichmann et al. 2012)	Acute myocardial infarction	30 days definition	Hospital admissions	Temperature and measured pollutants levels	Adults
(Juster et al. 2007)	Acute myocardial infarction	30 days definition	Hospital admission rates	Smoking ban implementation	Adults
(Pascal et al. 2013)	Stroke	Life time incidence	Hospital records	Traffic noise and ambient air pollution	Adult

Health institutions in the area

Data from the 'Al-Shifa' health system were obtained from the Department of Information Technology of the MoH for eight health institutions found in Liwa and Sohar governorates in Oman for the period from January 1st, 2006 to December 31st, 2010. Because of the different establishment dates of these institutions and the different introduction dates of 'Al-Shifa' system, the dates of the available data differ between them. Along with Sohar city, the capital of Sohar province, these data represented a total of 59 villages. Data from private institutions were not available on this electronic system. **Table II.3 6** shows the institutions, their estimated distance from the industrial area, their level of care, and the years for which the data were available. These institutions were uniformly distributed in the study area.

Table II.3-6: Health institutions in the studied area, their data availability, distance from the refinery and their level of care.

Health institution	Estimated distance from refinery in km	Level of care	Years of data availability
Liwa Health Centre	5	Primary health care[1]	2006-2010
Nabar Health Centre	8	Primary health care	2007-2010
Al-Multaqa Health Centre	10	Primary health care	2006 - 2010
Sohar Polyclinic	21	Secondary Health Care[2]	2010
Sohar Hospital	21	Tertiary Health Care[2]	2008-2010
Uwainat Health Centre	35	Primary health care	2007 - 2010
Wadi Ahin Health Centre	57	Primary health care	2006 - 2010
Wadi Hibi Regional Hospital	65	Secondary Health Care	2010

[1]Comprises family physicians' consultation rooms, a basic laboratory and an x-ray room.
[2]Have different specialty physicians, more specialised investigations and admission rooms.

c. Demographic and meteorological data

Demographic data for area-specific population by age and gender, educational and occupational statuses were obtained from the Omani national census of 2010. The area-specific population was used as an offset for the models. Education and occupational status were used to construct the SES indicators for each village.

Age and gender-specific smoking prevalence data were derived from a study done by Al Riyami et al*.* (Riyami & Afifi 2004), and the Global Youth Tobacco Survey (GYTS-Oman) (El-aziz et al. 2007). Meteorological data such as daily wind speed, wind prevailing direction and temperature were obtained from the Omani Department of Meteorology for the period of January 1^{st}, 2006, to December 31^{st}, 2010.

d. Exposure assessment

In the next section the exposure classification methods used in the study will be discussed.

Air quality from MECA monitors

The air quality data in the area were obtained from MECA for the period 2007-2009. Daily levels of PM_{10}, SO_2, nitric dioxide (NO_2), CO and O_3 data were recorded by a static monitoring station located 300 meters southeast of the refinery, (**Figure II.3 3**). However, after examining these air quality data, they were incomplete for more than 50% of the recording period. Therefore, these data could not be used in the exposure classification in this study.

Figure II.3-3: The static air pollution-monitoring unit used by MECA. Note: although it is a mobile unit, it was kept in one place during the three years of monitoring (2007-2009).

Exposure classification method

Due to lack of air pollution monitoring or measurements in the area, a proximity method to classify the exposure of the villages around SIZ was employed. Villages were classified according to their distance from the source of pollution. The oil refinery was used as a landmark source from which to estimate the distance, as this industry is the main source of exposure in SIZ and was one of the first to begin operations. The proximity approach is widely used in many influential environmental epidemiology studies (Bentov et al. 2006; Briggs 2003; Elliott et al. 2001; Sarov et al. 2008; Shore et al. 1993; F. A. Wichmann et al. 2009; Yang et al. 2004). In addition, this method is used frequently in many environmental investigation studies such as in environmental impact assessment and environmental justice studies (Huang & Batterman 2000). For example, the United

States Environmental Protection Agency (US EPA) has used this approach in its environmental risk assessment framework (U.S. Environmental Protection Agency 2003).

Determining the minimum distance for exposure classification: a literature review

Previously published evidence was used to determine the most appropriate definition of the minimum distance for exposure. In several epidemiologic studies, the designation of the minimum proximity distance for exposure classification was mostly arbitrary (Greaves et al. 1981; Shore et al. 1993; Linos et al. 1991). However, one study defined the distance depending on residents' odour complaints (Sarov et al. 2008), while others defined it by using environmental sampling (Polissar et al. 1990; Kimbrough et al. 1995). The threshold distance used in the studies assessing the effects of petrochemical industrial complex ranged from 3 km (Yang et al. 2004) to 20 km (Bentov et al. 2006), whereas two studies used a 20 km distance for the metal smelters (Greaves et al. 1981; Sarov et al. 2008).

Table II.3 7 shows a literature review of the epidemiological studies that used proximity method for their exposure classification and their reasoning for choosing their distances.

Table II.3-7: Comparison of epidemiological studies that used the proximity distance for their exposure assessment.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Lewin et al. 2013)	Canada	2013	Aluminum smelters	Asthma and bronchiolitis hospital admission	Living within 2.5 and 7.5 km from the smelter, using case-crossover design. Additionally they used wind roses analysis and environmental monitoring data.	The distance was chosen to capture most of the population around the smelter.	Similarity between the two buffer zones, 2.5 and 7.5 km. Odds Ratio (OR) for asthma hospitalisation was: 1.45 (95 % CI: 1.00–2.12) in age group 2-4 year old.
(Dales et al. 2013)	Canada	2013	Steel plant	Pulmonary function test examination	Exposure group spent 8 hours within 0.9 km from a steel plant. The control was living approximately 4.5 km from the smelter.	Arbitrarily chosen distance.	Pulmonary function tests were lower in population living near the plant compared to living 4.5 km away from the steel plant.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Kim et al. 2013)	South Korea	2013	Traffic related and industrial complex	Allergic diseases in children by using ISAAC questionnaire.	The studied schools were classified according to zones: located near green areas (control), near main traffic and near industrial complex.	The classification was verified by traffic counts and air pollution monitoring.	Asthma, allergic rhinitis and atopic dermatitis treatment increased in schools of traffic related and industrial complex compared to control zone. For dermatitis, RR: 1.42 (95% CI: 1.02– 1.97)
(Tanyanont & Vichit-Vadakan 2012)	Thailand	2012	Petrochemical industrial complex	Acute respiratory and eye symptoms	Living within 5 km from the petrochemical complex.	Distance was determined by a previously unpublished report.	Living within 5 km from the petrochemical complex was associated with greater risk of acute respiratory and irritative symptoms. In eye irritation RR: 1.59 (95% CI: 1.45 - 1.76)

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Papadimitriou et al. 2012)	Greece	2012	Industrial area with liquid waste and various industrial emissions	Prevalence of atopy: hay fever, allergic conjunctivitis, dermatitis and pulmonary function test examination	Comparing industrial and rural area of residency. Children studied resided around 5 km from the industries.	Arbitrarily chosen distance.	Eczema and reduced spirometric indices was more in the industrial area compared to the rural area.
(Li et al. 2011)	China	2011	Industrial park including refineries and petrochemical industrial complexes	Health effects from exposure to soil contaminants: also called persistence toxic substances.	Exposure area within three blocks radius from the industrial area.	Distances were determined by soil sampling	Associations were found only for dermatitis, OR: 1.72 (95% CI: 1.05–2.80)
(Mohai et al. 2009)	United States of America	2009	Different polluting facilities.	Inequity of racial and socio-economic distribution around plants	Distance of 1.6 km from the polluting industries.	From Toxic Release Inventory (TRI) and maternal address.	Racial and socioeconomic disparities were significantly evident around the industries.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(F. A. Wichmann et al. 2009)	Argentina	2009	Petrochemical industrial complex	Respiratory health effects such as asthma.	People living within 10 km from the industries	Distances were chosen arbitrarily	Children living within 10 km from the petrochemical complex have more respiratory health effects. For example, asthma OR: 2.76 (95% CI: 1.96-3.89)
(Smargiassi et al. 2009)	Canada	2009	Petroleum refinery	Hospital admission of respiratory diseases in children	By measuring the levels SO_2 levels and by dispersion model	Using estimated SO_2 levels	Association between peak SO_2 levels and asthma hospitalisation. For same day SO_2 peak levels asthma OR: 1.42 (95% CI: 1.10–1.82).
(Zeka et al. 2008)	United States of America	2008	Traffic-related air pollution	Birth outcomes	200m grids around the main highway.	They used distance from the main road as a variable in their study.	Positive associations in low birth weight and distance from the main traffic and low SES groups.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Sarov et al. 2008)	Israel	2008	17 heavy industrial plants, such as heavy metal smelters, hydrocarbons (polycyclic, aromatic and alipathic)	Perinatal mortality	People living within 20 km from the industries.	Based on geographical distribution and odour complaints from residents around industries	Mothers living near the industrial park (within 20 km) have a greater risk of perinatal mortality RR: 1.45 (95% CI: 1.22–1.72).
(Brender et al. 2008)	United States of America	2008	Superfund sites	Chromosomal abnormalities	Women living in distances: from 0.5 km to 8 km from the superfund	Distances chosen arbitrarily	There was association between the occurrences of chromosomal anomalies in offspring of women living within 0.5 km from superfund site.
(Kaatsch et al. 2008)	Germany	2008	Nuclear power plant	Childhood leukemia	Exposure was classified according to zones: 5 and 10 km from the plant.	Arbitrarily chosen distance.	Positive associations of leukemia within 5 km from the nuclear plant.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Patel et al. 2008)	India	2008	Dyes, pharmaceutical and agrochemical industries.	Respiratory symptoms and pulmonary function tests.	Exposure was classified according to the following zones from the industries: 2,3,5 and 20 km as control.	Distances were chosen arbitrarily	No difference in respiratory symptoms was found between exposed and control villages. Obstructive airway abnormalities found to be more near the industrial area, RR: 2.56 (95% CI: 1.19-5.47)
(Généreux et al. 2008)	Canada	2007	Traffic-related air pollution.	Adverse birth outcomes.	200 m grid from the highway.	Distance selected based on the assumption that pollutant levels decrease after 200 m	Adverse birth outcomes in wealthy women living near highway. For example, in preterm birth OR: 1.58 (95% CI: 1.23 - 2.04)

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Suarez et al. 2007)	United States of America	2007	Superfund sites	Neural tube defects	Exposure was classified according to zones: of 0.8 km to 4.8 km distances	From TRI and maternal address.	No associations were detected between superfund sites and neural tube defects.
(Kuehn et al. 2007)	United States of America	2007	Superfunds sites	Congenital malformations	Exposure was classified according to the following zones: ≤0.8 km, >0.8–≤1.6 km, >1.6-≤3.2 km, >3-≤8 km and >8 km (as a control zone)	Distances were chosen arbitrarily	Positive association of congenital anomalies with proximity to superfund sites. For example, mothers living within 0.8 km have OR: 1.33 (95% CI: 1.27-1.40) of having congenitally malformed babies.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Kouznetsova et al. 2007)	United States of America	2007	Persistent organic pollutants (POP) waste sites such as: dioxins/furans, Polychlorinated biphenyl (PCBs) and persistent pesticides.	Hospitalisation of diabetic patients.	According to ZIP codes containing these industries	ZIP code based	Positive association found between living near the POP sites and diabetic hospitalisation, RR: 1.23 (95% CI: 1.15–1.32)
(Choi et al. 2006)	United States of America	2006	PCB-contaminated harbor	Cord serum PCB levels in infants	Living within 8 km from the harbour	Arbitrary distance choice.	No association found between PCB and residential distance from the superfund site.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Bentov et al. 2006)	Israel	2006	Chemical facilities with various products such as heavy metals, hydrocarbons (polycyclic, aromatic and alipathic)	Major congenital malformations (MCM)	Living within 20 km from the industries	Based on geographical distribution and odour complaints from residents around industries.	Mothers living within 20 km from industrial park have greater risks of (MCM) RR: 1.17 (95% CI: 1.04–1.29) compared to those living away.
(Yu et al. 2006)	Taiwan	2006	Petrochemical industrial complexes	Leukemia admissions of patients > 29 years old	Patients living within 3 km radius from the industrial complex. There is exposure wedges according to prevailing wind.	The distance was derived based on previous studies conducted in the study area.	Living within 3 km from the industries was positively associated with increased leukemia cases in the older age group of 20-29, RR: 1.54 (95% CI: 1.14 - 2.09).
(Palmer et al. 2005)	Great Britain	2005	Waste landfills	Congenital anomalies	Living within 2 km from the landfill.	Based on Elliott et al (Elliott et al. 2001)	Mothers living within 2 km from landfill had a standardised RR of 1.39 (95% CI, 1.12–1.72) of congenital anomalies.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Kloppenborg et al. 2005)	Denmark	2005	Waste landfills	Congenital anomalies	Exposure was classified according to the following zones: 0-2 km, 2-4 km and 4-6 km	zones were based on previous studies	Small risk for cardiovascular anomalies was detected.
(Yang et al. 2004)	Taiwan	2004	Three refineries	Preterm delivery	Exposure was classified according to zones of 3 km radii.	Distances were chosen arbitrarily	Mothers living near the refineries have more risk to give birth to preterm infants adjusted OR: 1.14 (95% CI=1.01–1.28).
(Crosignani et al. 2004)	Italy	2004	Traffic-related air pollution	Childhood leukemia	Exposure was classified according to the following zones: 20 m, 20-150 and >120 m. Estimation of benzene levels by dispersion model	Determined from previous studies and benzene dispersion model.	Positive association between estimated benzene levels and leukemia. RR: 3.91 (95% CI: 1.36–11.27) when living near a major road.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Pignato et al. 2004)	Italy	2004	Petrochemical industries and oil refineries.	Prevalence of self-reported asthma and asthma-like symptoms.	Comparing 4 Italian cities located near heavy industrial complexes with control cities.	Using cities borders	The reported asthma attack prevalence in the exposed cities is higher than the one reported in the control cities, 5.2% and 3.7%, respectively.
(Johnson et al. 2003)	Canada	2003	Industrial plants: smelters (copper, lead, steel), oil refineries and pulp mills (Kraft and sulfate)	Reported cases of NHL	Exposure was classified according to two zones: 0.8 km and 3.2 km	Cut-off distance was based on a study done by Linos et al. (Linos et al. 1991).	Associations between NHL and proximity were strong only in women, OR: 1.48 (95% CI: 1.10-1.99), living in proximity to copper smelters OR: 5.1 (95% CI: 1.5-17.7) and living in proximity to sulfite pulp mills OR: 3.7 (95% CI: 1.5-9.4)

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Maheswaran & Elliott 2003)	Great Britain	2003	Traffic-related air pollution	Mortality of stroke	Exposure zones were bases on the following distances from roads; 200, 500 and 1000 meters	Distance was determined by census blocks	Men living within 200 m from the main road had 7% (95% CI: 4 - 9) more risk of stroke compared to men living more than 1 km away.
(Hoek et al. 2002)	Netherlands	2002	Traffic-related air pollution.	Cardiopulmonary mortality	Distances were classified as: 100 m from the freeway and 50 m from the major road	Estimated levels of pollution when living near the roads from other Dutch traffic studies.	People living near the major road had a great incidence of cardiopulmonary mortalities (RR: 1.95; 95% CI: 1.09-3.52)
(Aylin et al. 2001)	Great Britain	2001	Coke plant	Emergency admissions of cardiovascular and respiratory diseases	People living within 7.5 km from the plant.	Arbitrarily defined distance.	For each kilometre closer to Teesside coke works, the respiratory diseases RR increased by: 1.09 (95% CI 1.06 to 1.12) and asthma RR by: 1.09 (95% CI 1.04 to 1.15).

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Elliott et al. 2001)	Great Britain	2001	Landfill site	Still birth and congenital anomalies	Mothers living within 2 km form the landfill site	Based on previous studies and estimated dispersion of landfill emissions	Mothers living within 2 km from the landfill had increased risks of congenital malformation RR: 1.01 (95% CI: 1.005 - 1.023)
(Venn et al. 2001)	Great Britain	2001	Traffic-related air pollution	Wheeze in 4-16 year old children.	Children residing within 150 m from the main road	Distance was selected based on the assumption that pollutants will reach their background levels after 150 m from the road.	Positive association of wheeze and living near the main roads, OR: 1.08 (95% CI: 1.00 - 1.16).
(Petrela et al. 2001)	Brazil	2001	Aluminum plant	Hospital admissions of respiratory diseases	Exposure assessment by dust analysis around communities of the industrial area (radius of 40 km) versus control.	Dust analysis	RR of the selected respiratory diseases: 4.11 (95% CI: 2.96-5.70) compared to the control communities.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Wilkinson et al. 1997)	Great Britain	1997	Pan Britannica Industries	Incidence and mortality of cancer	The following eight zones were developed: 1,2,3,4.3,5.3, 6.1, 6.8, and 7.5 km.	Distances were chosen arbitrarily	Declining risk of cancer mortality with distance. OR: 1.04 (95% CI: 1.02 - 1.06) of cancer from 0-7.5 km.
(Yang et al. 1997)	Taiwan	1997	Petrochemical industrial complex	Health survey of respiratory and acute irritative symptoms.	They divided schools into exposed (situated near a petrochemical complex) and control.	Distances were chosen arbitrarily	Greater incidence of acute irritative symptoms were found in the exposed area. For example, eye irritation RR: 2.16 (95% CI: 1.43-4.35).
(Morris & Knorr 1996)	United States of America	1996	Nuclear power plants	Leukemia admissions	People living within 6.4 km from the plant	Using radioactive measurements and analysis.	Evidence of greater incidence of leukemia (OR = 3.46, 95% CI = 1.50-7.96) in adults living within 6.4 km from the nuclear power plant, especially in the downwind period.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Kimbrough et al. 1995)	United States of America	1995	Lead smelters	Lead blood levels	Children living within 3.2 km from the smelter.	EPA-proposed distance after studying the soil and air lead levels.	The mean blood lead levels in the studied children population were below the level of concern by the Center for Disease Control and Prevention (US).
(Kilburn & Warshaw 1995)	United States of America	1995	Oil refineries	Neurological functions	Exposure was classified according to the following zones: 1.2, 2.4, 3.6, and 4.8 km radii	By direct environmental sampling and dispersion models	Exposed people had altered neurological functions.
(Pekkanen et al. 1995)	Finland	1995	Oil refineries	Leukemia cases	Exposure was classified according to the following zones: 4, 8, 12 and 16 km.	Arbitrarily defined geographical area	No association between distance from refinery and cases of leukemia.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Edwards et al. 1994)	Great Britain	1994	Traffic-related air pollution	Admission of asthma in children <5 year old	Two zones were classified: 200 m and 500 m from the main road.	These distances were chosen because they are the closest possible allowing distances by the mapping system used in the study.	Positive association between proximity to road and asthma admission in children
(Shore et al. 1993)	United States of America	1993	Multiple fume producing factories	Leukemia and lymphoma cases.	Exposure was classified according to zones of: 1.5km, 1.5-3km and more than 8 km from the factories.	Arbitrarily defined geographical area	Leukemia risk increased by 40% when living within 8 km from the industries. (OR= 1.4; 95% CI: 1.0-1.9).
(Baghurst et al. 1992)	Australia	1992	Lead smelters	Lead blood levels	Children living within 30 km from the smelter.	Cohort of children living in that area. In addition, they used topsoil lead levels for exposure assessment.	Blood lead levels were significantly higher in the children living in the Lead Smelting city of Port Pirie.

Authors	Country	Year	Pollutant source	Outcome	Distance	Justification for choosing the distance	Results
(Linos et al. 1991)	United States of America	1991	Multiple factories with fume	Leukemia and lymphoma	People living within 3.2 km from the factories.	Arbitrarily defined geographical area.	Significant 40% increase in the development of non-Hodgkin's lymphoma in people living within 3.2 km from the factories.
(Polissar et al. 1990)	United States of America	1990	Arsenic plant	Arsenic urine samples	People living within 12.8 km from the factories.	Environmental sampling.	Urine concentration dropped to background levels within 2.5 km from the smelter
(Greaves et al. 1981)	United States of America	1981	Iron smelter	Lung cancer	People living within 20 km from the smelter.	Arbitrarily defined geographical area, tried to fill between the distances of two previous studies.	No association between lung cancer and the distance from the smelter.
(Matanoski et al. 1981)	United States of America	1981	Arsenic plant	Mortality of cancer	People living within 1.2 km from the plant.	Arbitrary and choosing participants within 1.2 km from the plant.	Excess in mortality rate from lung cancer was found among men living in a heavily industrialised area.

International housing policies

In addition, these exposure distances may be retrieved from international housing policies, which decide the minimal distance of housings from industrial areas. For instance, the Government of Western Australia recommends a separation distance of 2 km from oil refineries and residential areas (Segui 2005). Similarly, the Government of South Australia recommends a 2 km distance from a refinery (Torr & Watson 2000) (see **Table II.3 8**).

Table II.3-8: Example of international housing policies for the minimum acceptable distance from industry to residential areas.

Industry type	MAD	Government body	Country	Reference
Petrochemical industries	>2 km	EPA Victoria	Australia	(EPA Victoria 2013)
Metal production	>1-2 km			
Aluminum production	>1.5-2 km	EPA Western Australia	Australia	(Segui 2005)
Petroleum refining	>2 km			
Petroleum refining	>2 km	EPA South Australia	Australia	(Torr & Watson 2000)
Aluminum by electrolysis	>2 km			
Petroleum refining	>2 km	Auckland council	New Zealand	(Wickham 2012)
Metal processing	>1km	Department of Environment	Malaysia	(Department Of Environment 2013)

MAD: minimum acceptable distance
EPA: Environmental Protection Authority

Crude rates analysis

To further establish the effects of proximity to the industrial area on disease, the crude incidence of all respiratory diseases (RS) against the distance from the refinery was plotted. The villages were aggregated according to their approximate distance from the refinery. In each village, the crude incidence rate of RS was calculated by dividing the sum of RS counts over the total population of the village.

The resulting plot of the crude incidence rates against the distance from the refinery is shown in **Figure II.3 4**. It shows that the crude incidence rates increase when the distance from the refinery decreases. It also shows that most of the high crude incidence rates were situated between 5 and 10 km.

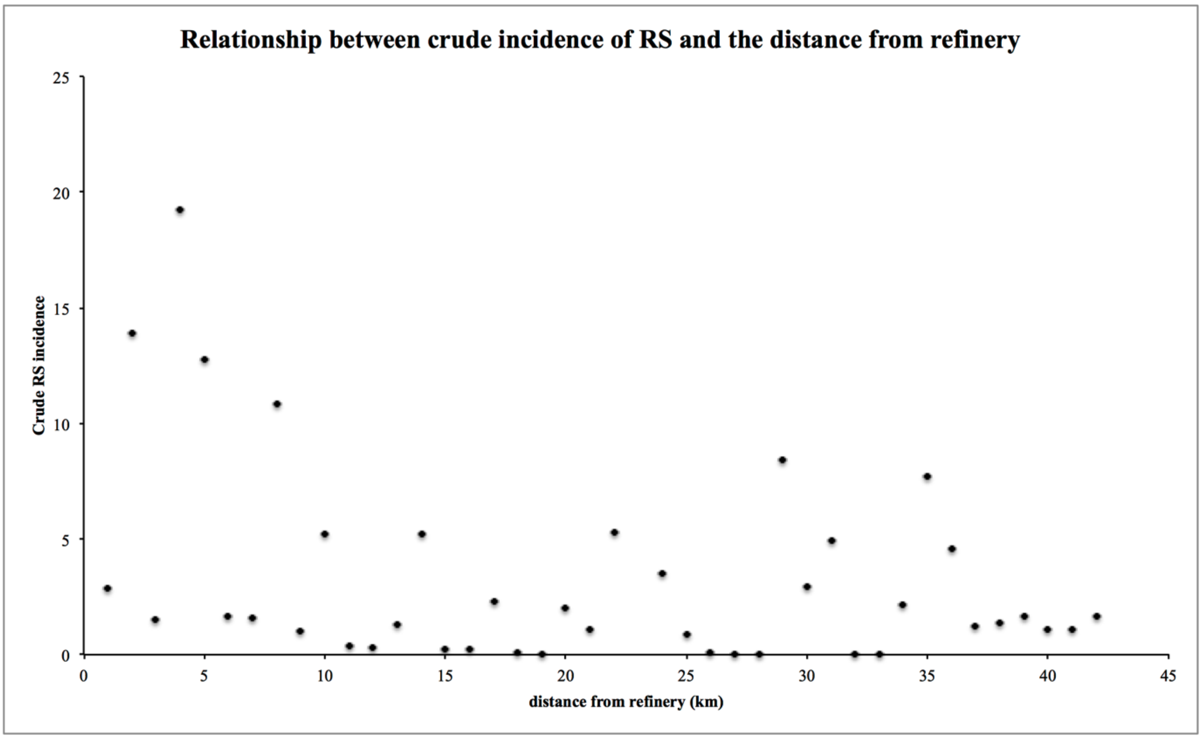

Figure II.3-4: Relationship between all respiratory diseases (RS) crude incidence and the distance from refinery (km) *. * Villages with approximately similar distances from the refinery were aggregated and their crude incidence rate for RS was plotted against the distance from the refinery.

Final exposure classification distances

Taking into consideration this previous evidence and to increase the power of the study, an incremental distance of 5 km from the refinery was decided to classify the area around SIZ. Therefore, three exposure zones were described: high exposure zone for those living ≤5 km from the refinery, intermediate, those living within >5-10 km and control exposure zone as living ≥20 km from refinery. There were no villages located between 10 and 20 km from the refinery, therefore this distance was not represented in the study **(Figure II.3 5).**

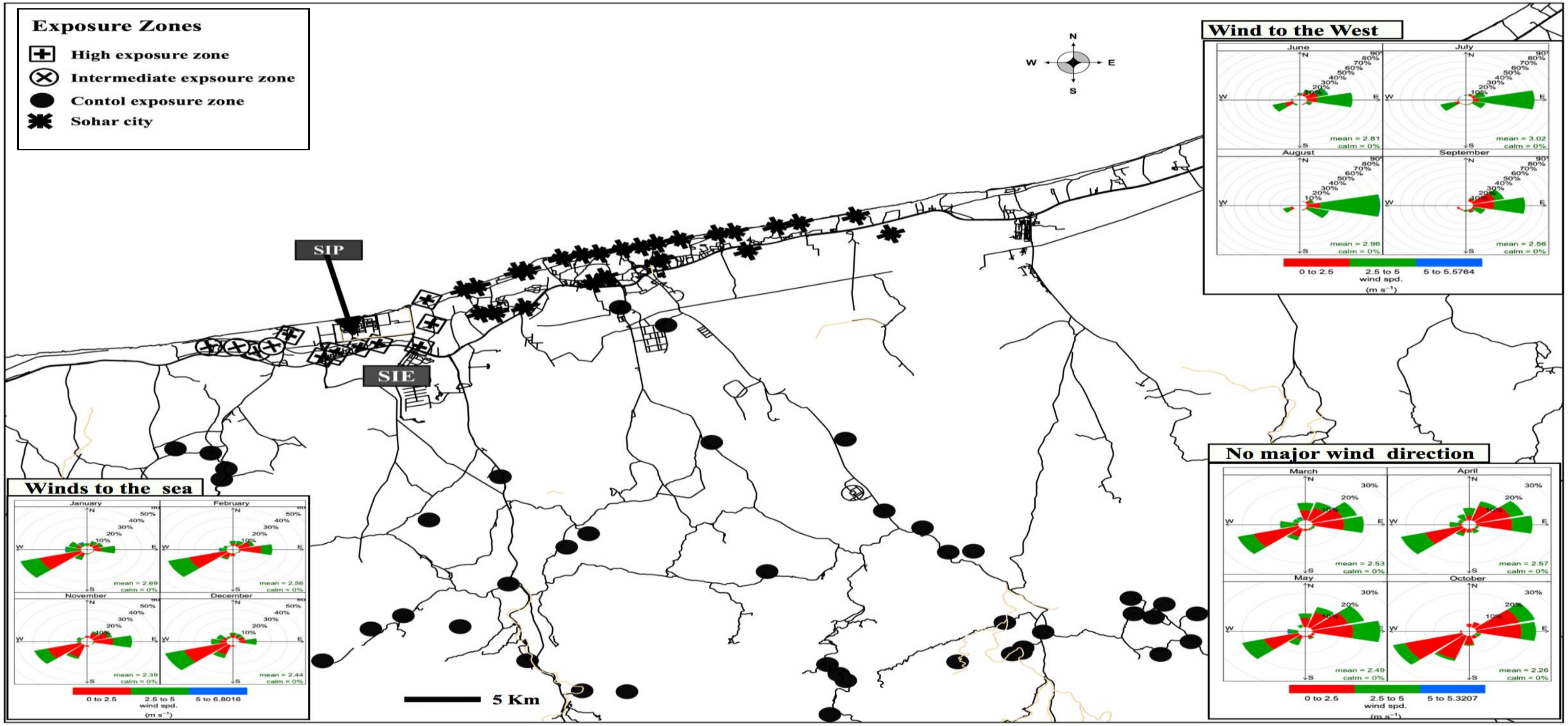
Exposure Zones
High exposure zone
Intermediate expsoure zone
Contol exposure zone
Sohar city
SIP
SIE
5 Km
N
W
E
S
Wind to the West
June
July
August
September
0 to 2.5
2.5 to 5
wind spd.
5 to 5.5764
Winds to the sea
January
February
November
December
0 to 2.5
2.5 to 5
5 to 6.8016
No major wind direction
March
April
May
October
0 to 2.5
2.5 to 5
5 to 5.3207

Figure II.3-5: Exposure classification of the study area*. * The prevailing wind direction is illustrated by wind roses with the corresponding direction. The approximate location of the villages is illustrated. SIP: Sohar Industrial port; SIE: Sohar Industrial Estate. Villages are only located north to SIE.

Validation of study exposure assessment approach

Wind roses

A homogenous pollutant spread is not a typical scenario, as was assumed in the proximity exposure method. Pollutant dispersion is affected by metrological parameters such as wind speed and direction, along with the terrain factors (Briggs 2003). To ensure the validity of the proximity exposure definitions, monthly wind roses for the study period were constructed using wind speed and direction, obtained from the Omani Department of Meteorology. The data were arranged daily from January 1^{st}, 2006 to December 31^{st}, 2010. Wind roses were done using the package *'openair'* of R software, **(Figure II.3 6).**

The prevailing winds pointed to the west during summer and September, suggesting that the pollutants could be carried farther inland. However, wind roses pointed towards the coast in winter and November and had no major direction in the remaining months. This indicated that during summer and September, the high and intermediate exposure zones could likely reveal similar pollutant patterns, **(Figure II.3 5).**

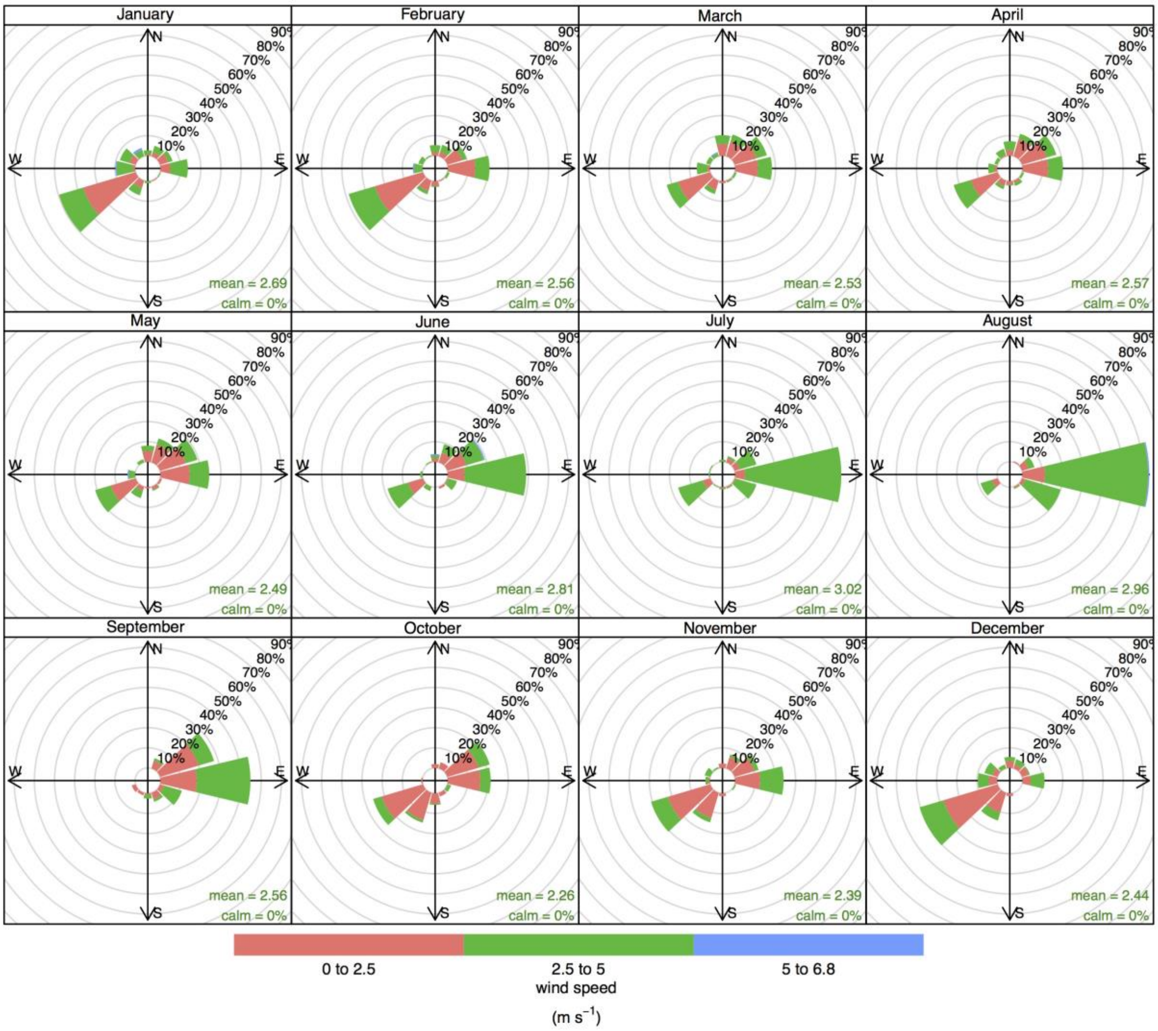

Figure II.3-6: Monthly wind roses plot in the area for the period from January 1st, 2006 to December 31st, 2010.

Dispersion model

To verify and define the extent of the exposure zones, the dispersion of pollutants was predicted using SO_2. SO_2 was specifically chosen because of the availability of its emission data from the oil refinery for a very limited period, 15 days. Prediction of SO_2 dispersion in the area was done through the California Puff model (CALPUFF), a complex non-steady state dispersion model adopted and used by the United State's Environmental Protection Agency (U.S. Environmental Protection Agency 2012).

To run CALPUFF, two main sets of data were needed: the emission data and metrological data, also called California Meteorological Model (CALMET) data.

The emission data for the oil refinery, including stack parameters such as number of stacks, location, height and diameter, emission rate, emission temperature and velocity, were obtained from AbdulWahab *et al.* (Abdul-Wahab et al. 2011). The CALMET data were produced using the High-resolution Metrologic Mesoscale Model (MM5) and terrain data (Scire & Zhong-Xiang 2012). MM5 data for the same year of the emission data were asked for, from and including January 3rd, 2008 to December 30th, 2008.

CALPUFF modelling output was programmed to produce a discrete output. In this output type, the model produces a daily SO_2 concentration for user-defined virtual points around the dispersion source, which is the oil refinery in this study. Three points were chosen on the map representing the centre of each exposure zone. The results of the modelled SO_2 concentration throughout the year were extracted and graphed for each month (**Figure II.3 7**). The predicted SO_2 concentration showed a relative two to four times change for distances from 5 to 10 km. These findings also supported the proximity exposure classification used in this analysis.

The CALPUFF model has been used frequently in epidemiological studies to evaluate the effects of industries on health (Levy et al. 2002). In Oman, AbdulWahab *et al.* evaluated the performance of CALPUFF and compared it with a local monitor observation of SO_2 for 15 days (Abdul-Wahab et al. 2011). They found considerable agreements between the observed and the expected data by CALPUFF. The modelling results were almost similar to those produced by AbdulWahab *et al.,* particularly in terms of the direction of the spread.

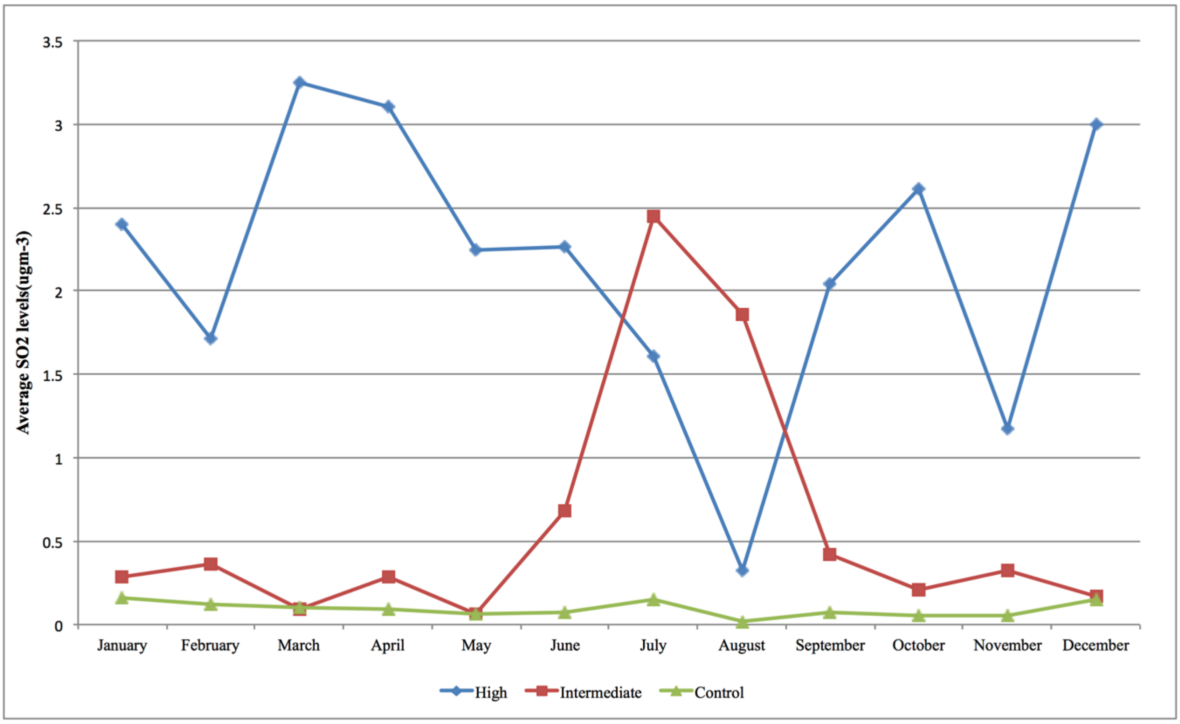

Figure II.3-7: Monthly CALPUFF estimated levels of SO_2 in each exposure zone.

II.4.Analysis

a. Data cleaning in preparation for the model

All data cleaning and statistical modelling was done using Excel and R software version 3.1.2. Modelling of the data was carried out using the *GAM* function of packages (mgcv and MASS) (RCore 2012).

Health data cleaning

Health data cleaning involved the removal of the missing data and the reformatting of some data to be used in the analysis. For example, to create the age variable of the patient, the date of the visit was subtracted from the patient's date of birth. In the data set, different villages' names were entered with different spellings during their translation from Arabic to English by the registering administration staff of the clinics. Using the *gsub* function in R software, this issue was resolved by transferring the various villages' spelling names into a unified name from the census 2010 data. Moreover, villages registered in the system as 'unspecified', or those which were not from Sohar or Liwa provinces, were omitted. In addition, some of the small villages, which were registered in the health data, were not found in the census data. These were merged with the nearest village that was found in the census data. This combination with the nearby village should not affect the results of the study as we are measuring the health effects in villages in relation to the villages' distance from the oil refinery.

The *ICD-10* classification was cleaned to include the selected studied diseases and reorganised into dummy variables for easier disease selection in the dataset. Each daily episode of the disease was assigned as a 'new' or 'follow up' event according to the event definition described in the methodology.

Villages' location, determined in the methodology, from the oil refinery was added to the dataset. Then, the described exposure classification zones were constructed according to the village's distance from the refinery and coded as a factor in the dataset.

Population data cleaning

Population data were cleaned for the names of the villages to be similar to the health data villages' names. In addition, the age groups in the data were aggregated according to the study's age group classification. The logarithm of the age-gender specific villages/exposure zone population was calculated to be used as an offset variable in the model.

Indices of SES were available for all the villages in the study. The percentages of the population with 'no education', 'high education' and 'employment' in each village was used to determine SES. The 'high education' percentage was defined as the proportion of individuals in each village that had received a bachelor degree and above. For children, SES was determined as the percentages of the total adult population with 'no education', 'high education' and 'employment', which is a representative of the parent's education and employments. Two levels of SES were then defined by stratifying the 'no education', 'high education' and 'employment' proportion distributions across all villages into two equal strata: ≤, and >50%.

Smoking prevalence data cleaning

Age and gender specific smoking prevalence data were derived from a study done by Al Riyami *et al.* (Riyami & Afifi 2004) and the Global Youth Tobacco Survey (GYTS-Oman) (El-aziz et al. 2007). The results of these studies are summarised in **Table II.4 1**.

Table II.4-1: Smoking prevalence in the different gender and age groups in Oman(Riyami & Afifi 2004).

Age groups (years)	Prevalence in males (%)	Prevalence in Females (%)*
20-29	11.5	0.1
30-39	17.5	0.6
40-49	18.7	0.9
50-59	14.6	0.7
60-64	7.4	2.2
≥ 65	7.9	0.8

*The smoking prevalence in females is very low compared to the males.

Meteorological data cleaning

The daily temperature and wind data were provided by the Omani Department of Meteorology for the entire study period. Wind data included wind prevailing direction and speed, whereas the temperature data included the minimum, maximum, and mean temperature reading of a meteorological station located in Sohar city. These data were obtainable for the period of January 1st, 2006, to December 31st, 2010.

Compiling the main dataset

The main dataset for the model was then compiled using the previously listed datasets: the health data, geographical location data, population data, age and gender specific smoking prevalence data and meteorological data. Therefore, the main dataset was constructed to contain the daily data of the patient's visit, his/her disease in the form of an *ICD-10 code*, his/her age, his/her gender, his/her village, latitude and longitude of the village, his/her exposure zone, logarithm of age-gender specific zone population, different SES strata of the village, and age-gender specific smoking prevalence. In addition, the dataset contains the month, year, season, mean temperature, wind speed and wind direction.

b. Data analysis

For a convenient analysis, two main age groups were created: children (<20 years old) and adult (≥20 years old). Subsequently, each major age group was further classified into smaller age classifications: The children's age groups (≤ 1 year, >1 to ≤ 14 and >14 to <20) and the adult age groups (≥20-49, ≥50 years).

Descriptive analysis

Total at-risk-population for each exposure zone was calculated. In addition, total visits for each studied disease in each exposure zone were computed. These were classified according to age and gender groups in each exposure zone. SES data were summed and presented with the mean and standard deviation for each exposure zone.

Modelling of the data

As this study's data comprised of time based counts, it was analysed using time series analysis. Time series analysis is superior in this case because it accounts for time variations of the time based counts, such as weather, seasonal variations, and long-term time trends. These can be enhanced further by the use of non-parametric time smoothing functions, such as the '*s*' function in the generalised additive model (GAM). In addition, time series can easily accommodate monthly collected data giving rise to greater power for the analysis (Brunekreef & Holgate 2002).

Model selection

Because the data are count data, a generalised linear model (GLM) with Poisson distribution was first selected. As the daily counts in this study contain zeros, and as the Poisson distribution cannot accept zero counts, monthly visits were used in the models. In addition, when using Poisson distribution, the data show overdispersion. This means that the variance is larger than the mean, when calculated using the following formula given by (Zuur 2009):

$$Dispersion\ parameter = (residual\ deviance)/(n - p)$$

Where *n* is the sample size and *p* is the number of explanatory variables. The dispersion parameter should be around one in a Poisson distributed GLM (Zuur 2009). In this data, the dispersion parameter was 273.1. This favoured the use of a negative binomial (NB) distribution to deal with this overdispersion (Zuur 2009). The resulted dispersion parameter of the NB GLM was 3.3.

Another diagnostic method is the influence graph. This was done by the function *Rcmdr* in R software. It suggested better model fit if using NB distribution compared to Poisson distribution. This is explained more in **Figure II.4 1** (Fox 1991)

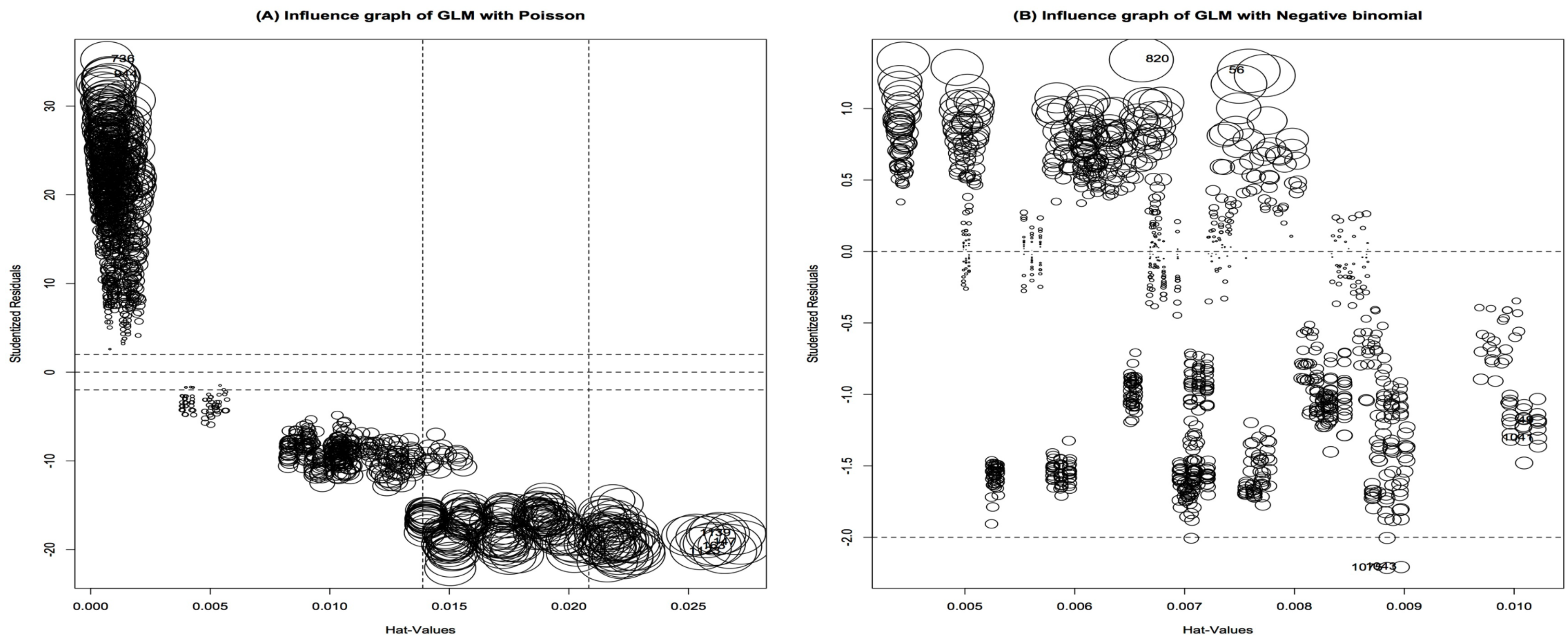
(A) Influence graph of GLM with Poisson
Studentized Residuals
Hat-Values
0.000 0.005 0.010 0.015 0.020 0.025
-20 -10 0 10 20 30
736
(B) Influence graph of GLM with Negative binomial
Studentized Residuals
Hat-Values
0.005 0.006 0.007 0.008 0.009 0.010
-2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0
820
56

Figure II.4-1: Comparison between the influence plots of GLM with (A) Poisson distribution and (B) NB distribution. The Hat-Values indicates the leverage of the data. The circles should ideally be located between 2h and 3h for a better model fit (the vertical dotted line in plot (A)). The studentised residuals represent the outlyingness of the data. For a better model fit, the circles should be located between the areas of 2, -2 in the graph (the dotted horizontal line). Clearly in graph (A), the hat-value and the studentised residuals were exceeded which was less exceeded in graph (B) indicating a better fit for NB GLM.

In addition, Akaike information criterion (AIC) was also used to monitor the goodness-of-fit for model selection. Different models with different families of distribution and variables were tested. However, the decreasing AIC numbers suggested the use of a NB GAM with a penalised smoothing parameter, (see **Table II.4 2).** The smoothing parameter was used to capture the short and long-term trends in the monthly counts of the studied diseases. The background time trend that was accounted for in the model is plotted in **Figure II.4 2**.

Table II.4-2: Comparing the AIC[1] of different models with different distribution and variables, in modelling ARD in adult's age group.

Model	Family of Distribution	Variables	AIC
GLM[2]	Poisson	• Exposure zone • ns[3] (month) • Smoking prevalence	317386
GLM	Negative Binomial	• Exposure zone • ns (month) • Smoking prevalence	14029
GAM[4]	Negative Binomial	• Exposure zone • s[5] (month) • Smoking prevalence	3773
GAM	Negative Binomial	• Exposure zone • s (month) • Smoking prevalence • Autocorrelation structure	3772

[1] Akaike Information Criterion
[2]Generalised linear model.
[3]Natural cubic spline from the library (*splines*) in R.
[4] Generalised additive model.
[5] Penalised spline from the library (*mgcv*) in R.

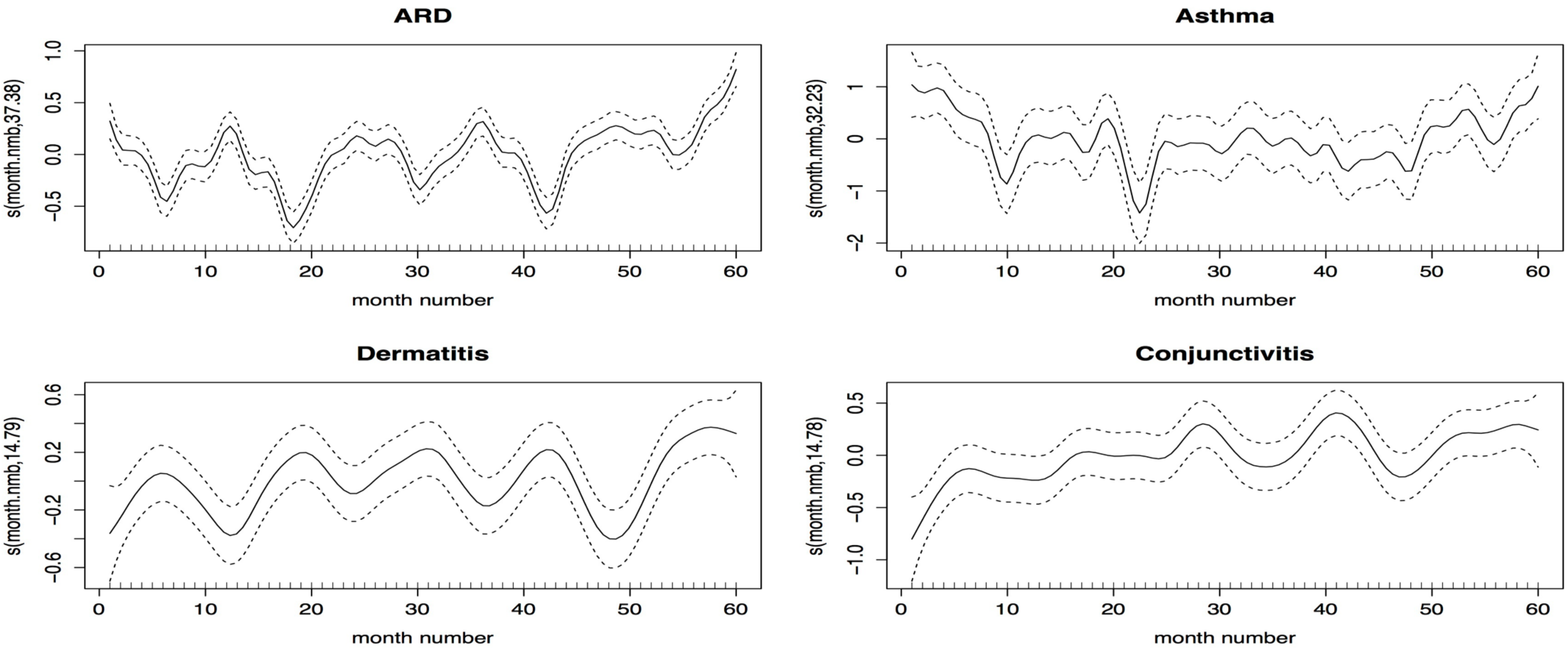

Figure II.4-2: The background time trend that was controlled for in the model by the smoothing function of the GAM model. The dotted line represents the 95% CI of the trend.

Positive autocorrelation (AC) was detected in the data using the *acf* (autocorrelation factor) function in R software and was controlled by an AC structure of order 1 (corAR1) (Zuur 2009). **Figure II.4 3** shows the AC for ARD, as an example, before and after the application of AC structure. This figure shows that after the application of AC structure (corAR1) in the model, the vertical lines (representing AC factor) do not cross the horizontal dotted lines (representing 95% CI). This indicates the control of residual AC in the data using the AC structure.

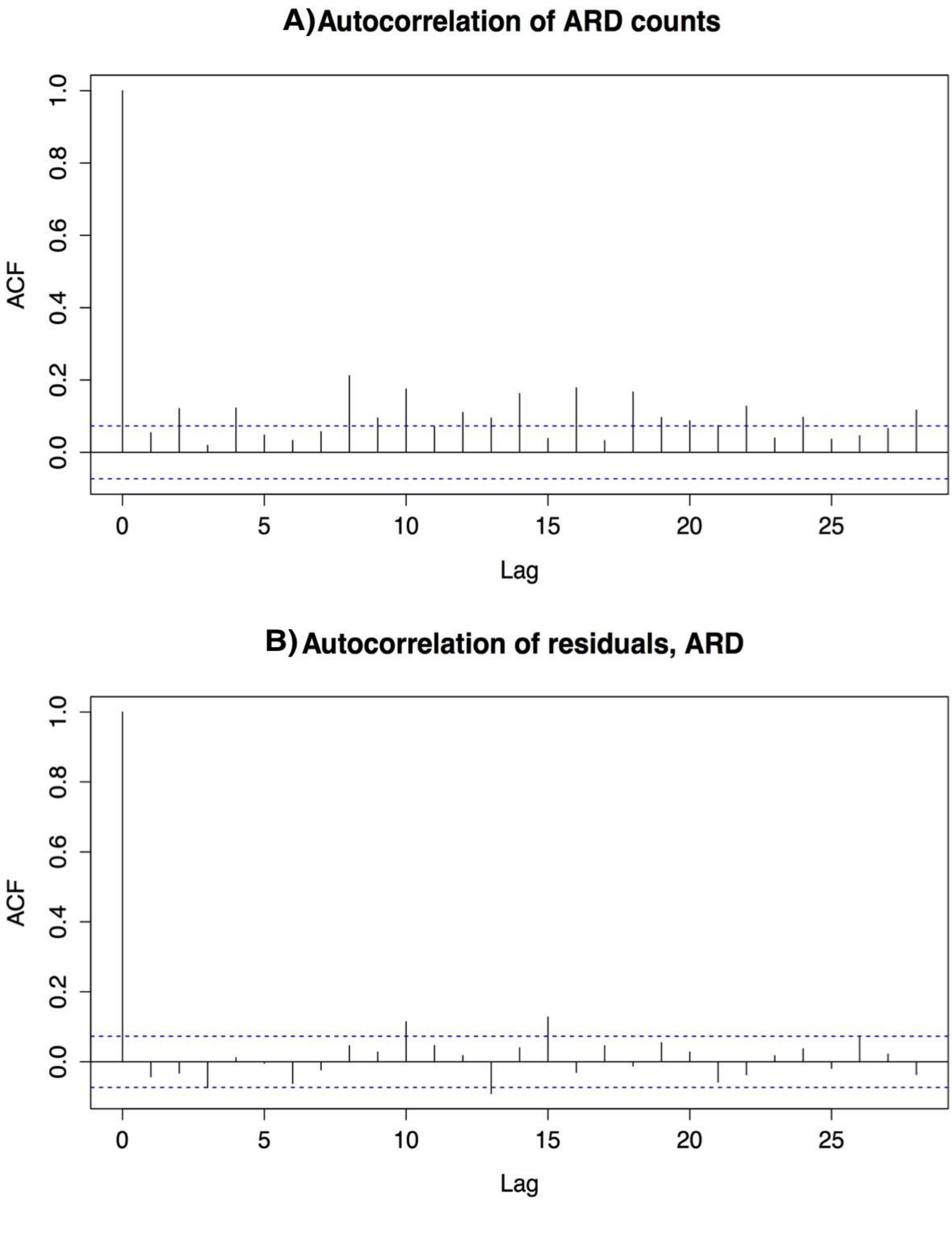

Figure II.4-3: Plot of the AC factor in the model residuals for ARD, before (A) and after (B) applying an autocorrelation structure.

Confounders and effect modifiers of the study

In epidemiology, a variable is said to be a confounder if it is a risk factor for both the outcome and the exposure but is not known to be affected by either of them. That is, it should not be in the causal pathway of the exposure to cause the outcome (Delgado-Rodríguez & Llorca 2004). On the other hand, effect modification in the data is performed to test how the effect of the exposure is different across different classification of the data, such as, age, gender and SES. If the effects are different across strata, they are called 'modified' or 'heterogeneous' in each group. Otherwise, if the effects are similar across strata, they are called 'uniform' or 'homogenous' (Rothman et al. 2008).

Smoking was not equally distributed in the study population. Latest statistics show that the average smoking prevalence amongst males is 13%, while it was only 0.8% amongst the females (Riyami & Afifi 2004; El-aziz et al. 2007), (**Table II.4 1**). Because of the large difference in smoking prevalence between gender groups in this study population, smoking was controlled for in the analyses. Other potential confounders including daily temperature, season, and individual year, were statistically tested and found not to change the exposure-response estimate by more than 10%, thus were not considered further. The use of time smoothing function in the model potentially controlled for other time-varying confounders.

Effect modification assessment by gender and age was done in the two major categories: children (further classified into: ≤ 1 year, >1 to ≤ 14 and >14 to <20) and the adults (further divided into: ≥20-49, ≥50 years). SES was not considered as a confounder in this study, because no differences in the distribution of the SES indices across the exposure zones were found. Therefore, SES was only tested as an effect modifier across the two SES strata, ≤, and >50%.

Model presentation

The NB model equation estimating the monthly RR in the different zones was expressed as follows:

In the children's age group:

$$(Monthly\ events)_i \sim NB\ (\mu_i, k)$$

$$E\ ((Monthly\ events)_i) = \mu_i$$

$$Log\ (\mu_i) = \beta_0 + \beta_1(exposure) + s\ (TimeM) + corAR1 + e$$

In the adult age group:

$$(Monthly\ events)_i \sim NB\ (\mu_i, k)$$

$$E\ ((Monthly\ events)_i) = \mu_i$$

$$Log\ (\mu_i) = \beta_0 + \beta_1(exposure) + s\ (TimeM) + \beta_2(smoking\ prevalence) + corAR1 + e$$

Where NB is negative binomial distribution, β_0 is the model intercept, βn is the model coefficient for the corresponding variable, *k* is the dispersion parameter, *s* is the penalised smoothing spline function for the monthly time trend (*TimeM*), *corAR1* is the autocorrelation structure and *e* is the error term.

RR for the different exposure zones was calculated as [$\exp^{(\beta 1)}$] and the 95% confidence interval (CI) levels were calculated using the formula: $\exp^{(\beta 1 \pm 1.96\ X\ SE)}$

Modelling of the combined exposure zone

Because of the similarity in the exposure-effect trends between the high and intermediate exposure zones, also supported by patterns of potential pollutant dispersion observed using wind roses and dispersion model, modelling was performed combining the two zones into one zone of ≤ 10 km distance from the oil refinery. This combination will also increase the power of the study.

c. Sensitivity analysis

To further explore the relationship between exposure and the studied diseases, monthly follow-up frequencies for ARD and asthma were also modelled, using the same model structure, and stratified according to age and gender groups.

Additional analysis of the monthly follow-up frequency for MS and GID, diseases that are not presumed to be affected by air pollution, was performed. Monthly follow-up visits of MS and GID were modelled using the same model structure as for other disease definitions, but with the total exposure zone population as an offset due to lack of age and gender-specific information for these groups.

d. Sohar city

Initially, analysis of the exposure zones was performed including Sohar city. However, Sohar city showed a smaller number of monthly counts of the studied diseases when compared with the remaining exposure zones. This was also evident in the protective effects found in Sohar city models when compared to the combined zone, (appendix 2: **Table 0 1** and **Table 0 2**). The latest statistics from MoH revealed that out of the fifty-one private health clinics found in the studied area; 48 (94%) of these clinics are located in Sohar city, including 20 medium size health complexes and two private hospitals (MoH 2012). In contrast, the three remaining private clinics, which were located on other zones, comprised of only one medium sized and two small private clinics. Hence, to ensure minimal contribution of selection bias, Sohar city was excluded from the analysis**. Table II.4 3** illustrates the number and type of private clinics in Sohar and the other exposure zones.

Table II.4-3: Private clinics that opened before 2011 in Sohar and the remaining exposure zones (MoH 2012).

Type of clinic	Sohar city	Remaining exposure zones
Small clinics	24	2
Medium clinic	20	1
Private hospital	2	0
Paediatrician	2	0
Optician	9	1
Dentist	20	1
Ayurveda clinic	2	0

II.5.Results

The results of the study will be presented in two sections: the results in the children's population (<20 years old) and the results in the adult population (≤20 years old). For both major age classifications, the results will be presented descriptively and analytically.

a. Results in the children age group (<20 years old)

Descriptive statistics

The total number of visits for the selected diseases was 197,263. The total population-at-risk of the 2010 census was 25,215 (**Table II.5 1**). A greater proportion of males in the studied population-at-risk, especially in the ages >1 to <20 years is noted. This difference was more pronounced in the high exposure group. Moreover, the difference between gender groups was also noted in the monthly visit counts of the all studied diseases. Additionally, **Table II.5 1** shows the small number of asthma cases, especially in the infant's age group.

Figure II.5 1 shows the monthly counts of the studied diseases. There is an evident seasonal variability in the monthly event counts for conjunctivitis, in winter and spring, and dermatitis, in spring. However, no obvious seasonal trends were found in ARD and asthma counts as most respiratory infections in children are caused by different virus strains with varying seasonality and susceptible age groups giving rise to the multiple peaks throughout the year (Gorjipour et al. 2012).

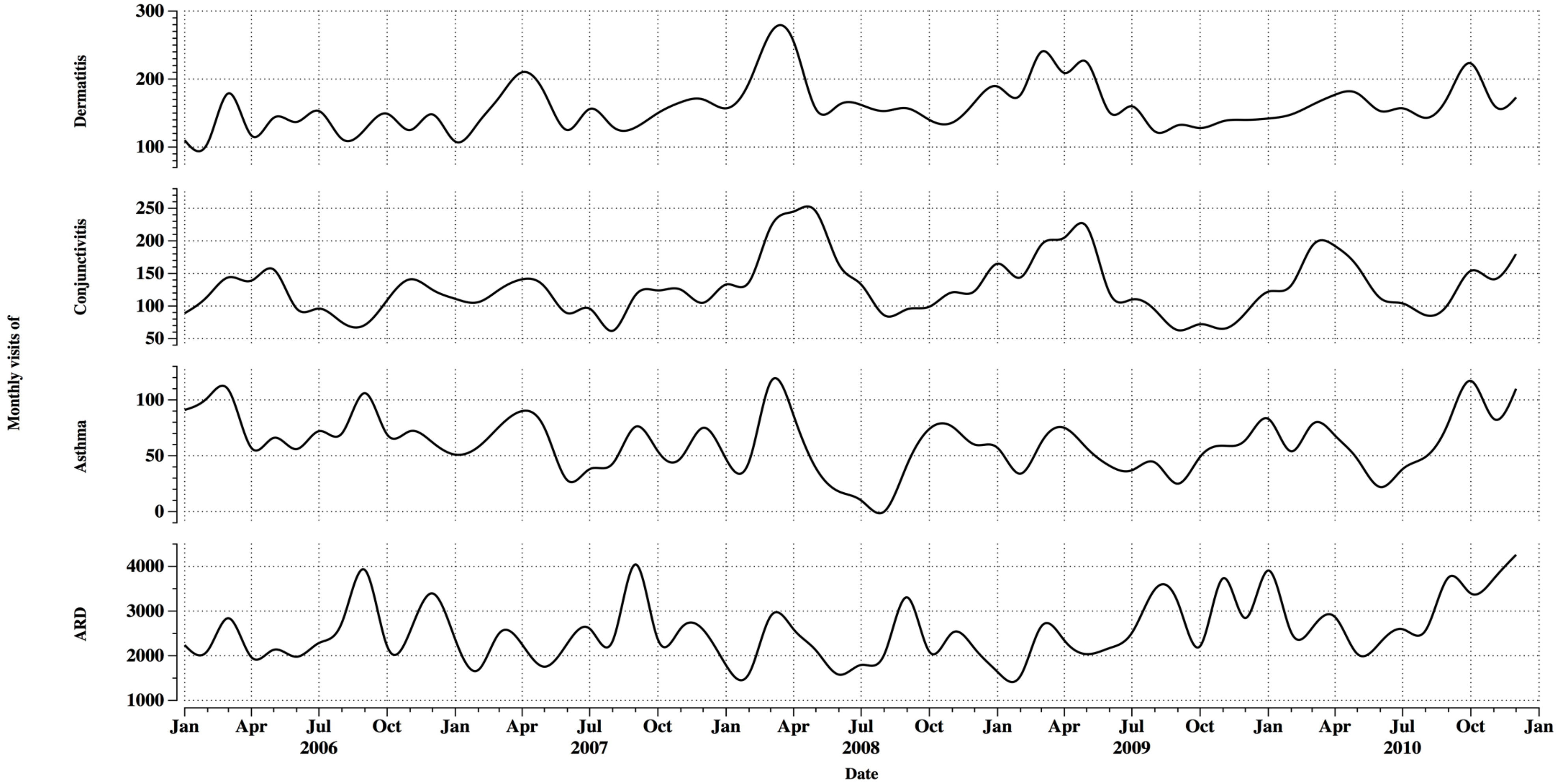

Figure II.5-1: Monthly event counts of acute respiratory diseases, asthma, conjunctivitis and dermatitis*. *The monthly events were summed for all zones and plotted against the date, age < 20 years.

Table II.5-1: Characteristics of the studied population including the total population in the zones, total number of monthly events classified by age group and gender, age < 20 years. Socio-economic indicators are also listed.

Study population	Age Category	Gender	Exposure zone		
			High	Intermediate	Control
Total population-at-risk (%)[1]	≤1 year	F	1267 (13.6)	1366 (16.4)	1307 (17.2)
		M	1293 (13.9)	1421 (17.1)	1334 (17.5)
	>1 - ≤14 years	F	1769 (19.0)	1873 (22.5)	1690 (22.2)
		M	2699 (29.0)	2173 (26.1)	1944 (25.6)
	>14 - <20 years	F	592 (6.4)	565 (6.8)	482 (6.3)
		M	1683 (18.1)	912 (11.0)	845 (11.1)
Socio-economic indicators[2]	Mean ‘no education’% (SD)		67.8 (19.2)	49.9 (6.1)	53.4 (17)
	Mean ‘high education’%[3](SD)		3.4 (2.4)	4.5 (1.3)	1.9 (2.4)
	Mean ‘employment’% (SD)		83.4 (9.4)	73.7 (3.5)	71.9 (11.7)
ARD[4] monthly visits (%)[5]	≤1 year	F	6438 (8.1)	5988 (8.1)	1929 (8.5)
		M	8949 (11.2)	8837 (12.0)	2562 (11.3)
	>1 - ≤14 years	F	24255 (30.4)	21982 (29.8)	7048 (31.1)
		M	31336 (39.3)	28556 (38.8)	8968 (39.6)
	>14 - <20 years	F	3476 (4.4)	3247 (4.4)	820 (3.6)
		M	5233 (6.6)	5080 (6.9)	1308 (5.8)
Asthma monthly visits (%)	≤1 year	F	25 (1.4)	17 (1.1)	7 (1.8)
		M	42 (2.4)	50 (3.3)	13 (3.2)
	>1 - ≤14 years	F	566 (32.3)	463 (30.1)	114 (28.4)
		M	937 (53.5)	779 (50.7)	209 (52.1)
	>14 - <20 years	F	68 (3.9)	83 (5.4)	33 (8.2)

Study population	Age Category	Gender	Exposure zone		
			High	Intermediate	Control
		M	115 (6.6)	144 (9.4)	25 (6.2)
Conjunctivitis monthly visits (%)	≤1 year	F	396 (11.2)	287 (8.9)	100 (10.4)
		M	492 (13.9)	463 (14.4)	156 (16.2)
	>1 - ≤14 years	F	853 (24.1)	742 (23.1)	239 (24.8)
		M	1225 (34.7)	1111 (34.6)	346 (35.9)
	>14 - <20 years	F	224 (6.3)	229 (7.1)	41 (4.3)
		M	345 (9.8)	382 (11.9)	81 (8.4)
Dermatitis monthly visits (%)	≤1 year	F	559 (11.4)	354 (9.9)	156 (11.4)
		M	727 (14.9)	587 (16.3)	256 (18.7)
	>1 - ≤14 years	F	1359 (27.8)	927 (25.8)	360 (26.3)
		M	1681 (34.4)	1265 (35.2)	430 (31.4)
	>14 - <20 years	F	235 (4.8)	164 (4.6)	68 (5.0)
		M	326 (6.7)	296 (8.2)	99 (7.2)

[1]Percentage to the total counts in the exposure zone. [2]Showing the mean percentage of the villages of each zone with the standard deviation. [3]High education: individuals with bachelor degree and above. [4]Acute respiratory diseases; The total number of villages in the study is 59; 8 are located in the high exposure zone; 4 are located in the intermediate; the remaining 47 smaller villages are located in the control zone. [5] Percentage to the total counts in the zone.

Results of Models

Results of the analysis of the selected disease incidence for the three exposure zones are presented in **Table II.5 2**. It shows strong evidence that high and intermediate exposure zones had greater effects in all diseases compared to the control exposure zone. The overall similarity in the trends between the two exposure zones suggested the feasibility of combining them into one zone of ≤10 km radius from the refinery.

Table II.5-2: Multivariable Analysis[1] of acute respiratory diseases, asthma, conjunctivitis and dermatitis incidence[2] in association with high and intermediate exposure zones.

Diseases	High RR (95% CI)	Intermediate RR (95% CI)
ARD	2.6 (2.3-2.8)	2.3 (2.1-2.6)
Asthma	3.6 (3.0-4.4)	3.7 (3.1-4.5)
Conjunctivitis	3.1 (2.8-3.4)	3.2 (2.9-3.5)
Dermatitis	3.0 (2.7-3.3)	2.5 (2.3-2.7)

[1] Adjusted for time trend.
[2] Age and gender standardised according to census population figures for 2010.
RR risk ratio; CI confidence interval; ARD acute respiratory diseases.

Table II.5 3 shows the results of the analysis combining the high and intermediate zones stratified by age category and gender. Positive associations for all studied diseases in the combined exposure zones compared to the control exposure zone were evidenced. Results also suggest that the exposure did not affect males and females differently. Similarly, no differences between the age groups were found in ARD, conjunctivitis and dermatitis. The age classification in asthma, however, suggested that children >1 to ≤14 years, had greater effects than young adults >14 to <20 years.

Table II.5-3: Multivariable Analysis[1] of acute respiratory diseases, asthma, conjunctivitis and dermatitis incidence[2] in association with combined exposure zone.

Exposure groups	Combined[3] RR (95% CI)
ARD	
Overall	2.5 (2.3-2.7)
Males	2.3 (2.1-2.7)
Females	2.6 (2.3-2.9)
≤1 year	2.6 (2.4-2.9)
>1 - ≤14 years	2.4 (2.2-2.6)
>14 - <20 years	2.6 (2.3-3.1)
Asthma	
Overall	3.7 (3.1-4.5)
Males	3.6 (2.8-4.7)
Females	3.8 (2.9-5.1)
≤1 year	3.6 (2.2-6.1)
>1 - ≤14 years	4.6 (3.8-5.7)
>14 - <20 years	2.6 (1.9-3.5)
Conjunctivitis	
Overall	3.1 (2.9-3.5)
Males	2.9 (2.5-3.3)
Females	3.5 (3.1-4.1)
≤1 year	3.3 (2.8-3.8)
>1 - ≤14 years	3.0 (2.7-3.4)
>14 - <20 years	3.8 (3.0-4.8)
Dermatitis	
Overall	2.7 (2.5-3.0)
Males	2.6 (2.3-3.0)
Females	2.9 (2.6-3.3)
≤1 year	2.8 (2.5-3.3)
>1 - ≤14 years	3.0 (2.7-3.3)
>14 - <20 years	2.5 (2.0-3.1)

[1] Adjusted for time trend.
[2] Age and gender standardised according to census population figures for 2010.
[3]Including high and intermediate zones, control zone as reference.
RR risk ratio; CI confidence interval; ARD acute respiratory diseases.

Moreover, results indicated increased follow-up frequencies in the combined exposure zones compared to the control exposure zone for ARD and asthma, (**Table II.5 4**).

Table II.5-4: Multivariable Analysis[1] of acute respiratory diseases and asthma follow-ups[2] in association with combined exposure zone. Results are also stratified by age category and gender[3].

Exposure groups	Combined[4] RR (95% CI)
ARD Follow-ups	
Overall	2.5 (2.8-2.7)
Females	2.5 (2.2-2.9)
Males	2.4 (2.1-2.8)
≤1 year	2.9 (2.6-3.2)
>1 - ≤14 years	2.4 (2.2-2.7)
>14 - <20 years	2.5 (2.1-2.8)
Asthma Follow-ups	
Overall	3.2 (2.5-4.0)
Females	3.2 (2.3-4.4)
Males	3.1 (2.3-4.2)
≤1 year	4.4 (1.9-10.1)
>1 - ≤14 years	3.5 (2.8-4.4)
>14 - <20 years	2.5 (1.6-3.9)

[1] Adjusted for time trend.
[2] Follow-ups were defined as any repeated patients' visits within one month of the previous visit.
[3] Age and gender standardised according to census population figures for 2010.
[4] Including high and intermediate zones, control zone as reference.
RR risk ratio; CI confidence interval; ARD acute respiratory diseases.

The models could not capture any differences between SES strata, (**Table II.5 5**).

Table II.5-5: Multivariable Analysis[1] of acute respiratory diseases[2] in association with combined exposure zone. Classification by two SES parameters.

SES classification	RR[3] (95% CI)
≤50% ‘no education’ strata	2.3 (2.1-2.6)
>50% ‘no education’ strata	2.7 (2.4-3.0)
≤50% ‘high education’ strata[4]	2.6 (2.4-2.9)
>50% ‘high education’ strata	2.3 (2.1-2.5)
≤50% ‘employment’ strata	2.6 (2.4-2.8)
>50% ‘employment’ strata	2.3 (2.1-2.5)

[1] Adjusted for time trend.
[2] Age and gender standardised according to census population figures for 2010.
[3]Risk ratio of combined zones in reference to control zone.
[4] Stratified using the percentage of people in the village that have bachelor degree or higher
SIE: socio-economic indices; RR risk ratio; CI confidence interval.

b. Results in the adult age group (≥20 years old)

Descriptive statistics

Results of the analysis of ARD, asthma, conjunctivitis and dermatitis

During the study period, the total number of visits for the selected diseases was 74,047. The total population-at-risk was 27,688 (**Table II.5 6**). This table also shows the greater number of males compared to females in the total population-at-risk in the age group ≥20-49 years. This is more evident in the high exposure zone. However, for each exposure zone, the proportion of the event counts for males and females were comparable. A noticeable small percentage of event counts occurred in the ≥50-year-old group in all exposure zones, except for asthma.

Figure II.5 2 shows the monthly event counts of ARD, asthma, conjunctivitis, and dermatitis with clear seasonal variability. For ARD, more monthly event counts were noted in autumn and winter, whereas for dermatitis and conjunctivitis these events were higher in spring and summer **(Table II.5 6).**

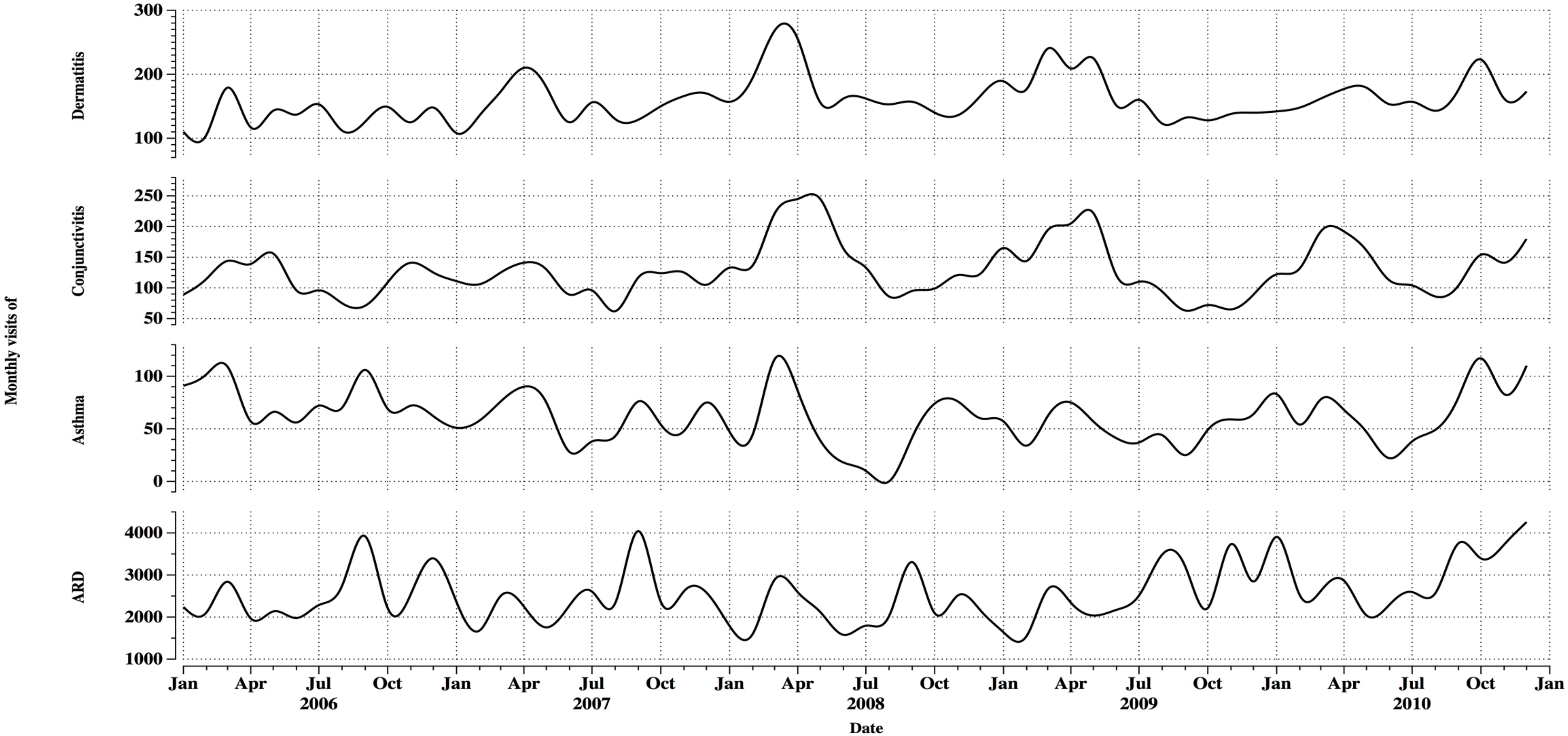

Figure II.5-2: Monthly event counts of acute respiratory diseases, asthma, conjunctivitis and dermatitis, age ≥ 20 years*. *Monthly events for each selected cause were summed for all exposure zones and plotted against the date of visit.

Table II.5-6: Descriptive characteristics of the studied population including the total population-at-risk in the exposure zones and total number of monthly events, classified by age group and gender, age ≥ 20 years.

Study population	Age Category	Gender	Exposure Zone		
			High	Intermediate	Control
Total population at risk (%)[a]	≥20-49 years	F	3239 (26.7)	3159 (35.2)	2076 (31.5)
		M	7607 (62.7)	4498 (50.2)	3233 (49.0)
	≥50 years	F	576 (4.7)	598 (6.7)	616 (9.3)
		M	705 (5.8)	712 (7.9)	669 (10.1)
Socio-economic indicators[b]	Mean ‘no education’% (SD)		67.8 (19.2)	49.9 (6.1)	53.4 (17)
	Mean ‘high education[c]’% (SD)		3.4 (2.4)	4.5 (1.3)	1.9 (2.4)
	Mean ‘employment’% (SD)		83.4 (9.4)	73.7 (3.5)	71.9 (11.7)
ARD[d] monthly visits (%)	≥20-49 years	F	11814 (42.9)	8892 (40.5)	3595 (39.3)
		M	9980 (36.3)	9116 (41.5)	3354 (36.7)
	≥50 years	F	2830 (10.3)	1802 (8.2)	1160 (12.7)
		M	2889 (10.5)	2146 (9.8)	1035 (11.3)
Conjunctivitis monthly visits (%)	≥20-49 years	F	869 (30.5)	840 (32.7)	275 (31.8)
		M	981 (34.5)	974 (37.9)	256 (29.6)
	≥50 years	F	415 (14.6)	314 (12.2)	155 (17.9)
		M	581 (20.4)	439 (17.1)	179 (20.7)
Dermatitis monthly visits (%)	≥20-49 years	F	1105 (39.0)	665 (31.0)	404 (41.5)
		M	963 (34.0)	965 (45.0)	260 (26.7)
	≥50 years	F	333 (11.8)	196 (9.1)	118 (12.1)
		M	433 (15.3)	320 (14.9)	191 (19.6)

Study population	Age Category	Gender	Exposure Zone		
			High	Intermediate	Control
Asthma monthly visits (%)	≥20-49 years	F	461 (33.9)	502 (35.2)	106 (25.4)
		M	246 (18.1)	271 (19.0)	122 (29.3)
	≥50 years	F	223 (16.4)	216 (15.1)	98 (23.5)
		M	430 (31.6)	437 (30.6)	91 (21.8)

[a] Percentage to the total counts in the exposure zone. [b] Showing the mean percentage of SES category for the villages of each exposure zone with the standard deviation. [c] High education: individuals with bachelor degree and above. [d] Acute respiratory Diseases. The total number of villages in the study is 59; 8 are located in the high exposure zone; 4 are located in the intermediate; the remaining 47 smaller villages are located in the control zone.

Descriptive analysis of the CVD and COPD

Table II.5 7 shows the descriptive analysis of the monthly counts for CVD and COPD. Due to the small number of visits for CVD and COPD, data were insufficient for the analysis. The low number of these diseases, which mostly affect the elderly age group, potentially reflects the fact that the Omani population is young, with only 4.3% of the population aged ≥60 years (NCSI 2013).

Table II.5-7: The number of monthly cases for CVD and COPD in the different exposure zones classified by age group and gender, age ≥ 20 years.

Classification	Age Category	Gender	Exposure Zone		
			High	Intermediate	Control
COPD[1]	≥20-49 years	F	7	3	4
		M	3	2	0
	≥50 years	F	21	22	1
		M	15	6	6
IHD[2]	≥20-49 years	F	11	9	20
		M	26	17	27
	≥50 years	F	13	8	10
		M	42	28	42
Stroke	≥20-49 years	F	15	10	16
		M	18	13	26
	≥50 years	F	5	3	5
		M	21	5	13

[1] Chronic Obstructive pulmonary diseases. [2] Ischemic Heart Disease.

Results of the models of ARD, asthma, conjunctivitis and dermatitis

In **Table II.5 8**, associations for all disease events and exposure definitions are presented. The results show greater effects in all diseases in the high and intermediate exposure zones compared to the control exposure zone. Similar to the children age group, the similarity in the trend suggested the feasibility of combining the two zones into one exposure zone of ≤10 km radius from the refinery.

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Table II.5-8: Multivariable Analysis[a] of acute respiratory diseases, asthma, conjunctivitis and dermatitis incidence[b] in association with high and intermediate exposure zones.

Studied disease	High Exposure Zone RR (95% CI)	Intermediate Exposure Zone RR (95% CI)
ARD	2.3 (2.1-2.5)	1.8 (1.7-2.0)
Asthma	3.5 (2.8-4.3)	3.8 (3.0-4.7)
Conjunctivitis	2.9 (2.5-3.4)	2.5 (2.2-2.9)
Dermatitis	2.3 (2.0-2.6)	1.8 (1.5-2.0)

[a] Adjusted for time trend and smoking prevalence.
[b] Age and gender standardised according to census population figures for 2010.
RR risk ratio; CI confidence interval; ARD acute respiratory diseases.

Table II.5 9 shows the RR in the combined exposure zone, overall and stratified by gender and age groups. Positive associations were found for all selected diseases in the combined exposure zone compared to the control exposure zone. Stratifying the data by age category showed greater effects in the ages ≥50 years in all diseases and exposure zones, compared to the ≥20-49 years age group. No differences in the effects by gender were found.

Table II.5-9: Multivariable Analysis[a] of acute respiratory diseases, asthma, conjunctivitis and dermatitis incidence[b] in association with combined exposure zone

Stratification	Combined[c] RR (95% CI)
ARD	
Overall	2.0 (1.9-2.2)
Males	1.9 (1.7-2.1)
Females	2.0 (1.8-2.2)
≥20-49 years	1.8 (1.6-1.9)
≥50 years	2.3 (2.1-2.5)
Asthma	
Overall	3.6 (3.0-4.4)
Males	2.5 (2.0-3.0)
Females	2.9 (2.3-3.5)
≥20-49 years	1.9 (1.6-2.4)
≥50 years	3.7 (3.0-4.6)
Conjunctivitis	
Overall	2.8 (2.5-3.2)
Males	2.5 (2.2-2.9)
Females	2.4 (2.1-2.7)
≥20-49 years	2.2 (2.0-2.5)
≥50 years	2.7 (2.3-3.2)
Dermatitis	
Overall	2.1 (1.8-2.4)
Males	2.1 (1.8-2.4)
Females	1.8 (1.6-2.1)
≥20-49 years	1.8 (1.6-2.0)
≥50 years	2.2 (1.9-2.6)

[a] Adjusted for time trend and smoking prevalence.
[b] Age and gender standardised according to census population figures for 2010.
[c] Including high and intermediate exposure zones, control exposure zone as reference.
RR risk ratio; CI confidence interval; ARD acute respiratory diseases.

Table II.5 10 shows the results of exposure-ARD visits associations by categories of SES indices. Greater effects were observed for villages with lower proportions of ‘high education’ and ‘employment’.

Table II.5-10: Multivariable Analysis[a] of acute respiratory disease[b] in association with combined exposure zone. Classification by three SES parameters, age ≥ 20 years.

SES classification	RR[c] (95% CI)
≤50 % ‘no education’ strata	1.9 (1.8-2.0)
>50% ‘no education’ strata	2.1 (2.0-2.3)
≤50 % ‘high education’ strata	2.2 (2.1-2.4)
>50% ‘high education’ strata	1.7 (1.6-1.8)
≤50 % ‘employment’ strata	2.3 (2.2-2.5)
>50% ‘employment’ strata	1.6 (1.5-1.7)

[a] Adjusted for time trend and smoking prevalence.
[b] Age and gender standardised according to census population figures for 2010.
[c] Risk ratio of combined exposure zones in reference to control exposure zone.
RR risk ratio; CI confidence interval.

Results of the analysis for monthly follow-ups for ARD, asthma, MS and GID are given in **Table II.5 11**. Excess risk was observed for follow-up frequencies in the combined exposure zones compared to the control exposure zone for ARD and asthma. No association between exposure and MS and GID follow-up counts was observed.

Table II.5-11: Multivariable Analysis[a] of acute respiratory diseases, asthma, MS and GID follow-up[b] frequencies[c] in association with combined exposure zone.

	Combined[d] RR (95% CI)
ARD	1.7 (1.5-2.0)
Asthma	2.2 (1.9-2.6)
MS	0.9 (0.9-1.0)
GID	0.9 (0.8-1.0)

[a] Adjusted for time trend and smoking prevalence.
[b] Follow-ups were defined as any patient’s visit to the doctor occurring within the defined period for the ‘new event’ definition.
[c] Crude exposure zone population was used as the model offset according to census population figures for 2010.
[d] Including high and intermediate exposure zones, control exposure zone as reference.
RR risk ratio; CI confidence interval; ARD acute respiratory diseases; MS All musculoskeletal diseases; GID Gastrointestinal diseases.

II.6.Discussion

This study was carried out to examine the acute health impacts on people living near a major industrial park in Oman. After adjusting for age, gender, time trend and smoking prevalence, findings suggested that living closer to the industrial park increased the risk of health care visits from acute respiratory tract diseases, asthma, conjunctivitis and dermatitis two- to threefold when compared to the control zone. The use of non-parametric time-series based models allowed for the adjustment of temporal changes such as seasonal, long, and short-term variations of events in the classified area.

In this study, no air quality data for the study area or any information on the actual emissions of the industries were found that would enable the construction of full dispersion models. This led us to use proximity to source a method to classify villages' exposure around SIZ. The proximity approach has been utilised frequently in many influential epidemiological and public health studies, particularly in the assessment of health effects around petrochemical industrial complexes (Yang et al. 2004; Bentov et al. 2006) and heavy metal smelters (Greaves et al. 1981; Johnson et al. 2003), (**Table II.3 7**). In addition, many governmental environmental protection bodies uses this method in their policies, for example, the US EPA (U.S. Environmental Protection Agency 2003) and the United Kingdom's Health and Safety Executive (Health and Safety Executives 2011). Because this method is easy, quick and economic, it is used frequently to assess health effects from industrial chemical spillages (Dayal et al. 1995) and environmental justice studies (Perlin et al. 1995).

In this study, three exposure zones were used to investigate the effects of the industrial park. However, the high and intermediate exposure zones were later combined to assess effect modification by other factors based on similarity of the RR also supported by pollutant spread suggested by wind roses and dispersion model. This combination of the two exposure zones ensured sufficient sample size to explore different categories of effect modification, such as gender, age and SES groups using data stratification. Nevertheless, the similarity of the RR between the high and intermediate zones also highlighted the absent dose-response relationship between exposure and disease. This might be partly explained by the heterogeneous pollutant spread in the areas which, in our study, were difficult to assess and which need better exposure measurements in the future. Another explanation of this lack of the dose-response relationship between the two exposure zones might be the unmeasured confounding effects of the SES and other cultural differences between the two exposure zones. However, we were not able to rule these other factors out as possible confounding to dose-response effects. Such differences are better conceptualised and studied by conducting more studies and researches in the area.

The combination of the two exposure zones into one zone of ≤10 km suggested the widespread health effects of the industrial park. This extent of health effects is possibly due to the unfavourable geography of the area, also noted in a recent meteorological study by Al-Khadouri et al. (Al-Khadouri et al. 2014). The authors showed that the air quality in SIZ is prone to stagnation and recirculation with no single episode of ventilation. These characteristics facilitate a stagnant pollutant mass in the area that was shown, by numerical simulation, to reach >10 km inland. In this study, exposure was classified as a 5 km incremental distance also supported by the use of two other approaches, wind roses and dispersion model. These distances have also been used in previous epidemiological and policy studies (Tanyanont & Vichit-Vadakan 2012; F. A. Wichmann et al. 2009).

a. Effects in children (<20 years old)

The results agree with the existing epidemiological evidence regarding the health effects on the respiratory tract system (Smargiassi et al. 2009; F. A. Wichmann et al. 2009), eyes (Yang et al. 1997) and skin (Papadimitriou et al. 2012) in children living near a petrochemical complex. Children living near these complexes had increased respiratory symptoms and twice more asthma exacerbation than those living away (Smargiassi et al. 2009; F. A. Wichmann et al. 2009). Yang et al. found that these children had 90 % more irritative symptoms of eyes and throat when living near petrochemical complexes (Yang et al. 1997). This is because petrochemical complexes inside SIZ are known to emit a number of environmental pollutants including SO_2, NO_x and VOC (Nielsen 2013). Such pollutants can cause skin and mucosal lining irritation, especially in the eyes and respiratory tract, and particularly in children (Patnaik 2007).

Epidemiological studies reveal that children living in the proximity of aluminum smelters are prone to impaired lung function (Ernst et al. 1986), possibly related to emitted aluminum compounds, SO_2 and fluoride compounds (Nielsen 2013). In addition, Lewin A at al. found 30 % more asthma hospitalisation in children living near aluminum smelters (Lewin et al. 2013). Whereas children living near iron smelters have been found to suffer declining lung functions (Spektor et al. 1991) and increased allergic sensitisation and allergic symptoms (Wilhelm et al. 2007) due to emissions of SO_2, NO_x and heavy metals (Nielsen 2013).

This study did not show any difference in exposure-disease associations between the age groups in ARD, conjunctivitis and dermatitis. However, it suggested greater associations for ages <14 years old in asthma. This is likely to be due to the susceptibility of these age groups because of their less mature respiratory and immune systems (Schwartz 2004). Children also spend most of their time outdoors, and breathe 50% more air per body mass compared to adults, thus they inhale more pollutants than adults do.

A greater number of males amongst the age group >1 - <20 years was noted in the exposure zones for both study and at-risk-populations groups. Gender differences were not as pronounced in the control zone. To understand these patterns, the 2010 census data was used to compare the study population structure with the entire Omani population, (**Figure II.6 1**). Results suggested that the difference in the gender ratio in the study area starts from ages 10-14 years old, a phenomenon not observed in the entire Omani population. One possible explanation for this greater number of young males in the study area might be due to the increasing labour force migration to this industrial area. This was also supported by the World Bank statistics of 2009, which showed that 87% of the young (aged 15-24 years) labour force in Oman was males (World Bank 2014b).

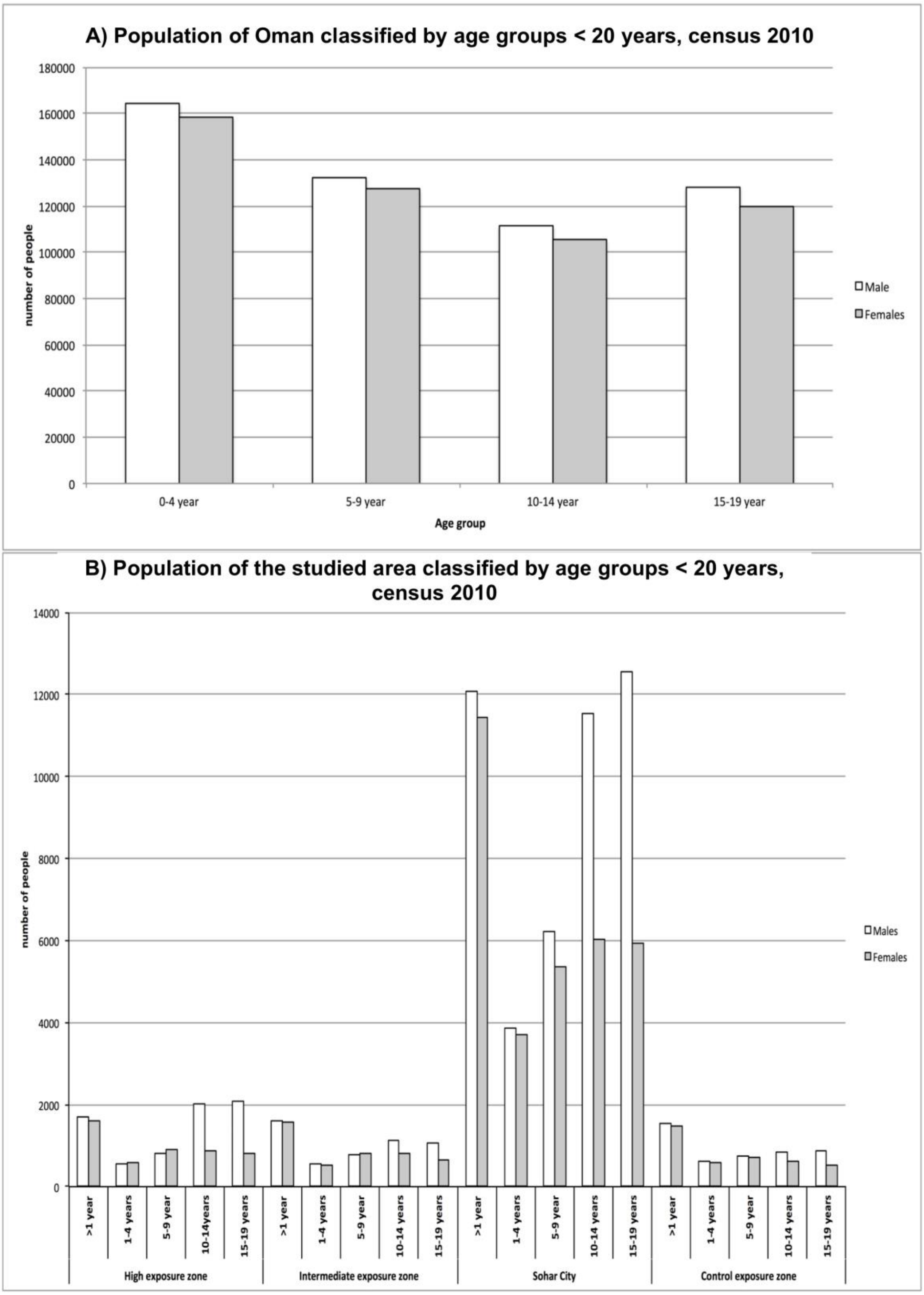


Figure II.6-1: Analysing the population pyramid in the children's population, A) in entire Oman, B) in the study population.

Findings of the analysis suggested greater follow-up frequencies for ARD and asthma associated with proximity to SIZ, which also confirmed the robustness of the exposure classification in capturing exposure effects.

b. Effects in adults (≥ 20 years old)

Supporting this study results, epidemiological studies have shown that, in adults, living near a petrochemical complex is associated with approximately a twofold increase in acute irritant symptoms of the respiratory tract and eye, and asthma (Yang et al. 1997; Patel et al. 2008; Rajab et al. 2000). A study in China showed that persistent toxic substances from these industries have doubled the risk of developing dermatitis in people living in proximity to them (Li et al. 2011). According to a Brazilian study, living near aluminium smelters has been associated with a fourfold increase in respiratory disease admissions (Petrela et al. 2001), whereas a Canadian study showed that living near iron smelters has been associated with acutely declining lung functions (Dales et al. 2013).

In this study, living within proximity of exposure source showed a greater risk of ARD and asthma amongst the ≥50 years old age group, and this finding may suggest increased vulnerability amongst the older age group (Braun & Anderson 2007). The gender stratified exposure-disease associations, specifically for asthma and conjunctivitis, did not correspond to the overall RR. One explanation is the unequal distribution of smoking prevalence amongst these two groups in Oman. The average smoking prevalence amongst males is 13%; this is only 0.8% amongst females, (**Table II.4 1**). The effect of the unequal smoking prevalence between the gender groups was also verified after performing another modelling, excluding the smoking prevalence, which showed corresponding gender stratified exposure-disease associations with the overall RR, (**Table II.6 1**).

Table II.6-1: Multivariable Analysis[a] of Asthma and conjunctivitis incidence[b] in association with combined exposure zone. Results are stratified by age category and gender.

Stratification	Combined[c] RR (95% CI)
Asthma	
Overall	3.9 (3.1-4.8)
Males	4.9 (3.6-6.6)
Females	3.0 (2.4-3.8)
≥20-49 years	2.3 (1.8-2.9)
≥50 years	3.9 (3.0-4.7)
Conjunctivitis	
Overall	2.9 (2.5-3.4)
Males	3.1 (2.5-3.8)
Females	2.7 (2.2-3.2)
≥20-49 years	2.3 (2.0-2.6)
≥50 years	2.9 (2.3-3.2)

[a] Adjusted for time trend.
[b] Age and gender standardised according to census population figures for 2010.
[c] Including high and intermediate exposure zones, control exposure zone as reference.
RR risk ratio; CI confidence interval.

Some suggestion of unequal effects by the SES group was observed, with those classed as disadvantaged showing a greater ARD and asthma-exposure diseases association. This is potentially due to other unfavourable circumstances associated with disadvantaged SES such as general health, habits (smoking and alcohol drinking), occupational and other environmental factors, including disadvantaged air quality due to living near industrial sources (Link & Phelan 1995).

To ensure that the exposure effects were adequately captured, the follow-up frequencies of the ARD, asthma, MS and GID were compared. Unlike the effects in the ARD and asthma, which showed increased risks associated with exposure, non-pollutant related diseases suggested no differences in the follow-up frequency between exposure zones. Hence, this confirmed that the exposure assessment approach could differentiate exposure effects.

The results showed that the number of young males (≥20-49 year old) was greater compared to the young females especially in the high exposure zone. This disproportionate gender distribution in the area is also observed for the entire Omani population pyramid, using the 2010 census. This phenomenon could be explained by the high number of working male expatriates in this age group, as evidenced by the Omani population pyramid, (**Figure II.6 2**).

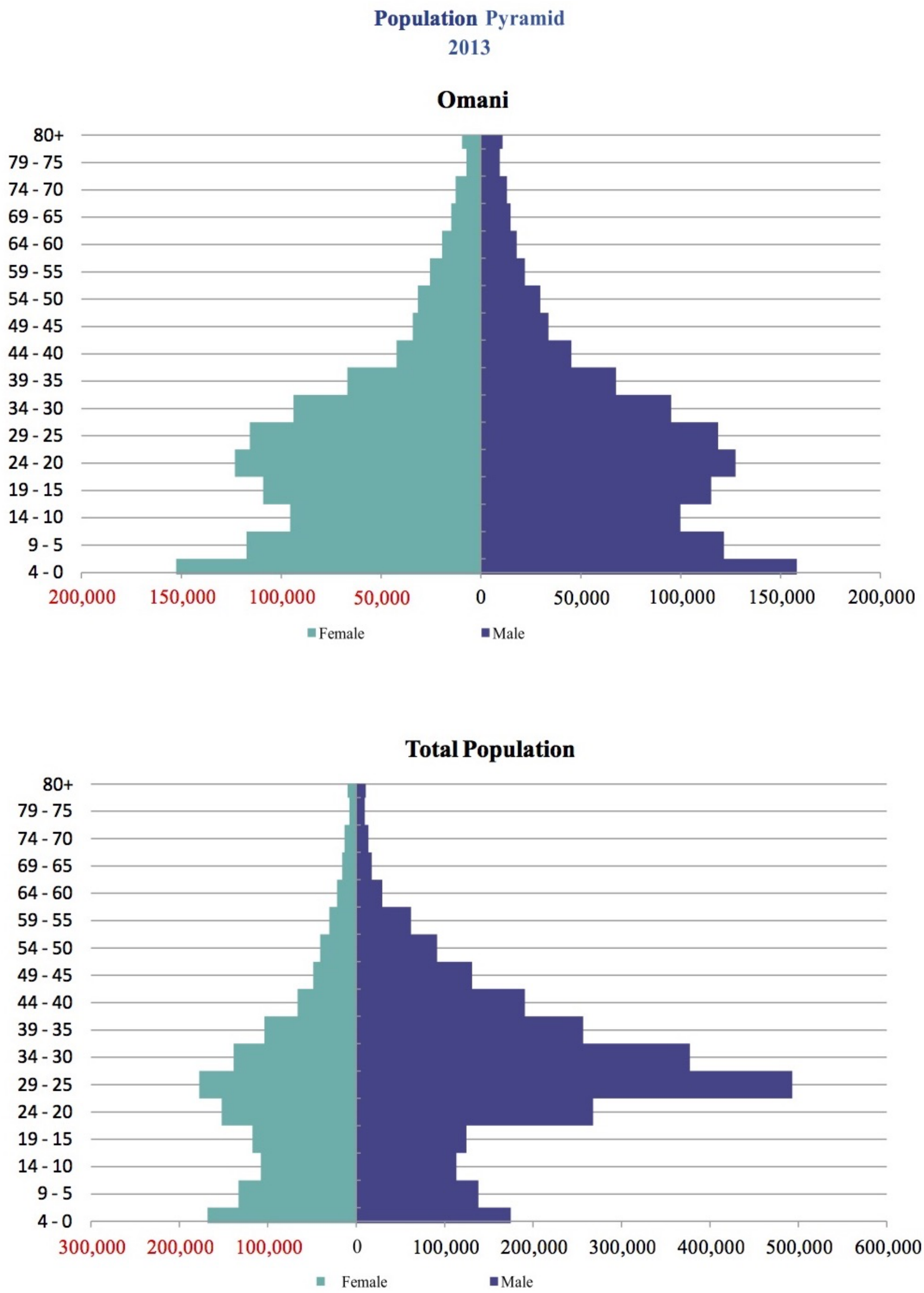


Figure II.6-2: The population pyramid of Oman in 2013. Omanis only (top chart) and Omanis with expatriates (bottom chart). The figure is taken from (NCSI 2013).

Epidemiological evidences concerning public health effects in people living near industrial activities are globally limited (Pascal et al. 2013). In Oman, this is the first environmental epidemiologic study investigating the health impacts of the country's rapid industrial development. It is suggesting that the inevitable economic growth and rapid development of Oman might have adversely affected health. This would signify the need for a more sustainable development in the country by implementing a powerful environmental health system to balance this rapid development. The necessity for an environmentally and socially sustainable development is being recognised in many rapidly developing economies around the world. For example, China has suffered tremendously from air pollution with an estimated 2.3 billion dollars (£1.5 billion) annual loss due to morbidities and mortalities related to air pollution (Alford et al. 2002). This triggered the Chinese government to implement more policies regarding environmental health. Furthermore, the WHO has estimated that environmental diseases in Oman accounted for around 17% of the total diseases in 2004 (WHO 2015), which should trigger the consideration of improvements in the environmental health system along with industrial development.

c. Limitations of the study

A few limitations of this study need discussion. These are discussed below.

Misclassification bias

Misclassification bias arises when there is uncertainty in the classification between exposed and non-exposed population in the study population (Delgado-Rodríguez & Llorca 2004). The use of a proximity method for exposure classification is subject to a misclassification bias. This is because of the uncertainty in outlining the limit of exposure zones, as pollutants do not respect boundaries (Rothman et al. 2008). Therefore, villages within each exposure zone may experience heterogeneity in exposure levels. However, exposure classification in this study used previous evidence from epidemiological and policy studies (Yang et al. 2004; Bentov et al. 2006) which supported the incremental distance used here. Additionally, analysis of wind roses and dispersion model confirmed the validity of the selected distances and has contributed to minimising this bias.

This misclassification bias might also result from the delineation of Sohar city borders in the exposure assessment. Villages, from other exposure zones, that are found near Sohar city might experience the same characteristics of Sohar city such as being urban and have more access to private health clinics. However, we tried to minimise this bias by using official governmental data, census 2010, that assign certain villages to the main city of Sohar.

The use of morbidity data

Morbidity data, used in this study, are deemed to give a less complete representation of the disease in a specific area, unlike the self-defining mortality data. This is because morbidity data depends on many factors, such as the diagnosing physician, the patients' comorbidities and the patients'/parents' threshold to seek medical help. The latter depends on the patient, his/her family, the surrounding society, and the accessibility to the health institution (Donaldson & Scally 2009). While more perceptive factors could not be factored in this study, the uniform distribution of the health institutions in the area ensured an easy access to health care providers for the population under study.

Selection bias from the use of state versus private health clinics

This type of bias arises when the study population does not fully represent the target population (Delgado-Rodríguez & Llorca 2004). In this study, only the state-related and not the private health institutions were considered, which might introduce this bias. However, out of 51 private clinics opened before 2011 (study relevant period), 48 of these private clinics were situated in Sohar city; 20 of these were medium size health complexes and 2 private hospitals. In contrast, the 3 remaining private clinics located in other exposure zones, only one clinic was labelled as a medium size health complex; the other two were small clinics (**Table II.4 3**) (MoH 2012). Therefore, after excluding Sohar city from the analysis, the influence of selection bias is quite small in the other exposure zones. In addition, the health data used in this study are from a total of 8 large state clinics (including hospitals). These are well distributed in the study area, ensuring good access of the study population to the state health institutions.

Disease definition of 'new' and 'follow-up' cases: another misclassification bias

The method used to distinguish new cases and follow-up visits can potentially introduce misclassification bias. To minimise this, many clinical and epidemiological definitions were used to ensure comprehensive definitions of new cases for each disease.

CHAPTER (III): INDUSTRIAL DEVELOPMENT IN OMAN: ENVIRONMENT AND PUBLIC HEALTH CONCERNS

III.1. Abstract

Environmental health threats can be better comprehended by understanding the interaction between their driving forces, the resulting states of environment and health, and the socio-political responses to these threats. The accelerated need for economic development in many developing countries has acted as a driving force leading to the movement of industrialization trend from developed to developing countries. This has negatively affected the state of environment and health in these countries, particularly due to the lack of strict environmental and public health policies. Oman, as a fast developing country, embraced rapid industrialisation to enrich its economic resources in the past 40 years. This is evident in the yearly increasing numbers of industries, which have resulted in increasing the energy production and urbanization trends in the country. As a result, the quality of environment and related population health has been affected, also suggested by the increasing annual levels of the per capita CO_2 emissions. The employment of a strong environmental health policy in Oman should therefore consider the interaction between these various causes of environmental health threats, and focus more on public and environmental health research. Any sustainable development should consider population health preservation as the main core of its program. The aim of this paper is to discuss the factors affecting environmental health threats, in particular from rapid industrial development in Oman and to suggest improved public health policies for maintaining a sustainable industrial development.

III.2.Introduction

In the discourse of environmental health threats, a dilemma between the need for a continuous industrial development and the maintenance of a good public health practice has been always discussed (McMichael, Butler, et al. 2003; King 1990; Pearce 1996; Gong et al. 2012). Although jeopardised by many adverse social, economic, and environmental circumstances, healthy environment and healthy choices should be available for everybody (McMichael & Butler 2006).

The rapid drive for economic prosperity in developing countries has created an opportunity for accelerated trend for industrialisation and urbanisation (World Bank 2014b). As epidemiological problems shifted from communicable to non-communicable diseases in these countries, public health attention and practise should change to accommodate this transition. The presence of less mature public and environmental health policies and related legislations in developing, compared to developed, countries has promoted the movement of many public health challenges, such as smoking promotion and industrial instalments, from developed to developing countries (Pearce 1996).

Industrialisation trend negatively affects population health through air, water and noise pollution (Shen 1999). These effects are enhanced by the social and other health effects resulting from urbanisation, which follows industrialisation trends (McMichael 2000; Gong et al. 2012). The driving forces for industrialisation with its resulting environmental and public health states require a proper response from the health system. Although essential for the countries welfare and resources, the industrial movement and associated subsequent urbanisation poses many public health challenges (Gong et al. 2012; McMichael 2000). These health challenges necessitate the initiation of powerful legislative environmental and public health systems along with any plans of industrialisation.

Oman, as one of the developing countries, is heading steadily towards industrial development and urbanisation. Driven by its need to decrease its dependency in fossil fuels production, the country is trying to diversify its economy by the accelerated investment in heavy industrial sectors (Times of Oman 2014). As a result, many industries and industrial areas have been developed in Oman. One example, the Sohar industrial zone contains several petrochemical and other heavy industries, and more are planned in the next few years (ONA 2009; Al-Wahaibi & Zeka 2015a). In this paper, a conceptual analysis of the dynamics that drive environmental health threats globally, in the Arab Gulf States (AGS) and Oman were presented. Then, the situation of environmental health in Oman and the need for a public health system improvement was discussed along with the industrial development. This is accompanied by suggesting the most pertinent practices and solutions to improve environmental health practice in the country.

III.3. Driving forces, state of environment and public health, and response in developing countries: a conceptual model

In the conceptual analysis of public health threats due to industrialisation, it is useful to utilise one of the simplest forms of the linkage-based sustainability assessment frameworks, which is pressure, state and response (PSR) (Waheed et al. 2009). Developed by Statistics Canada and later adopted by many countries (Rapport et al. 1979), this framework describes that there are continuous dynamic interactions between the driving forces, the resulting disadvantaged environment and public health situations, and the social and political responses from these interactions. The basic understanding of the interaction between these components helps in evaluating and measuring the causes of the environmental health threats, thus directing the efforts and policies towards correcting and neutralizing them (Jeon & Amekudzi 2005).

On a global public health scale, the interaction between the PSR triad is best illustrated by discussing the phenomenon of climate change and global warming with its resulting public health threats. It was due to the improvement of the health services that the global human population has increased to reach 7.2 billion by the year 2013 (United Nations Statistics Division 2013). This growth, with its subsequent industrialisation and urbanisation trends, has questioned the capacity of the biosphere for regeneration due to the increased extraction of the natural environmental resources. Wackernagel et al. showed that global extraction of environmental resources has reached about 25% more than it can be renovated by the environment (Wackernagel et al. 2002). As a result of these continuous pressures, the state of the environment is negatively affected in the planet. Its temperature is steadily increasing due to the increasing levels of anthropogenic CO_2 and other greenhouse gases release, leading to the phenomena of global warming (McMichael 2011). The resulting phenomenon has affected human health by, for example, changing infectious disease patterns along with other public health risks caused by population displacement because of the resulted extreme weather events (McMichael, Campbell-Lendrum, et al. 2003). The same approach of PSR interaction can be used to analyse the interaction between industrial development and public and environmental health.

a. Industrialization: a major pressure for public health in developing countries.

The continuous search for economic prosperity and welfare has led developing countries to adopt industrialisation, hence shifting industrial movement from developed to developing countries (McMichael 2000; World Bank 2014b). In its latest report, the World Bank has estimated that although the annual per person-energy consumption was 14 times greater in developed countries compared to developing countries, developing countries have more than doubled their energy production and consumption during the period from 1990-2011 (World Bank 2014b). Along with urbanisation, which follows industrialisation, this might aggravate the disadvantaged environment and exert more pressures on the population health in these countries (McMichael 2000; Pearce 1996; Shafik & Bandyopadhyay 1992).

On investigating the resulting causes of this industrial shift, it has been argued that the relatively faster epidemiological shift from communicable to non-communicable diseases in developing countries has not been appropriately accompanied by the development of powerful, legislative public health systems (Ärnlöv & Larsson 2015). It is because of the development of good public health practises in developed countries, industrial activities and other unhealthy practises, such as smoking promotion, have transferred to developing countries (McMichael 2000; Pearce 1996; Shafik & Bandyopadhyay 1992). Strict environmental regulations, resulting from the good public health standards in developed countries, forced the industries to transfer their entire industrial activities or their waste materials to the less developed countries (Shafik & Bandyopadhyay 1992). Along with the loosened environmental controls and public health infrastructure, the transfer has also been greatly facilitated by the minimal wages of labour in these countries, attracting more industrial sectors (ILO 2013). The presence of this phenomenon has further worsened the environmental and public health situation in developing countries resulting in increasing environmental pressures and public health threats in recent years (McMichael 2000; Pascal et al. 2013; Mudu et al. 2014).

As part of the fast developing countries, these driving forces of industrial movement might be evident in the discussion of pressures in the context of Oman and its adjacent AGS. Along with Oman, AGS include United Arab Emirates (UAE), Bahrain, Kuwait, Qatar and Saudi Arabia. The discovery of the fossil fuel in these countries has marked the beginning of an energy exportation economy enhanced by the rapid stride for fast development and industrialisation (Ramazani & Kechichian 1988). Due to the presence of not well-established public health and environmental policy and infrastructure, AGS might experience the public health challenges discussed earlier due to industrialisation and urbanisation (Yeatts et al. 2012).

To further examine the pressures in the AGS, including Oman, selected country profile indicators from the World Bank WorldData database were used (World Bank 2014a). Suggested by Schirnding Von Y et al. (Schirnding 2002), these profiles include indicators examining the pressures driving environmental state, such as: life expectancy at birth , infant mortality rates, total population number, energy use, road sector gasoline fuel consumption per capita, percentage of urban population and industry value added. Indicators investigating the resulting environmental state (Schirnding 2002) were also selected such as, CO_2 emission per capita and CO_2 emission from manufacturing industries. These country profiles were extracted and arranged for the 6 states of the AGS and plotted for the period from 1990 to 2011(**Figure III.3 1 to Figure III.3 3**). On the macro scale, the increased life expectancy and the decreased infant mortality rates might have resulted in the exponential growth of the total population number in the AGS (**Figure III.3 1**). This figure also shows the overall increased net migration in the AGS, notably Oman. This might be due to the migration of labour forces due to industrialisation and increased job opportunities. Because of the increasing population numbers, the need for energy consumption from industrialisation and transportation has also increased. This leads to increasing trends of urbanisation in these states, which might affect environmental and public health states (**Figure III.3 2**)

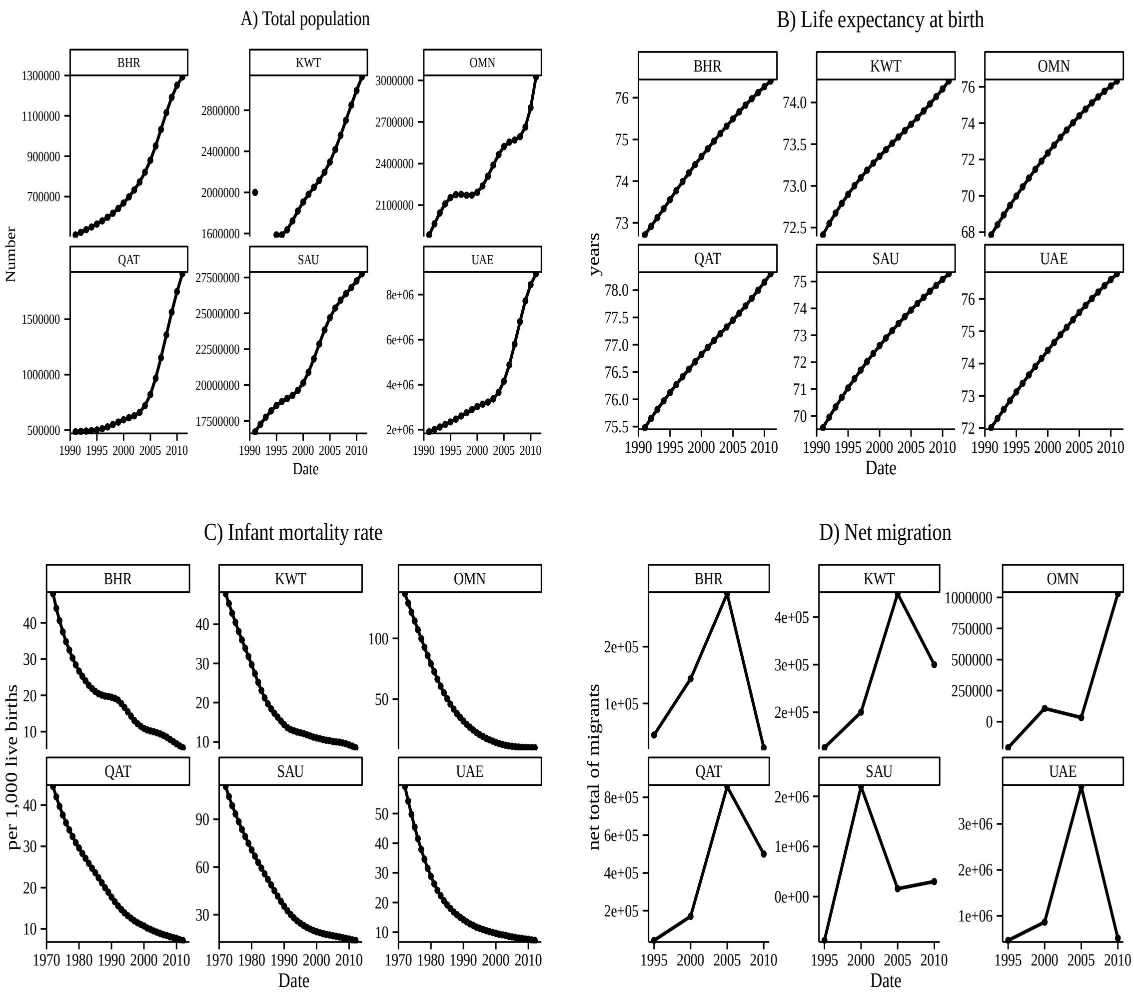


Figure III.3-1: Demographic and population parameters suggesting the driving forces for environmental and public health threats in the AGS. Note the increasing trend of the net migration in Oman. AGS: Arab Gulf States; UAE: United Arab Emirates; BHR: Bahrain; KWT: Kuwait; OMN: Oman; QAT: Qatar; SAU: Saudi Arabia. Net migration = the difference between people moving to the country and people leaving the country in one year. Data are from the World Bank WorldData database (World Bank 2014a).

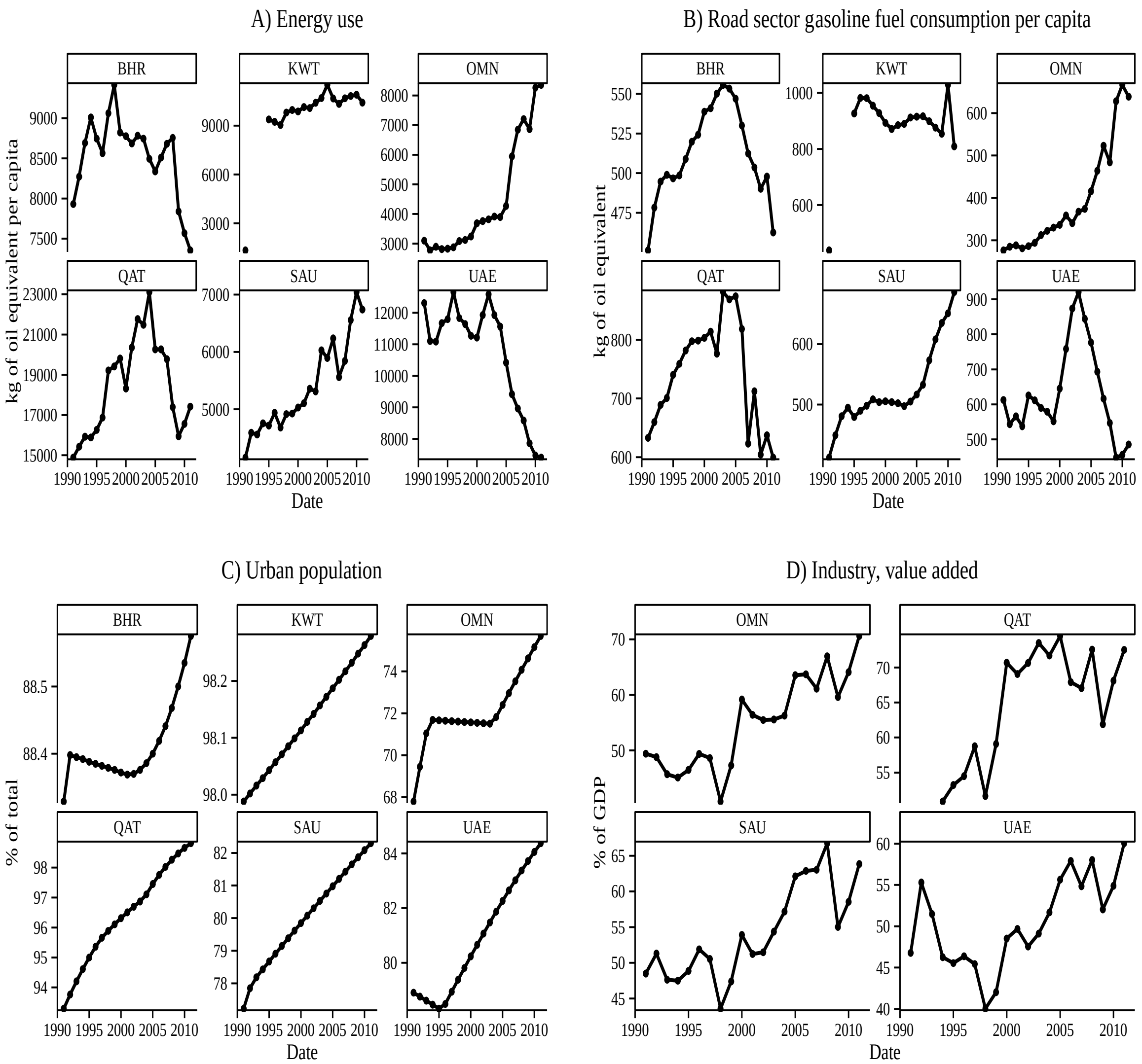


Figure III.3-2: Parameters indicating the pressures on the environment in the AGS. There is a tendency for the UAE, Qatar and Bahrain to step down in their total and road-related energy use per capita in the last 10 years. AGS: Arab Gulf States; UAE: United Arab Emirates; BHR: Bahrain; KWT: Kuwait; OMN: Oman; QAT: Qatar; SAU: Saudi Arabia. GDP: gross domestic product. Industry, value added: the contribution of industries to the total GDP of the country. Data are from the World Bank WorldData database (World Bank 2014a).

b. Industrialisation: environment and public health state in developing countries

The previously discussed driving forces of industrial movement towards developing countries have negatively affected their environment and public heath state. Depending on their type and activity, industries release different toxic emissions to the atmosphere such as, PM, SO_2, NO_x, VOC and O_3 (Nielsen 2013). Besides, they are also a source for toxic chemical waste products that lead to water pollution and soil contamination (Shen 1999).

Due to the insufficient environmental and air quality policies, environmental states in developing countries were negatively affected. This was evident in a recent WHO report which showed that the most polluted cities in the world are those located in the developing countries of the Eastern Mediterranean region and South-East Asia. These cities reported an annual average levels of 208 ug/m^3 of PM_{10} compared to 26 ug/m^3 in the developed cities (WHO 2014). Such levels are well above the WHO recommended level for the annual PM_{10}, which is 70 ug/m^3 (WHO 2006). For Oman, and its surrounding AGS, it is difficult to investigate environmental state due to the unavailability of data. However, one can use CO_2 emissions per capita or from industries an indicator of the increased industrial activity and disadvantaged air quality in the area (Schirnding 2002). All of the AGS showed increasing annual CO_2 levels emitted per capita and from industries during the last 20 years highlighting increasing activities of industrialisation and urbanisation, and large potential for deterioration of environmental quality **(Figure III.3 3).**

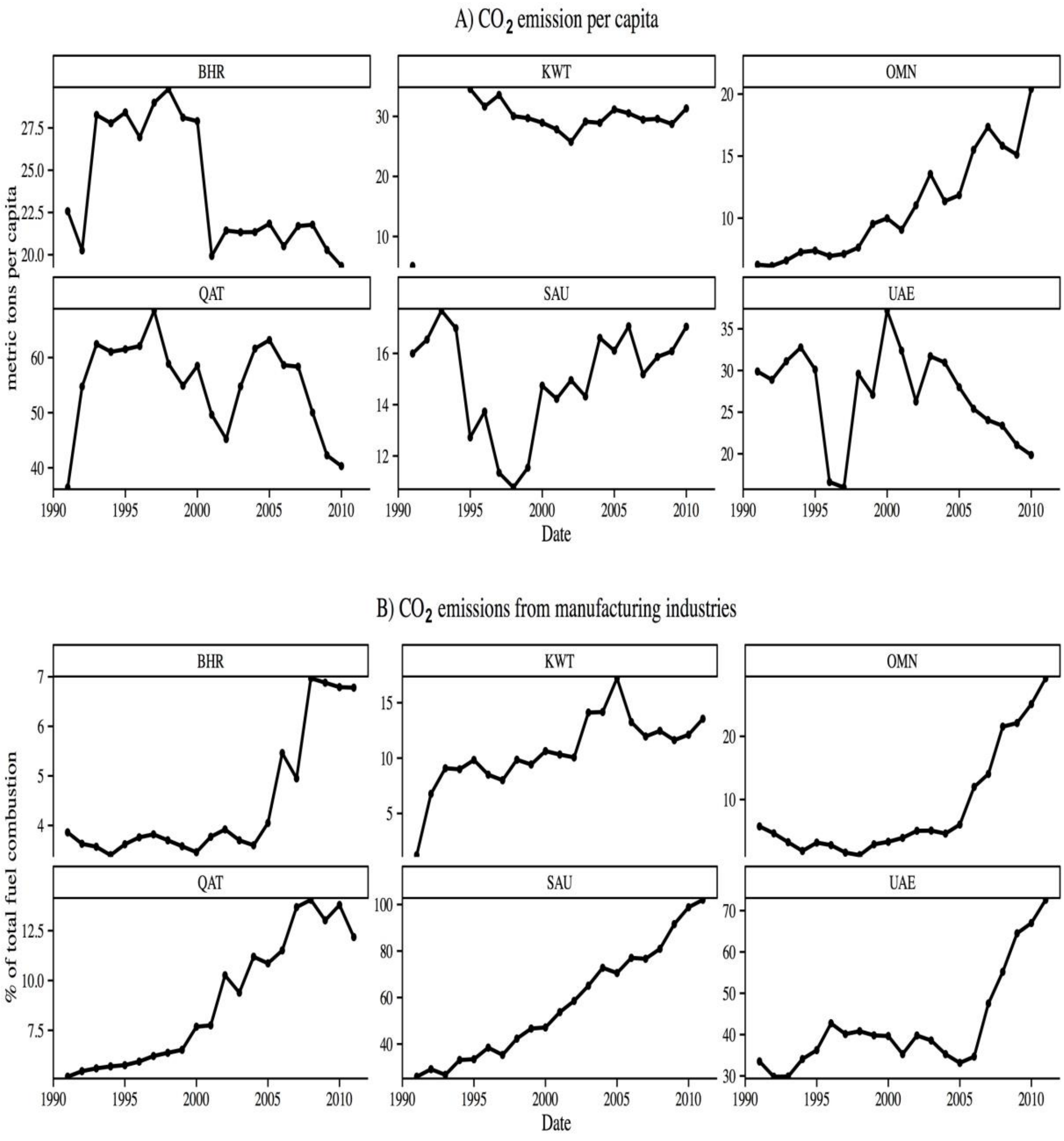


Figure III.3-3: Parameters indicating the quality of environment in the AGS. Note that UAE, Qatar and Bahrain had decreased their trends of per capita CO_2 emissions during the last 10 years, however their levels are still high compared with the other AGS. AGS: Arab Gulf States; UAE: United Arab Emirates; BHR: Bahrain; KWT: Kuwait; OMN: Oman; QAT: Qatar; SAU: Saudi Arabia. Data are from the World Bank WorldData database (World Bank 2014a).

The effects of industries on health have been long noted. Historically, the 'London Big Smoke' of 1952 is an example of the large negative effects of industrialisation. In this event an estimated over 12,000 excess deaths were recorded in association with the high air pollution levels (Davis et al. 2002). Subsequently, many epidemiological studies have been conducted to investigate the possible effects of environmental pollution and human health. These have suggested the correlation between air pollution levels, with increasing morbidity and mortality particularly from respiratory and cardiovascular diseases (Brunekreef & Holgate 2002; Arbex et al. 2012). Furthermore, in 2012, it was estimated that 7 million global deaths per year are attributed to air pollution (Burki 2014), increasing the awareness of air pollution as one of the main environmental contributors to disadvantaged public health.

Along with the previously discussed effects, industrialisation might affect public health through the increasing trends of urbanisation that usually follows industrialisation. This is causing many biological, physical and social public health threats (McMichael 2000; St Louis & Hess 2008). Industrialisation leads to urbanisation through the increased migration of people, which seek job opportunities and financial securities, to the urbanised cities. In China, and because of the industrial trend embraced by the country, the urban population has increased from 191 million in 1980 to 600 million in 2009 due to rural to urban migration (Gong et al. 2012). These migration trends might cause social changes that lead to disruptive urban communities with imbalanced ethnic and racial composition. Subsequently, this might create minority populations which have disadvantaged SES and increasing rates of violence and crimes (Vlahov & Galea 2002).

Urbanisation through its effects on life style, nutrition and other social changes might exert public health challenges by increasing obesity, cardiovascular diseases and neuropsychiatric disorders caused by stressful life situations (McMichael 2000). Furthermore, the rapidly increasing number of motor vehicles in the urbanised cities causes air pollution through their emissions of toxic substances. This is beside the increasing mortality and morbidity of road traffic accidents (McMichael 2000; Gong et al. 2012).

Industrialisation and urbanisation have been also associated with noise pollution (Vlahov & Galea 2002), which is linked with hypertension, cardiovascular diseases and hearing impairment (Passchier-Vermeer & Passchier 2000). Public health effects of industrialisation and urbanisation might even extend to the rural areas that were the source of the migrating manpower. This is because the migrating population might leave behind disruptive families and deranged social structure (Gong et al. 2012).

The disadvantaged environmental states in developing countries were reflected in the increased environmentally linked illnesses. It has been estimated that 25% of the total mortalities in the developing countries were environmentally related; this estimate was 17% in the developed countries (Prüss-Üstün & Corvalán 2006). Furthermore, the WHO has estimated that urban air pollution-related deaths in developing countries was twice that of developed countries (WHO & UNEP 2008). A retrospective study conducted in Indian megacities, revealed high to critical levels of air pollutants especially near traffic and commercial sites; these levels were found to be associated with increased incidence of respiratory, cardiovascular diseases and cancers (Rumana et al. 2014).

Very few studies have investigated the public health states of the dynamic interaction between the driving forces and the resulting environmental and health quality in the AGS (MacDonald Gibson et al. 2013; Rajab et al. 2000; Al-Mutairi & Koushki 2009; Alhyas et al. 2011; Aljefree & Ahmed 2015; Alhyas et al. 2012; Memish et al. 2014). In the UAE a study found that outdoor air pollution is the major cause of death, attributing 7.3% of the total country’s mortality (MacDonald Gibson et al. 2013). In Bahrain, a retrospective study examined the incidence of abortion before and after Gulf War, which started in 1991, suggested increases in the abortion incidence in the country after the war, possibly because of smoke pollution and toxins from burning oil fields that passed through the food chain system (Rajab et al. 2000). Recently, the WHO has estimated that the burden of environmental diseases in the AGS was in the range of 17-20% from the total burden of diseases. In Oman, the estimation of the burden of environmental disease was 17%. These estimates are considered high when compared to the United Kingdome estimate, for example, which was 14 % (WHO 2015).

Several studies found that rapid urbanisation of the AGS was associated with increased incidence of non-communicable diseases such as obesity (Alhyas et al. 2011), cardiovascular diseases (Aljefree & Ahmed 2015), type 2 diabetes mellitus (Alhyas et al. 2012), and road traffic accidents (Memish et al. 2014). AGS rapid urbanisation trend has been also found to worsen air quality. In 2009, a study done in Kuwait found that the measured air pollutants, in particular total sulfates and NO_x, were 100% higher in the urban when compared to the rural cities (Al-Mutairi & Koushki 2009). This highlighted the possibility of adverse health effects due to increasing traffic vehicles.

c. Response to industrialisation

Globally, greater environmental exposure with its related health effects occurs in the poor disadvantaged communities leading to the concept of ‘environmental inequity’ and its related activist movements, such as ‘environmental justice movement’ (Coughlin 1996). Such responses helped draw attention to the deprived communities decreasing the resulted environmental disadvantage due to low SES and ethnicity. Poor and minority communities are particularly at risk of living near polluting sources, hence getting more environment-related adverse health effects (Mohai et al. 2009), likely due to residing in poor quality houses and near polluting industries. This is combined with the attraction of increasing job opportunities provided by the polluting industries in the area. Because of the small income, these communities have difficulty in their mobility away from the polluting environment (Coughlin 1996); they often have diminished access to media and political representation, which ultimately leads to lack of political power to influence the establishment of polluting industries in their area (McGranahan & Murray 2012; Butler & McMichael 2005). In most cases, the offending industries use their authority, public relation and corrupted and misleading scientific researches to obscure any public health movement in these deprived regions. In developing countries, these issues might be more pronounced in particular when aggravated by the absence of good environmental health standards and laws (Butler & McMichael 2005).

The absence of environmental and public health controls and regulations in developing countries resulted in catastrophic events, like in the classic example of the Bhopal incident. A pesticide industry was started in 1969 in Bohpal, India. Because of the absent environmental lows for settlements near industries, this industry stimulated an increasing number of populations, with low SES, to reside near its vicinity. The presence of a lake of drinking water near the industry that was possibly polluted by the pesticides worsened the situation in the area (Bowonder 1985). In 1984, an accidental leak of toxic gas from the industry resulted in an estimated more than 16,000 mortality and more than 500,000 morbidity with long-term effects not yet understood (Srinivasa 2000). This example would highlight the need for proper safety regulations and controls that should also consider the social aspects in developing countries. These include considering the displacement of population, especially those with low SES, near the planned industries (Bowonder 1985).

Therefore, the response for environmental and public health threats caused by industries should involve political, social and economic aspects. For example, in India, Chaplin argued that the main obstacles to the implementation of a good environmental health system is the presence of a serious government, with the full resources to deal with increasing poverty, poor sanitation and air quality (Chaplin 1999). The main player in her argument is the high social class who tries to monopolize politics and resources against the poorer, illiterate and powerless lower class communities. Governments and other responsible stakeholders should properly respond to protect population health even the absence of strong evidence of population harm- using precautionary principle (Martuzzi & Tickner 2004). It has been argued that by using this principle, government might avoid many social and economic losses due to ‘suspected’ risks from industries. This principle assumes that actions should be undertaken with public health prevention programs along with the commencement of further public health researches to produce stronger evidences. Thus, implementing this principle will also improve public health researches by increasing and promoting the innovation of scientific methods and justifications (Todt & Luján 2014).

The interactions between the driving forces, the resulting environmental and health states and responses highlighted the need for a holistic response to deal with the public health threats caused by the rapid industrialisation in the developing countries.

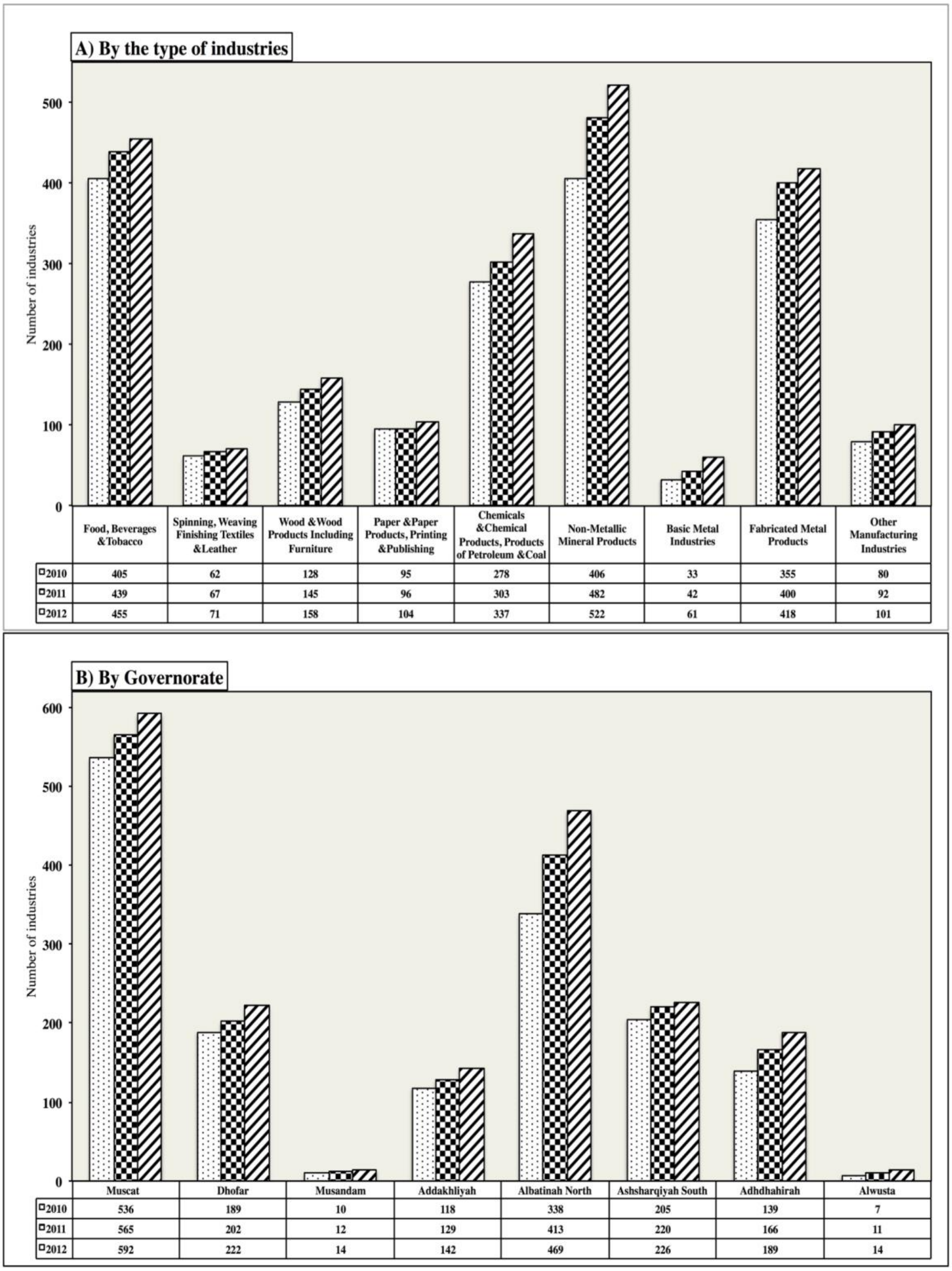
III.4. Industrial development in Oman: public health concerns

Since the 1970s, Oman has directed its fossil fuel income to establish its infrastructure, education and health care system. Unlike the other AGS, the Omani oil reserve is limited and is expected to finish within 30 years from 2014 (Oman Observer 2014a). This has created a stronger driving force in Oman to empower and introduce other resources of income such as, establishing heavy industries (International Business Publications 2009).

This accelerated need of the Omani government to start heavy industrial development was reflected in the increased dependency on industries for the total country income in the last 20 years (**Figure III.3 2**). The Omani government is trying to achieve a 15 % of its gross domestic product from of the industrial sector by the year 2020 (International Business Publications 2009). This trend was also evident analysing data from the Omani National Centre for Statistics and Information, which showed that the number of industries has increased from 1,842 in 2010 to 2,227 in 2012. Petrochemical and metal related industries has increased from 711 in 2010 to 816 in 2012 (NCSI 2013). These statistics also showed that more than 50% of these industries are located in Muscat and Al-

Batinah North region, the most populated governorates in the country, raising concerns over potential environmental and public health threats (**Figure III.4 1**). As the number of the industries increases, the demand for expatriate manpower and labour also increases. This was reflected by the steady increase in the net migration in the last 15 years in Oman, unlike the other AGS (**Figure III.3 1**).

The number of industries in Oman from 2010 to 2012 according to (A) type of industries (B) the Governorate:



	Food, Beverages &Tobacco	Spinning, Weaving Finishing Textiles &Leather	Wood &Wood Products Including Furniture	Paper &Paper Products, Printing &Publishing	Chemicals &Chemical Products, Products of Petroleum &Coal	Non-Metallic Mineral Products	Basic Metal Industries	Fabricated Metal Products	Other Manufacturing Industries
2010	405	62	128	95	278	406	33	355	80
2011	439	67	145	96	303	482	42	400	92
2012	455	71	158	104	337	522	61	418	101

	Muscat	Dhofar	Musandam	Addakhliyah	Albatinah North	Ashsharqiyah South	Adhdhahirah	Alwusta
2010	536	189	10	118	338	205	139	7
2011	565	202	12	129	413	220	166	11
2012	592	222	14	142	469	226	189	14

Figure III.4-1: The number of industries in Oman according to (A) industrial type, (B) governorate. Data are taken from NCSI (NCSI 2013).

These environmental pressures, along with the steadily increasing urbanisation and increased transport related fuel consumption (**Figure III.3 2**), might affect environmental quality and possibly aggravate public health situation in the country. This was reflected in the relatively sharper growth of CO_2 per capita levels in Oman, which was almost doubled during the period from 2005-2010 (**Figure III.3 3**).This sharper growth might indicate a faster environmental degradation in the country compared to its neighbouring AGS. Similar doubling of CO_2 levels was noted in the CO_2 industrial emissions, (**Figure III.3 3**).

In Oman, few studies were conducted to examine the effects of urbanisation on the population health markers (Al-Lawati et al. 2008; Al-Lawati & Jousilahti 2004; Ganguly et al. 2008; Al-Moosa et al. 2006). These have mainly concentrated in the prevalence of the non-communicable diseases in Oman, such as cardiovascular diseases, diabetes and obesity caused by urbanisation (Al-Lawati et al. 2008; Al-Lawati & Jousilahti 2004; Ganguly et al. 2008; Al-Moosa et al. 2006) For example, Al-Moosa et al. (Al-Moosa et al. 2006), found that the urbanised regions in Oman have greater prevalence of diabetes mellitus, obesity and hypertension when compared to the rural areas.

However, no studies were conducted to investigate the possible public health effects of the industrial development in the country. A recent epidemiologic study assessed the acute health effects in a population living in proximity to one of the newly developed industrial parks in Oman, Sohar industrial zone (Al-Wahaibi & Zeka 2015a; Al-Wahaibi & Zeka 2015b). This study investigated the association of the number of acute respiratory infections, asthma and allergic diseases with living in proximity to this industrial port. Findings suggested two-to threefold greater risk of acute respiratory infections, asthma and allergic diseases for people living within 10 km from the port when compared to those living > 20 km. These effects were found to be greater in children, age’s ≥50 years and in those with lower SES. These findings highlight that this industrial development has adversely affected population health of the surrounding communities.

a. The current situation of environmental health system in Oman

Currently, the Omani regulations for air pollution are specified under guidelines released by Ministry of Regional Municipalities, Environment and Water Resources (MRMWR) in 2004 (MRMWR 2004). It is mainly directed towards stationary sources, like industries, specifying some standards to control toxic emissions from industries. Examples of these standards are: the recommended stack heights for each industry and allowable emission rates for different pollutant. There are no national standards for ambient air quality; nevertheless, MECA is in the process of producing them. Although poorly maintained, there are only three air quality monitors established around major industrial areas: Rusail, Raisout harbor and Sohar industrial port. Furthermore, the current environmental impact assessment (EIA) guidelines from MECA are out-dated lacking for the health and social aspects of the assessment. Such aspects were proposed earlier by the MoH, in its guidelines for environmental health impact assessments, to be added to any EIA conducted in the country (Wahaibi & Mandhry 2014). Beside the lack of proper environmental indicators, there are no existing implemented systems to monitor for health indicators related to environmental health in Oman. These indicators are important in the assessment and follow up of the progress of the environmental health system in the country.

In the presence of this not well mature environmental health system, the rapid industrial movement in Oman, with its accelerated urbanisation, might cause a great challenge to public and environmental health in the country in the future. Therefore, a proper environmental and public health system is needed in Oman, which will ensure population wellbeing without the need to interrupting the wheel of its industrial development.

III.5. Towards a harmony between industrial development and public health

The effects of industrialisation on the country's economy could go in to two opposite directions. On one hand, one can argue that industrialisation is important for the country to ultimately increase its income, which will help improving the health system and thus improving its population health. On the other hand, the uncontrolled environmental pollution and its health effects might cause adverse consequences on the economy of the country (Shen 1999). For example, it has been estimated that Europe has spent more than 329 billion euros (£236.2 billion) on damages caused by industrial emission from 2008 to 2012 (EEA 2014). In China, it has been estimated that 2.3 billion dollars (£1.5 billion) of the Chinese annual loss was due to morbidities and mortalities related to air pollution (Alford et al. 2002).

These resulting negative states of the environment and health from industrialisation merit a proper public health system to balance the preservation of population health practises and sustain industrial development, simultaneously. This sustainable development could be achieved by improving the cooperation between the thinking of various human life aspects such as demography, epidemiology, ecology, sociology, economy and engineering in any industrial development. This will ultimately ensure human wellbeing, equity, autonomy and security (McMichael, Butler, et al. 2003). Subsequently, the main aim of sustainable development is to maintain a good quality of environment and thus public health for both the current generation (ensuring intra-generational equity) and the future subsequent generations (ensuring inter-generational equity) (Jabareen 2006).

Although, sustainable development achievement is a multidisciplinary action, public health preservation should be the fundamental goal of this development (King 1990). This is because sustainability programmes through maintaining good ecological and economical complex systems, they eventually maintain the population health through the subsequent generations rendering population health as the 'bottom line' concern of any sustainability program (McMichael 2006). This might be further strengthened through increasing public health researches that help outlining the interaction between the social, ecological and political aspects of industrialisation on health. In addition, wide range population based research will help producing more evidences to implement public health preventive actions (Pearce 1996).

Because sustainability and sustainable development is a multidisciplinary field, different conceptual frameworks from different disciplines have been proposed to approach it. The PSR linkage-based sustainability framework was utilized in this paper discussion to highlight the interaction between the driving forces that may affect the public health state and responses to industrial development. However, for a complete and an extended picture of the interaction between socioeconomic, political and health factors it is preferable to use the Driving Force-Pressure-State-Exposure-Effect-Action (DPSEEA) framework, developed by WHO (Briggs et al. 1997). DPSEEA, a form of linkage-based sustainability framework, assumes a ‘cause-effects’ relationship between its sections. The assessment and follow-up of the framework is estimated using different indicators in each of its sections. For example, the framework uses environmental and health indicators to assess ‘state’ and ‘health effects’, respectively, (**Figure III.5 1**). DPSEEA indicators are also necessary to convey the framework levels into information for the use of more evidenced based environmental policies. Because each section of the framework leads to the next one, any suggested environmental policy should ideally target all the framework sections simultaneously.

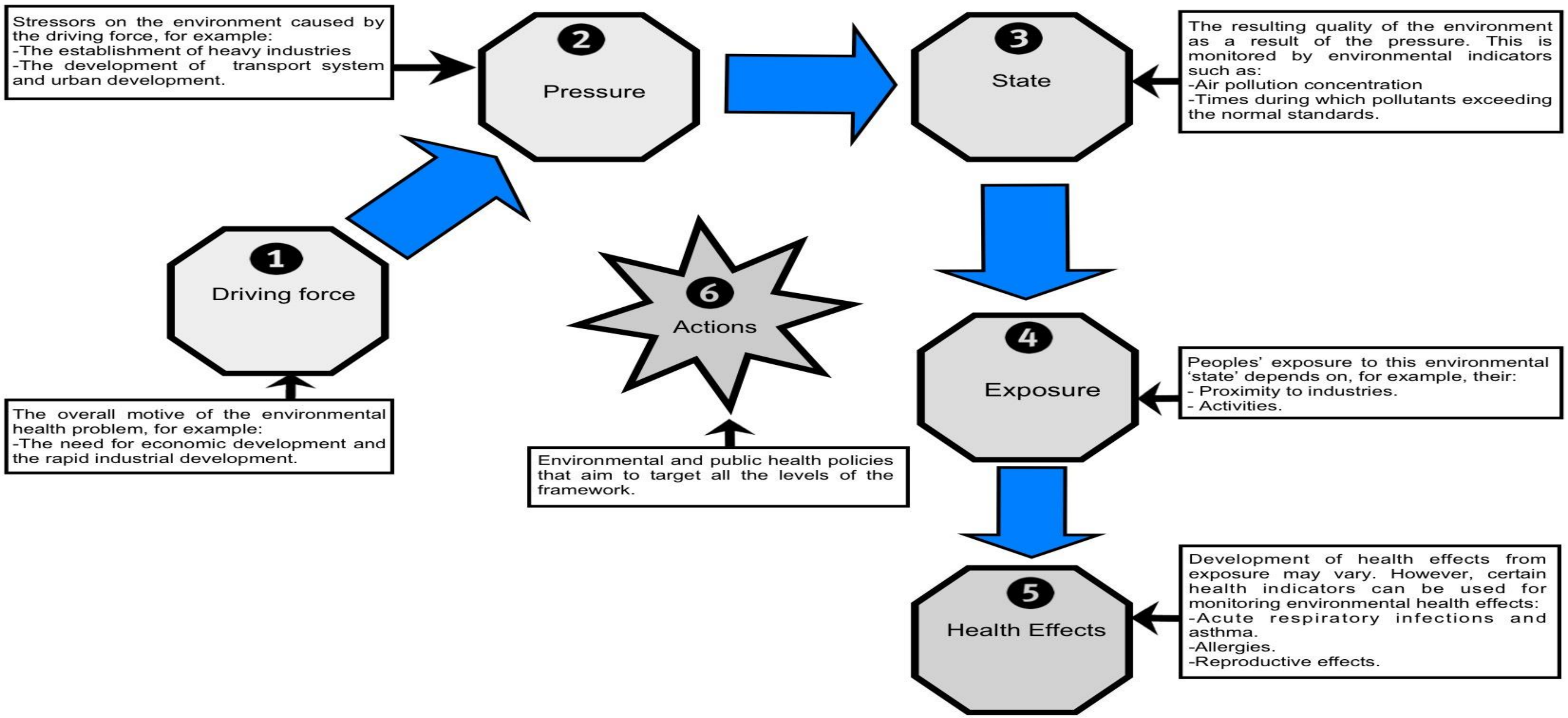


Figure III.5-1: Driving Force-Pressure-State-Exposure-Effect-Action (DPSEEA) framework. The rectangular boxes illustrate examples of the indicators that can be used to assess and monitor each part of the framework. The frame is modified from (Waheed et al. 2009).

DPSEEA framework is useful for the analysis of the social, economic and health problems caused by industrialisation near a deprived area, such as in the study of (Diab & Motha 2007). Similarly, DPSEEA could be used to analyse the situation of Sohar industrial port in Oman, (**Table III.5 1**).

Table III.5-1: Applying DPSEEA framework in Oman, SIZ[1] study as an example

Driving Force	The need for a rapid industrial development in Oman as a result of economic pressures due to diminished future oil reserves.
Pressure	SIZ was established with many heavy petrochemical and metal industries in proximity to residential areas.
State	Adverse air quality around SIZ was noted by residents in the form of daily smog and black smoke[2].
Exposure	People living in proximity to SIZ are largely exposed to air pollution. Children and old ages groups are particularly at risk.
Effects	Al-Wahaibi A et al. (Al-Wahaibi & Zeka 2015a; Al-Wahaibi & Zeka 2015b) suggested two-to-three folds increase in acute respiratory diseases, asthma and allergic diseases when living within 10 km from SIZ. Greater effects were noted in the extreme of age groups and the more deprived groups.
Actions	Residents around the port have many complaints regarding the smoke and pollution from the port's industries. The government responded by displacing them away from the port. This highlighted the need for a national environmental health policy[3] that targets each step of the framework.

[1] SIZ: Sohar Industrial Zone. [2]The need for 'environmental monitoring system' in the form of air monitoring stations around the port is necessary to evaluate the state of the environment around SIZ. [3]A suggested environmental health policy is illustrated in **Table III.5 2.**

Along with the other interactive components of the DPSEEA framework, **Table III.5 1** shows two types of actions due to the pollution from the port: community or residents' action and government's action. Actions from the residents around the port included complaints from the frequent smoke and smells resulting from the polluting industries of the port (Rejimon 2013). Residents were mainly concerned about their health and economical losses due to the port pollution. Recently, and as a precautionary principle, the government underwent a socio-political action involving the decision to transfer the entire residential area, located within 5 km from the port, away from the pollution hazards (Oman Observer 2014b). Nevertheless, this decision has cost the government more than 500 million RO (£840 million). Such economic loss demonstrated the urgent need for the establishment and reinforcement of a good environmental health system in the country, which will help the decision makers in investigating, planning and regulating future industrial areas in the country.

Hence, the interaction between the DPSEEA components in **Table III.5 1** shows the necessity for an action plan and environmental health policy that target each component of the framework to ensure more sustainable public health in the country. This policy should aim at strengthening environmental and public health regulations and policies in Oman, including air quality standards. The policy should also support the establishment of air quality monitoring systems and environmental health-disease indicators. These will help detect and monitor environmental and public health diseases caused by disadvantaged environmental states in the country. The plan should also aim to increase and improve human resources in public health and increase the coordination between stakeholders dealing with environmental and public health. Additionally, any suggested environmental and public health policy should focus on increasing public health research to produce evidence-based environmental and public health practice in Oman. Ultimately, the suggested policy should aim to establish a strong environmental and public health body in the country to, for example, reinforce public and environmental health laws and regulations to the polluting industries. The suggested improvement of the Omani environmental health policy is elaborated more in **Table III.5 2**.

Table III.5-2: A summary of the suggested policy improving environmental health system in Oman.

Regulations and policy reinforcement	The reinforcement of the current regulations and the review and modification of certain existing policies is very crucial. The introduction of an integrated impact assessment that combines environment, health and social aspects at the national levels is also important along with the introduction of the Omani Ambient Air Quality standards. All of these regulations should be incorporated towards the implementation of a national environmental health strategy.
Monitoring and infrastructure	For a proper environmental health policy, and to provide a close supervision of the environmental quality and health effects, there is a need to setup a monitoring system for both air quality and environmental health effects. The establishment of air quality monitoring stations and networks along the highways and around industrial zones should be introduced at a national level. This would ensure continuous real time temporo-spatial data of the levels of the major pollutants for proper environmental health analysis and actions. The introduction of health indicators for environmental health such as acute respiratory illness, asthma and allergies should also be established at the MoH level.
Human resources	The enforcement of the environmental health system with more trained personnel is essential. This is done by sending environmental health staff for further national and international training programs and qualifications such as, postgraduate studies and residency programs, covering the field of environmental and occupational health and epidemiology. Furthermore, frequent national workshops and conferences should be initiated in these fields to ensure the continuous staff development. On the national level, recruitment of expertise in different environmental health aspects will help in the development of a strong environmental health system. For example, they will help in the improvement of the guidelines for environmental and human impacts assessment.
Coordination and collaboration	Coordination should be established between different stakeholders that are involved with the environment and health, such as MoH, MECA, MRMWR, Ministry of Housing, Ministry of Commerce and Industry and etc. The coordination between these governmental bodies should involve the freedom of information exchange concerning health and environment. This coordination should setup the objectives and responsibilities for the future

	development of environmental and occupational authority centres, help in the formulation of the national environmental and occupational health strategy plans and addresses the national adaptation for emerging global issues such as climate change and health.
Establishment of a national centre for environmental and occupational health	There is a need to establish a powerful, legislative environmental and occupational centre that will act as a long-term centre for the development and the implementation of future environmental health policies in Oman. This centre should setup the preparedness guidelines for health and environmental emergency situations incorporate environmental health into industrial, transport and agriculture systems and educate the public about emerging environmental health issues.
Research	Researches in environmental health and their relation to the Omani social, demographic and economic aspects should be commenced. Such researches will help provide some evidence-based information for the decision makers and contribute largely to the evolution of the environmental and public health system in Oman.

III.6.Conclusion

The rapid trend of industrial development in Oman merits a proper understanding of the public health threats that may follow. The coexistence of industrial development and good sustainable population health is not impossible. This can be achieved through the strengthening of environmental and public health system, particularly by increasing public health researches. These will assist in producing more evidence-based policies that ensure public health sustainability of any future development.

CHAPTER (IV): CONCLUSION

The shifting of industrialisation, with its subsequent urbanisation, from developed to developing countries, has resulted in many public health threats in these countries. Oman, as one of the fast developing economies, has reinforced its industrial sector to enrich its economy, resulting in the establishment of many industrial areas, one of which is the Sohar industrial zone.

This study is the first environmental epidemiologic study done in Oman investigating the health impacts of the country's rapid industrial development. Similar studies elsewhere have been limited, especially those examining children population (Smargiassi et al. 2009; F. A. Wichmann et al. 2009; Yang et al. 1997; Papadimitriou et al. 2012; Ernst et al. 1986; Lewin et al. 2013; Spektor et al. 1991; Wilhelm et al. 2007). A recent review by Pascal et al. identified only 17 such studies globally (Pascal et al. 2013). Therefore the contribution of this study finding is important from country, regional and global perspective. This study had two key objectives. First, it aimed to assess through epidemiologic study the health effects of living in proximity of one of these developments and carried these out in two populations: a young population of <20 years old and an adult population of ≥20 years old. Second, it aimed to understand the public health implications of rapid development, in particular in the scenario Oman as a rapidly growing economy, but a developing country in other societal infrastructures.

Results of the epidemiologic studies suggested that children living within 10 km from SIZ are two to three times more likely to suffer from acute respiratory diseases, asthma, conjunctivitis and dermatitis, when compared to children living more than 20 km from the port. No differences in effects between gender and SES groups were detected; however, greater effects were noticed in the age group 2-14 years old in asthma.

Results also suggested that adults living within 10 km from the Sohar industrial zone were found to have around three times the risk of developing acute respiratory diseases, asthma, conjunctivitis and dermatitis, when compared to those living more than 20 km away. These risks were greater in the older population of more than 50 years and in the low socio-economic status groups.

Results of the second policy and health and environmental infrastructure assessment suggested that the inevitable economic growth and rapid development of Oman might have adversely affected its population health. This would signify the need for a more sustainable development in the country that preserves public health without affecting the industrial sector's growth. Such a sustainable development might be attained by implementing a powerful environmental health system with clear public health policies and environmental standards. In addition, creating an infrastructure for more air-quality-monitoring, improving human resources and increasing the coordination between different stakeholders of environmental health would help in the establishment of this strong environmental health system. Any suggested environmental health system should also focus on increasing public health research to produce evidence-based environmental and public health practices in Oman.

This study would advise the use of the precautionary principle of public health to protect the affected population from the exposure-disease effects. Such a principle suggests that public health actions towards a perceived risk should be undertaken even in the absence of a conclusive scientific evidence (Martuzzi & Tickner 2004). Recently, and based on this precautionary principle, the Omani government has proposed a 3-year plan to shift the entire population living within 5 km from the Sohar industrial zone to a nearby newly established area (Oman Observer 2014b). As this step would cost the government more than 500 million RO (£840 million), it would highlight the growing importance of a proper environmental health system in the country. Besides, more industrial parks are planned in the area resulting in potentially an unsustainable application of this precautionary principle in the future.

In addition, one should take into consideration the social and economic context of such displacement (Barnes et al. 2002). People, who are mainly fishermen, living within these communities are established there over centuries. Therefore this displacement will socially and economically affect them, by displacing them away from their neighbours and their source of income, the sea. Moreover, this displacement was not informed by a proper environmental assessment or study which indicated that pollution from Sohar industrial zone will not affect those who live more than 5 km from the port. Such assessment will also be needed to examine the pollution levels in the newly proposed residential area. Therefore, the presence of a proper environmental health system would assist in the planning of any newly proposed industrial areas to avoid future expenses and economical losses. For example, a strong, independent environmental health system/body in the country will provide an unbiased EIA for the area before the establishment of the industries. This will help advice the government of the proper location for future industrial planning to avoid adverse health threats in the surrounding population.

This study might be replicated in other industrial areas in Oman such as the Al-Duqum, Raysot and Al-Rusail areas. This will provide more evidence about the possible public health threats caused by these industries on the surrounding population. As some of these industries are older than the SIZ, one might also investigate the presence of the chronic health effects in the surrounding population, such as malignancies. This will ultimately help the process of public health protection in the area and, through environmental health system, advise the industries to take better environmental control of their toxic emissions.

IV.1.Future area for research

Future studies and suggested cohorts are being proposed in multiple industrial areas in Oman by the Omani government to study wider spectrum of health effects. Recently, The Research Council of Oman, which was established in 2005, decided to conduct further studies in Sohar industrial zone. In these proposed long-term studies, a complete air quality monitoring system in the area was proposed. These air quality data will be later combined with both retrospective health care data and possible long-term cohort study data. Longitudinal studies might also be used exploring long term effects of these industries. This could be conducted, for example, by studying and following up pregnant women to explore the possible reproductive health effects of the industries in the women and their offspring. Furthermore, future proposed studies might also include toxicological studies in the area investigating the type of pollutants and toxins produced by the industries and their effects on the cellular level. Other studies that will investigate the social and economic effects of the population surrounding the industries are also suggested. These, for example, might look at the social effects of moving the affected population form their homeland to another area with completely different social and geographical surroundings.

This study highlighted the importance of including environmental and public health development in any future industrial plans and developments of the country. The field of public and environmental health in Oman needs more exploration, improvement and, hence, strengthening. We hope that this study will act as the corner stone for environmental and public health research and development in Oman.

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APPENDICES

Appendix (1): Ethical approval

EC/94-1

Research Ethics Review Checklist Version 2

Research Ethics Review Checklist

This checklist should be completed for every research project that involves human participation, the collection or study of their data, organs and/or tissue. It is used to identify whether a full application for ethics approval needs to be submitted.

Before completing this form, please refer to the University Code of Research Ethics and General Ethical Guidelines and Procedures. The principal investigator or, where the principal investigator is a student, the supervisor, is responsible for exercising appropriate professional judgement in this review.

The checklist must be completed before potential participants are approached to take part in any research.

Section I: Project details

1. Project title: Effects of air quality on the health indicators in the residential area near Sohar Industrial Port (SIP) in the Sultanate of Oman.
2. Proposed start date: 1 October 2011
3. Proposed end date: 30 September 2014

Section II: Applicant details

2. Name of researcher (applicant):	Adil Said AlWahaibi
3. Status (delete as appropriate):	Postgraduate student
4. Brunel e-mail address:	Adil.Al-Wahaibi@brunel.ac.uk
5. Telephone number:	N/A

Section III: For students only

6. Module name and number or MA/MPhil course and School:	PhD Institute for the Environment Research
7. Supervisor's or module leader's name:	Ariana Zeka
8. Brunel e-mail address:	Adil.Al-Wahaibi@brunel.ac.uk

Issue date: 18 November 2008 Page 1

Supervisor: Please tick the appropriate boxes. The study should not begin until all boxes are ticked:

X	The student has read the University's Code of Research Ethics
X	The topic merits further research
X	The student has the skills to carry out the research
	The participant information sheet or leaflet is appropriate
	The procedures for recruitment and obtaining informed consent are appropriate
	A risk assessment has been completed.
	A CRB check has been obtained (where appropriate)

Comments from supervisor: As this is a statistical study of mortality data, no recruitment or participant information sheets are necessary.

Section IV: Description of project

Please provide a short description of your project:

This study is conducted to determine the health effects of air pollution in a newly developed industrial area in Oman. Data to be used in the study are as follows:

1. Daily admissions and patient visits will be obtained from health establishments covering the region. This data is administrative with no personal identifiers;

2. Oman weather data for the studied area;

3. Oman air pollution data for studied region;

All publications resulting from this work will report aggregate statistics only. Permission for the health data was granted by the Ministry of Health, Sultanate of Oman for the use of these data for the purpose of this scientific research. The data which have been supplied, have no individual identification markers and are completely anonymous. The ethical approval for the use of this data is attached with the form.

Section V: Research checklist

Please answer each question by ticking the appropriate box:

	YES	NO
1. Does the project involve participants who are particularly vulnerable or unable to give informed consent (e.g., children, people with learning disabilities, your own students)?	☐	X
2a. Will the study require the co-operation of another organisation for initial access to the groups or individuals to be recruited?	☐	X
2b. If the answer to question 2a is **Yes**, will the research involve people who could be deemed in any way to be vulnerable by virtue of their status within particular institutional settings (e.g., students at school, members of self-help group, residents of nursing home, prison or other institution where individuals cannot come and go freely)?	☐	X
3. Will it be necessary for participants to take part in the study without their knowledge and consent at the time (e.g., covert observation of people in non-public places)?	☐	X
4. Will the study involve discussion of sensitive topics (e.g., sexual activity, drug use) where they have not given prior consent to such discussion?	☐	X
5. Are drugs, placebos or other substances (e.g., food substances, vitamins) to be administered to the study participants or will the study involve invasive, intrusive or potentially harmful procedures of any kind?	☐	X
6. Will the study involve the use of human tissue or other human biological material?	☐	X
7. Will blood or tissue samples be obtained from participants?	☐	X
8. Is pain or more than mild discomfort likely to result from the study?	☐	X
9. Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?	☐	X
10. Will the study involve prolonged or repetitive testing?	☐	X
11. Will financial inducements (other than reasonable expenses and compensation for time) be offered to participants?	☐	X
12. Will the study involve recruitment of patients or staff through the NHS?	☐	X

If you have answered 'yes' to ***any*** of the questions in Section V, you will need to describe more fully how you plan to deal with the ethical issues raised by your research. You should use the appropriate School form or the University Application Form for Research Ethics Approval.

If you have answered 'no' to all questions, **send the completed and signed form to your School's Research Ethics Committee, for their records.**

If you answered 'yes' to ***question 12***, you will also have to submit an application to the appropriate external health authority ethics committee, **after** you have received approval from the School Research Ethics Committee.

Please note that it is your responsibility to follow the University's Code of Research Ethics and any relevant academic or professional guidelines in the conduct of your study. **This includes providing appropriate information sheets and consent forms, and ensuring confidentiality in the storage and use of data.** Any significant change in protocol over the course of the research should be notified to the School Research Ethics Officer and may require a new application for ethics approval.

Signed: [signature]
Date: 26 - 01 - 2012
Principal Investigator: Adil Said AlWahaibi
Supervisor or module leader (where appropriate): Ariana Zeka
Signed: Ariana Zeka
Date: 26 January 2012

Sultanate of Oman
Ministry of Health
Directorate General of Health Affairs
Office of the Director General

سلطنة عُمان
وزارة الصحة
المديرية العامة للشؤون الصحية
مكتب المدير العام

From: Ministry of health, Sultanate of Oman

PO Box 393, PC 113
Muscat, Sultanate of Oman

To: Institute for Environment

University of Brunel

Kingston Lane

Uxbridge

Middlesex UB8 3PH

Dr. Adil Said Al-Wahaibi (Brunel university ID number: 1029153), an employee of the Ministry of Health in Oman, is funded by the Oman Government to carry out a study that investigates health effects of recent industrial developments in the country. The study will require use of individual health data, for which Dr. Al-Wahaibi has the Ministry's ethical approval. These data will be given to Dr. Al-Wahaibi without personal identifiers, and publication of any research findings will be only in an aggregated form.

If you require any further information please do not hesitate to contact our office.

Yours faithfully

P.O. Box : 393, Muscat, Postal Code : 100
Tel.: (968) 24600808, Fax : (968) 24696099

ص.ب : ٣٩٣ ، مسقط ، الرمز البريدي : ١٠٠
هاتف : ٢٤٦٠٠٨٠٨ (٩٦٨) ، فاكس : ٢٤٦٩٦٠٩٩ (٩٦٨)

E-mail : dg.ha@moh.gov.om

Appendix (2): Sohar city model results

a. Children results

Table 0-1: Multivariable Analysis* of acute respiratory diseases, asthma, conjunctivitis and dermatitis incidence**, Age < 20 years, north AlBatina Region, Oman, 2006-2010. Results are also stratified by age category and gender, comparing Sohar city with the combined zone.

Exposure groups	Combined± RR (95% CI)	Sohar RR (95% C.I)
ARD		
Overall	2.5 (2.3-2.7)	0.4 (0.3-0.4)
Males	2.3 (2.1-2.7)	0.3 (0.3-0.4)
Females	2.6 (2.3-2.9)	0.4 (0.3-0.4)
0-1 year	2.6 (2.4-2.9)	0.3 (0.3-0.4)
2-14 years	2.4 (2.2-2.6)	0.3 (0.3-0.4)
15-19 years	2.6 (2.3-3.1)	0.4 (0.4-0.5)
Asthma		
Overall	3.7 (3.1-4.5)	0.4 (0.3-0.4)
Males	3.6 (2.8-4.7)	0.3 (0.2-0.4)
Females	3.8 (2.9-5.1)	0.4 (0.3-0.6)
0-1 year	3.6 (2.2-6.1)	0.6 (0.4-1.0)
2-14 years	4.6 (3.8-5.7)	0.3(0.2-0.4)
15-19 years	2.6 (1.9-3.5)	0.5 (0.4-0.7)
Conjunctivitis		
Overall	3.1 (2.9-3.5)	0.5 (0.4-0.5)
Males	2.9 (2.5-3.3)	0.4 (0.4-0.5)
Females	3.5 (3.1-4.1)	0.5 (0.4-0.6)
0-1 year	3.3 (2.8-3.8)	0.4 (0.3-0.5)
2-14 years	3.0 (2.7-3.4)	0.5 (0.4-0.5)
15-19 years	3.8 (3.0-4.8)	0.6 (0.4-0.7)
Dermatitis		
Overall	2.7 (2.5-3.0)	0.3 (0.3-0.4)
Males	2.6 (2.3-3.0)	0.3 (0.3-0.3)
Females	2.9 (2.6-3.3)	0.4 (0.4-0.5)
0-1 year	2.8 (2.5-3.3)	0.3 (0.3-0.4)
2-14 years	3.0 (2.7-3.3)	0.4 (0.3-0.4)
15-19 years	2.5 (2.0-3.1)	0.3 (0.3-0.4)

* Adjusted for time trend and season.
** Age and gender standardized according to census population figures for 2010.
± Including high and intermediate zones, control zone as reference.

b. Adults results

Table 0-2: Multivariable Analysis* of acute respiratory diseases, asthma, conjunctivitis and dermatitis incidence**, Age ≥ 20 years, north AlBatina Region, Oman, 2006-2010. Results are also stratified by age category and gender, comparing Sohar city with the combined zone.

Exposure groups	Combined± RR (95% CI)	Sohar City RR (95% CI)
ARD		
Overall	2.0 (1.9-2.2)	0.8 (0.7-0.8)
Males	1.9 (1.7-2.0)	0.6 (0.6-0.7)
Females	2.0 (1.9-2.2)	0.8 (0.7-0.8)
20-49 years	1.8 (1.6-1.9)	0.5 (0.5-0.6)
≥50 years	2.3 (2.1-2.5)	1.0 (0.9-1.1)
Asthma		
Overall	3.6 (3.0-4.4)	1.2 (1.0-1.5)
Males	2.5 (2.0-3.0)	0.7 (0.6-0.9)
Females	2.9 (2.4-3.5)	1.4 (1.2-1.7)
20-49 years	1.9 (1.6-2.4)	0.8 (0.6-0.9)
≥50 years	3.7 (3.0-4.6)	1.5 (1.2-1.8)
Conjunctivitis		
Overall	2.8 (2.5-3.2)	0.9 (0.8-1.1)
Males	2.5 (2.2-2.9)	0.9 (0.7-1.0)
Females	2.4 (2.1-2.7)	0.8 (0.7-1.0)
20-49 years	2.2 (2.0-2.5)	0.7 (0.6-0.8)
≥50 years	2.7 (2.4-3.2)	1.0 (1.0-1.2)
Dermatitis		
Overall	2.1 (1.9-2.4)	0.7 (0.6-0.8)
Males	2.1 (1.8-2.4)	0.6 (0.5-0.7)
Females	1.8 (1.6-2.1)	0.6 (0.6-0.7)
20-49 years	1.8 (1.6-2.0)	0.5 (0.4-0.6)
≥50 years	2.2 (1.7-2.6)	0.9 (0.7-1.0)

* Adjusted for time trend, smoking prevalence and season.
** Age and gender standardized according to census population figures for 2010.
± Including high and intermediate zones, control zone as reference.

Appendix (3): publication

To the BMC Public Health Editorial Team: 5th May 2015

Dear Dr Roberto Pasetto,

We appreciate the helpful comments you have provided to aid in strengthening our manuscript. Thank you for allowing us the opportunity to submit our revised manuscript (MS: 2098677791630563), 'Health Impacts From Living Near A Major Industrial Park In Oman' by Adil Al-Wahaibi and Ariana Zeka as a Research Article for your journal. We have addressed all the issues required by the reviewers. We have included the exact reviewer comments provided, and have addressed these in a point-by-point manner in this response letter. Our manuscript now consists of 3940 words (excluding Abstract of 277 words). We are grateful to you for considering our manuscript for publication in BMC Public Health.

Respectfully,

Adil Al-Wahaibi PgDip, MSc, M.D
Institute for the Environment
Brunel University London
Uxbridge, Middlesex, UB8 3PH
Tel: +44 (0)1895 267359
Fax: +44 (0)1895 269761
Email: Adil.Al-Wahaibi@brunel.ac.uk

Comments from Reviewer #1:

MINOR ESSENTIAL REVISIONS:

1. Change the terms "developing" and "developed" countries with "middle and low-income" and "high income" countries

Authors' Response: In response to this point we would like to highlight that the terms 'developing ' and 'developed' might be more appropriate to use in the context of the key points this paper addresses. For example, although the income per capita is considered high in Oman, also classified as an energy exporting country (United Nations Statistics Division 2014)*, the developing state of the health system and other societal systems infrastructure (including public and environmental health, and environmental policy) would classify Oman as a developing country. These essential societal systems are not yet comparable to those of developed countries, for example the Western Europe, USA or Japan. According to the United Nation classification of countries, Oman is considered a 'developing country'* (United Nations Statistics Division 2014)*. Other rapidly developing countries, with increasing wealth, do fall into a similar definition (China, India). Hence, the classification based on development, rather than simply on country income, is considered more appropriate within the context of the study aims, and the authors wish to keep the original definitions.*

2. Revise figure 1. It is not clear enough and the scale seems to be wrong

Authors' Response: Figure 1 was reviewed and the scale adjusted, as suggested by this Reviewer.

3. Smoking is a confounder per se for the diseases of interest and do not need to be statistically tested, while the other selected potential confounders can be chosen using a statistical approach.

Authors' Response: We appreciate the Reviewer's point. To address this comment we have now modified the Methods section were we discuss adjustment for potential confounders in the study. We are now stating that because of the large difference of smoking prevalence between gender groups in our study population, *smoking was controlled for in the analyses. Other potential confounders were statistically tested, and considered only if they modified the exposure-response estimate by more than 10%.*

4. Specify examples of "other environmental factors"

Authors' Response: In response to this comment we have now included a description of these other environmental factors (such as proximity to more polluted locations) in the revised manuscript.

DISCRETIONARY REVISIONS:

1. The reference 12 was published in 2004, two years before the establishment of the plant operation (2006). Which is the source of environmental contamination that can justify such environmental data?

Authors' Response: The 2004 study by Abdul-Wahab SA et al. was cited to highlight lack of studies conducted in this industrial development (Abdul-Wahab & Yaghi 2004)*. The authors of this earlier study concentrated on the total suspended particles that were produced by ceramic and food industries, found in the SIE at that time. The aluminium plant, the main industry for this area (SIE), started to operate in 2008. SIP which included the Sohar refinery and the other petrochemical industries were not in operation until early 2006. To clarify this we have slightly modified the section where this citation appears.*

2. I suggest also the following references:
"World Health Organization. Human health in areas with industrial contamination. Mudu P, Terracini B. Martuzzi M (eds). Copenhagen: WHO Regional Office for Europe. 2014. Available from: http://www.euro.who.int/en/publications/abstracts/human-health-in-areas-with-industrial-contam

Authors' Response: We welcome the Reviewer's suggestion of adding this reference to the paper, as it is very pertinent and of great value to the subject.

Comments from Reviewer #2:

The only comment is about the completeness of health data on primary, secondary and tertiary care visits obtained from MoH and analyzed in the paper.
In the "Methods" paragraph the authors state that for the 59 villages data from private institutions were not available on the electronic system. In the "Exposure classification" paragraph the authors state that in Sohar city 93% of the health clinics were private, hence Sohar city was excluded from the analysis.
The authors should give information on percentage of private institutions for the other villages. The above issue should be expanded on in the Discussion paragraph commenting on the direction of the bias possibly introduced by analyzing data on individuals selected on access to public institutions.
I'm confident the authors can address this issue and I recommend publication after they consider this comment. In summary my comment is somehow more than "Minor Essential Revisions" and less than "Major Compulsory Revisions".

Authors' Response: We appreciate the Reviewer comment. To elaborate more on this point, out of 51 private clinics opened before 2011 (study relevant period), 48 of these private clinics were situated in Sohar city; 20 of these were medium size health complexes and 2 private hospitals. In contrast, the 3 remaining private clinics located in other exposure zones, only one clinic was labelled as a medium size health complex; the other two were small clinics (MoH 2012)*. Therefore, after excluding Sohar city from the analysis, we think that the influence of selection bias is quite small in the other exposure zones. In addition, the health data used in this study are from a total of 8 large state clinics (including hospitals), well distributed in the study area, ensuring good access of the study population. We have edited the section in the manuscript where this issue appears to reflect the response to this comment. We have also discussed more on the effects of the selection of individuals on the bases of their accessibility to public/state health centre in the study's limitation section.*

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RESEARCH ARTICLE

Open Access

Health impacts from living near a major industrial park in Oman

Adil Al-Wahaibi* and Ariana Zeka

Abstract

Background: Oman is heading towards heavy industrialisation with rapid establishment of new industrial parks. One of these, the Sohar Industrial Zone (SIZ) started to operate in 2006 and includes many industries that potentially affect local air quality and the health status of its surrounding residents. The study aim was to assess the health effects in a population of ≥20 years old, living in the residential area around the SIZ.

Methods: Area-specific health care visits data for acute respiratory diseases (ARD), asthma, conjunctivitis and dermatitis were obtained for the period between January 1, 2006, and December 31, 2010. Exposure was defined as distance from the SIZ to determine high, intermediate, and control exposure zones (≤5, >5–10, and ≥20 km from the SIZ respectively). Generalized additive models were used to model age and gender adjusted monthly health events for the selected diseases, adjusted for age and gender-specific population smoking prevalence. The high and intermediate exposure zones were later combined in the models because of their similarity of effects. Exposure effect modification by age, gender and socio-economic status (SES) were examined.

Results: Living within the high and intermediate exposure zones was associated with a greater risk ratio for ARD (RR: 2.02; 95 % CI: 1.88–2.17), asthma (RR: 3.61; 95 % CI: 2.96–4.41), conjunctivitis (RR: 2.83; 95 % CI: 2.47–3.24), and dermatitis (RR: 2.11; 95 % CI: 1.86–2.39), compared to the control exposure zone. Greater exposure effects were observed amongst ages ≥50 years and lower SES groups.

Conclusion: This is the first study carried out in Oman to assess the link between environmental exposure and health. These findings hope to contribute to building up evidence for environmental health and sustainable development policy in the country.

Keywords: Environmental Exposure [N06.850.460.350], Primary Health Care [N04.590.233.727], Respiratory Tract Infections [C08.730], Hypersensitivity [C20.543]

Background

In the last few decades, the global trend for industrial development has migrated from developed to the less developed countries. As estimated by the World Bank, developing countries have more than doubled their energy production and consumption during the period from 1990–2011 compared to the developed countries [1]. This shift in energy production accompanied by the lack and inefficiency of environmental health policies, has also contributed to the geographic shift of the burden of environmentally related morbidities and mortalities [2]. A recent report of the World Health Organisation (WHO) estimates 25 % of mortalities in developing countries are environmentally related; this estimate is 17 % in developed countries [3].

Oman, through reforms in social and economic policies, which took place in the 1970s, started the development of different societal sectors including industries. The country has recently embraced a rapid industrialization trend to enrich its economy and decrease its dependency in fossil fuel [4]. As a result, many industrial parks including petrochemical industrial complexes were started in Oman, one of which is the Sohar Industrial Zone (SIZ). This industrial zone was established in 2006 and consists of two main industrial regions: Sohar Industrial Port (SIP) and Sohar Industrial Estate (SIE). Covering an area of 2058 hectares, SIP contains a wide range of petrochemical industries and

* Correspondence: Adil.Al-Wahaibi@brunel.ac.uk
Institute of Environment, Health and Societies, Brunel University London, Kingston Lane, Uxbridge, Middlesex, United KingdomUB8 3PH

an iron smelter. An oil refinery and a polypropylene plant started to operate in 2006, subsequently followed by two major industries: a power company and a methanol industry in 2007. A formaldehyde plant and a urea industry were established between 2008 and 2009; an iron smelter and an aromatics plant were appended in 2010. New expansions and developments will be established soon including more heavy industries and an airport [5]. SIE, which was built on 2100 hectares, is situated five kilometers southwest of SIP. Besides other complementary industries, Sohar Aluminium which started in 2008, is the most important industry in SIE for its size of investment [6]. Such industries potentially emit air pollutants and many environmental toxins such as sulphur dioxide (SO_2), nitric oxides (NO_x) and volatile organic compounds (VOC) [7].

Consistent epidemiological evidence elsewhere shows adverse health effects of air pollution, including increases in morbidity and mortality from respiratory and cardiovascular causes [8]. Several studies have also shown that there is a link between living near industrial complexes and occurrence of adverse health outcomes [9–11]. SIZ is situated near a heavily populated area, raising great concerns for community adverse health effects of its surrounding residents. Only two studies have assessed the environmental effect of SIZ in their surrounding area, suggesting adverse environmental conditions [12, 13]; one of these studies was conducted before the start of intensive industrial establishments in the area [13]. There has been no study of the health impacts of this industrial development, and more generally, in other similar developments in Oman. Hence, the aim of this study was to evaluate the acute health effects in an adult population living near the Sohar Industrial Zone.

Methods

Health and population data

As SIZ is situated between Liwa and Sohar provinces, health data on primary, secondary and tertiary care visits of the local population aged ≥20 years old were obtained from the Omani Ministry of Health (MoH). Data were gathered from the national Al-Shifa electronic health recording system from eight state health institutions in these provinces, for the period of January 1, 2006, and December 31, 2010. Along with Sohar city, the capital of Sohar province, this data represented a total of 59 villages. Data from private institutions were not available on this electronic system. The information obtained for each patient visit included: patient's consultation date, unique identification number, date of birth, village, health institution, and diagnosis determined by the *International Classification of Diseases 10Th Revision* (ICD-10 code). Ethical approval for the study was obtained from the Omani MoH and Brunel University Ethics Committee.

Based on previous evidence on the effects of air pollution on morbidity outcomes and availability of data, we selected to study respiratory and allergic diseases.

Diseases of the respiratory system included: acute respiratory diseases (ARD) defined as upper (ICD-10: J0-J06), other acute lower respiratory infections (ICD-10: J20-J22), and pneumonia (ICD-10: J12-J18); and asthma (ICD-10: J45 and J46). Allergic diseases included disorders of the conjunctiva (ICD-10: H10-H13), and dermatitis - including eczema (ICD-10: L20-L30 and ICD-10: L50-L54, respectively). Due to the small number of visits for cardiovascular diseases, stroke and chronic obstructive pulmonary disease, data were insufficient for the analysis. The low number of these diseases, which mostly affect the ≥60 years old age group, potentially reflects the fact that the Omani population is young, with only 4.3 % of the population aged over 60 years [14].

Demographic data for area-specific population by age and gender, educational and occupational statuses were obtained from the Omani national census of 2010. The area-specific population was used as an offset for the models. Education and occupational status were used to construct the socio-economic status (SES) indicators for each village. Age and gender-specific smoking prevalence data were derived from a study done by Al Riyami et al. [15], and the Global Youth Tobacco Survey (GYTS-Oman) [16]. Meteorological data such as daily wind speed, wind prevailing direction and temperature were obtained from the Omani Department of Meteorology for the period of January 1, 2006, and December 31, 2010.

Definition of the events

To assess health effects of living in proximity to SIZ, two case definitions were used for each of the selected diseases: incidence (new) and follow-up cases. Previous epidemiological studies examining respiratory morbidity in adults define a new case and duration of ARD differently. While some studies defined the new event as a patient coming after one disease-free day [17], others defined this duration as 3 days [18], one week [19] and 1 month [20]. Several published studies considered a new asthmatic attack as an attack occurring after 1 year from the previous one [21]. However, Eisner et al. defined this period as one-month free attack in studying the effects of passive smoking on adult asthma [22]. Previous clinical and epidemiological definitions of a new case of allergic disease vary from 10 days [23] up to 1 year [24]. Using this previous epidemiological evidence, we defined a new case as any unique patient visit occurring 1 month after the first visit, including this first visit, for all disease definitions. The use of the one-month lag between visits to define new cases in our study also ensured sufficient number of events to improve the study efficiency, and decrease the possibility of counting follow-up visits as new events. Follow-up visits were defined as any patient's visit occurring within the one-month period, between two new events.

Exposure classification

Due to lack of air pollution monitoring or measurements in the area, we employed a proximity method to classify the exposure of the villages around SIZ. Villages were classified according to their distance from the source of pollution. The oil refinery was used as a landmark source from which to estimate the distance, determined by this industry being the main source of exposure in SIZ and its early operation date. The proximity approach is widely used in many influential environmental epidemiology studies [10, 11, 25–29]. In addition, this method is used frequently in many environmental investigation studies such as in the environmental impact assessment and environmental justice studies [30]. For example, the United States Environmental Protection Agency (US EPA) has used this approach in its environmental risk assessment framework [31].

To determine the most appropriate definition of the minimum distance for exposure, we used previously published evidence. In several epidemiologic studies, the designation of the minimum proximity distance for exposure classification was mostly arbitrary [26, 32, 33]. However, one study defined the distance depending on residents' odor complaints [27], while others defined it by using environmental sampling [34, 35]. The threshold distance used in the studies assessing the effects of petrochemical industrial complex ranged from 3 km [10] to 20 km [11], whereas two studies used a 20 km distance for the metal smelters [27, 32]. We also reviewed several examples of international housing policies, which determined the minimal safe distance for residences from such industrial areas as >2 km (Additional file 1).

Based on the above discussion and to increase the power of the study, an incremental distance of 5 km from the refinery was chosen to determine exposure zones. We defined four exposure zones: high, for those living within ≤5 km; intermediate, living within >5–10 km; and control exposure zone, as living ≥20 km from the refinery. No villages were located between 10 and 20 km from the refinery; hence, this distance was not represented in the analyses. This study only included data from state health institutions, likely contributing to relatively smaller number of cases from Sohar city. The latest statistics from MoH revealed that out of the fifty-one private health clinics found in the studied area, 48 (94 %) of these clinics are located in Sohar city, including 20 medium size health complexes and two private hospitals [36]. In contrast, the three remaining private clinics, which were located in other zones, comprised of only one medium sized and two small private clinics. Hence, to ensure minimal contribution of selection bias, Sohar city was excluded from the analyses (Fig. 1).

To validate the proximity approach-based exposure classification, we constructed monthly wind roses of the area for the entire study period. The wind pointed to the west in the summer and in September, to the northeast, and towards the seaside in November and in winter, and had no major direction in spring and in October (Fig. 1). This indicated a possible similarity in the pollutant patterns between the high and intermediate exposure zones during the summer and the month of September.

Also, to verify our exposure classification distances, we carried out dispersion modeling using limited emission data for SO_2. SO_2 emission data were obtainable for the oil refinery for only the first 15 days of June 2008. To run the dispersion model, two main sets of data were needed: the SO_2 emission data, obtained from AbdulWahab et al. [37], and meteorological data produced using the high-resolution Meteorological Mesoscale Model (MM5) and terrain data [38]. Dispersion model predicted SO_2 concentration showed a relative two to four times change for distances from 5 to 10 km, supporting our 5 km incremental distances used to define exposure zones.

Statistical analysis

Monthly health care visits were modeled using a generalized additive model (GAM) in R software. Modeling diagnostics, including Akaike's Information Criterion, over-dispersion, and influence graphs suggested the use of a negative binomial distribution to count for data over-dispersion. Time, as month number, was defined as a continuous variable and smoothing functions were applied to capture underlying non-linear seasonal and longer-term trends of the selected diseases. Positive autocorrelation was detected in the data and was controlled by an autocorrelation structure of order 1 (corAR1). Exposure zones (with control zone as a reference), age category (≥20–49, ≥50 years old) and gender were all coded as factors in the model. The logarithm of gender and age group-specific population data were added as an offset in the model.

Smoking was not equally distributed in the study population. Latest statistics in Oman show that the average smoking prevalence amongst males was 13 %; this was only 0.8 % amongst the females [15, 16]. Because of the large difference of smoking prevalence between gender groups in our study population, smoking was controlled for in the analyses. Other potential confounders including daily temperature, season, and individual year, were statistically tested and found not to change the exposure-response estimate by more than 10 %, thus not considered further. The use of time smoothing

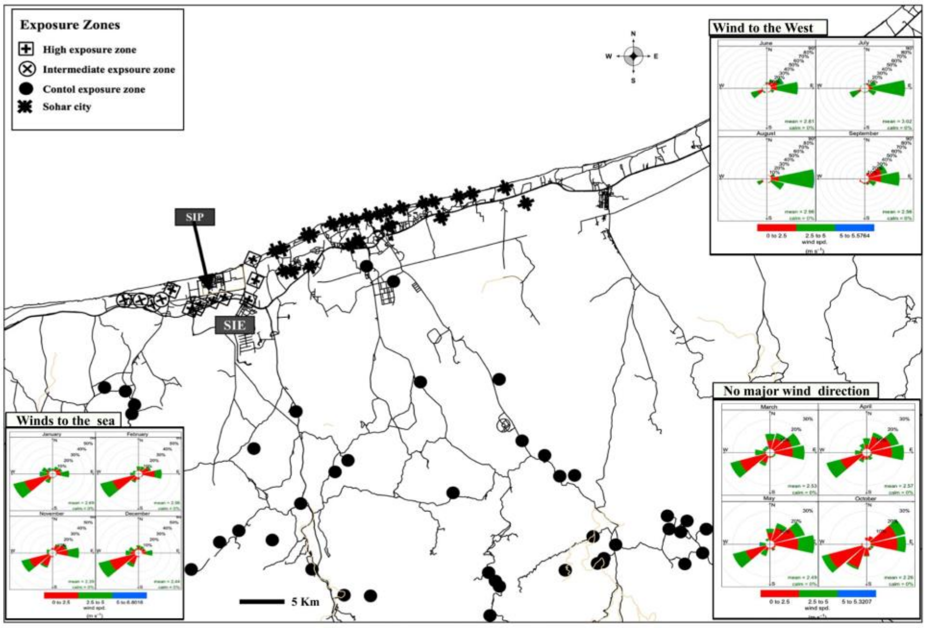

Fig. 1 Exposure classification of the study area*. * The prevailing wind direction is illustrated by wind roses with the corresponding direction. The approximate location of the villages is illustrated. SIP: Sohar Industrial port; SIE: Sohar Industrial Estate. Villages are only located north to SIE

function in the model potentially controlled for other time-varying confounders.

Risk ratios (RR) for the different exposure zones were calculated as [$\exp^{(\beta 1)}$] and the 95 % confidence interval (CI) levels were calculated using the formula: $\exp^{(\beta 1 \pm 1.96 \text{ X SE})}$.

All statistical analyses were conducted using R software version 3.1.2. Modeling was carried out using the *GAM* function (*mgcv and MASS*).

Because of the similarities of the RR between the high and intermediate exposure zones, we carried out further analysis combining these two exposure zones. The feasibility of this combination was also suggested by the similar distributions of pollutant dispersion observed by wind roses and dispersion model.

Sensitivity analysis

To ensure that our models were capturing exposure effects, we carried out additional analyses for follow-up visits of ARD, asthma, all musculoskeletal diseases (MS), and gastrointestinal diseases (GID). The latter two diseases are not evidenced to be affected by air pollution. Monthly follow-up visits of MS and GID were modeled using the same model structure as for other disease definitions, but with the total exposure zone population as an offset due to lack of age and gender-specific information for these groups.

We assessed for effect modification by gender, and categories of age and indices of SES. Models were stratified by gender, and age in two categories: ≥20–49 and ≥50 years old. Indices of SES were available for all the villages in the study. We used the percentages of the population with 'no education', 'high education' and 'employment' in each village to determine SES. The 'high education' percentage was defined as the proportion of individuals in each village that had received a bachelor degree and above. Two levels of SES were then defined by stratifying the 'no education', 'high education' and 'employment' proportion distributions across all villages into two equal strata: ≤, and >50 %.

Results

During the study period, the total number of visits for the selected diseases was 74,047. The total population-at-risk was 27,688 (Table 1). Table 1 also shows the greater number of males in the population of age

Table 1 Descriptive characteristics of the studied population including the total population-at-risk in the exposure zones and the total number of monthly events, classified by age group and gender

Study population	Age Category	Gender	Exposure Zone		
			High	Intermediate	Control
Total population at risk (%)[a]	≥20–49 years	F	3239 (26.7)	3159 (35.2)	2076 (31.5)
		M	7607 (62.7)	4498 (50.2)	3233 (49.0)
	≥50 years	F	576 (4.7)	598 (6.7)	616 (9.3)
		M	705 (5.8)	712 (7.9)	669 (10.1)
Socio-economic indicators[b]	Mean 'no education'% (SD)		66.8 (21.3)	52.9 (4.5)	47.6 (9.7)
	Mean 'high education[c] '% (SD)		1.7 (2.3)	3.8 (2.4)	10.4 (13.7)
	Mean 'employment'% (SD)		83.4 (10.2)	76.4 (3.1)	67.7 (11.3)
ARD[d] monthly visits (%)	≥20–49 years	F	11,814 (42.9)	8892 (40.5)	3595 (39.3)
		M	9980 (36.3)	9116 (41.5)	3354 (36.7)
	≥50 years	F	2830 (10.3)	1802 (8.2)	1160 (12.7)
		M	2889 (10.5)	2146 (9.8)	1035 (11.3)
Conjunctivitis monthly visits (%)	≥20–49 years	F	869 (30.5)	840 (32.7)	275 (31.8)
		M	981 (34.5)	974 (37.9)	256 (29.6)
	≥50 years	F	415 (14.6)	314 (12.2)	155 (17.9)
		M	581 (20.4)	439 (17.1)	179 (20.7)
Dermatitis monthly visits (%)	≥20–49 years	F	1105 (39.0)	665 (31.0)	404 (41.5)
		M	963 (34.0)	965 (45.0)	260 (26.7)
	≥50 years	F	333 (11.8)	196 (9.1)	118 (12.1)
		M	433 (15.3)	320 (14.9)	191 (19.6)
Asthma monthly visits (%)	≥20–49 years	F	461 (33.9)	502 (35.2)	106 (25.4)
		M	246 (18.1)	271 (19.0)	122 (29.3)
	≥50 years	F	223 (16.4)	216 (15.1)	98 (23.5)
		M	430 (31.6)	437 (30.6)	91 (21.8)

[a]Percentage to the total counts in the exposure zone. [b]Showing the mean percentage of SES category for the villages of each exposure zone with the standard deviation. [c]High education: individuals with bachelor degree and above. [d]Acute respiratory Diseases

groups ≥20–49 years old. This was more evident in the high exposure zone. However, for each exposure zone, the proportion of the event counts for males and females were comparable. A noticeable small percentage of event counts occurred in the ≥50 year old group in all exposure zones, except for asthma.

Figure 2 shows the monthly event counts of ARD, asthma, conjunctivitis, and dermatitis with clear seasonal variability. For ARD, more monthly event counts were noted in autumn and winter, whereas for dermatitis and conjunctivitis these events were higher in spring and summer.

In Table 2, associations for all disease events and exposure definitions are presented. The results show around two folds greater effects for all diseases in the high and intermediate exposure zones when compared to the control exposure zone. This similarity in the trend suggested the feasibility of combining the two zones into one exposure zone of ≤10 km radius from the refinery.

Table 3 shows the RR in the combined exposure zone when compared to the control zone, overall and stratified by gender and age groups. Positive associations were found for all selected diseases in the combined exposure zone. Stratifying the data by age category showed around 30 % change in the effects amongst ages ≥50 years, compared to the ≥20–49 years old age group for ARD and asthma. We found no differences in the effects by gender.

Table 4 shows the results of exposure-ARD visits associations by categories of SES indices. A 30 % greater effect was observed for villages with lower proportions of 'high education' and 'employment'.

Results of the model analyses for associations of the monthly follow-ups for ARD, asthma, MS and GID are given in Table 5. Excess risk was observed for follow-up frequencies in the combined exposure zones when compared to the control zone for ARD and asthma. These effects were comparable to the associations for 'new events'. We did not observe any association between exposure and MS and GID follow-up counts.

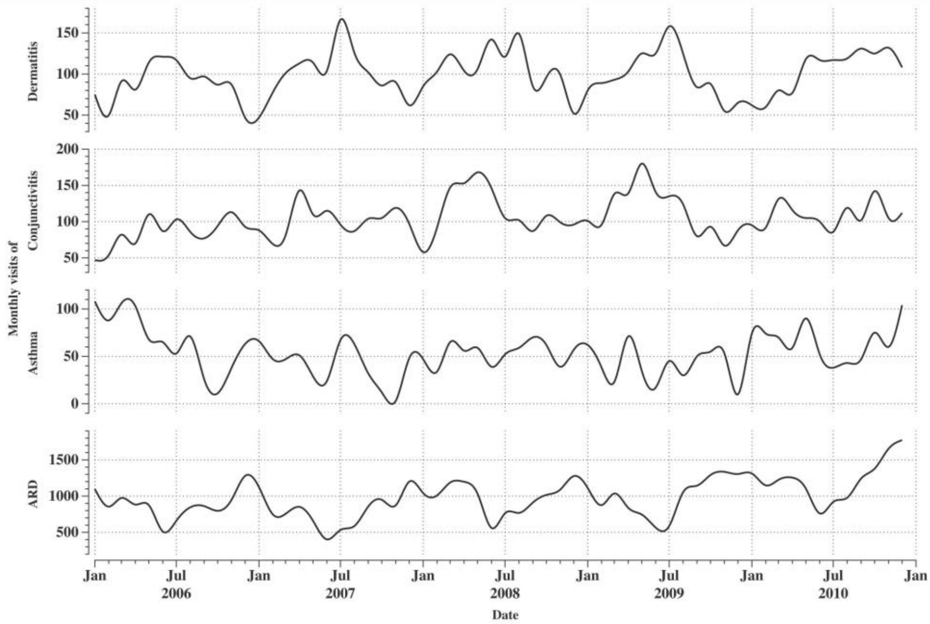

Fig. 2 Monthly event counts of acute respiratory diseases, asthma, conjunctivitis and dermatitis*. *Monthly events for each selected cause were summed for all exposure zones and plotted against the date of visit

Discussion

This study was carried out to examine the acute health impacts in adults living near a major industrial park in Oman. After adjusting for age, gender, time trend and smoking prevalence, findings suggested that living closer to the industrial park increased the risk of health care visits from acute respiratory tract diseases, asthma, conjunctivitis and dermatitis two to three folds when compared to the control zone. The use of non-parametric time-series models allowed for the adjustment of temporal changes such as seasonal, long, and short-term variations of events in the classified area.

Table 2 Multivariate Analysis[a] of acute respiratory diseases, asthma, conjunctivitis and dermatitis incidence[b]. Comparison between the high and intermediate exposure groups

Studied disease	High Exposure Zone RR (95 % CI)	Intermediate Exposure Zone RR (95 % CI)
ARD	2.30 (2.11–2.52)	1.83 (1.67–2.00)
Asthma	3.46 (2.80–4.29)	3.76 (3.04–4.66)
Conjunctivitis	2.92 (2.52–3.38)	2.50 (2.15–2.89)
Dermatitis	2.27 (1.97–2.62)	1.75 (1.52–2.03)

[a]Adjusted for time trend and smoking prevalence
[b]Age and gender standardized according to census population figures for 2010
RR, risk ratio; *CI*, confidence interval; *ARD*, acute respiratory diseases

In our study, we did not have any air quality data for the study area or any information on the actual emissions of the industries that would enable us to construct full dispersion models. This led us to use the proximity to source method to classify exposure for the population living around SIZ. The proximity approach has been utilized frequently in many influential epidemiological and public health studies, particularly in the assessment of health effects around petrochemical industrial complexes [10, 11] and heavy metal smelters [32, 39]. In addition, the approach has been used by governmental environmental protection bodies in their policies, such as the US EPA [31] and the United Kingdom's Health and Safety Executive [40]. Because this method is easy, quick and economic, it is used frequently to assess health effects from industrial chemical spillages [41] and environmental justice studies [42].

The combination of the two exposure zones into one zone of ≤10 km suggested the widespread health effects

Table 3 Multivariate Analysis[a] of acute respiratory diseases, asthma, conjunctivitis and dermatitis incidence[b]. Results are also stratified by age category and gender

Stratification	Combined[c] RR (95 % CI)
ARD	
Overall	2.01 (1.87–2.17)
Males	1.86 (1.70–2.05)
Females	2.02 (1.84–2.21)
≥20–49 years	1.75 (1.61–1.90)
≥50 years	2.27 (2.07–2.49)
Asthma	
Overall	3.60 (2.95–4.40)
Males	2.47 (2.01–3.04)
Females	2.85 (2.34–3.46)
≥20–49 years	1.93 (1.58–2.35)
≥50 years	3.73 (3.01–4.63)
Conjunctivitis	
Overall	2.82 (2.46–3.23)
Males	2.49 (2.17–2.87)
Females	2.37 (2.05–2.73)
≥20–49 years	2.22 (1.95–2.52)
≥50 years	2.73 (2.34–3.18)
Dermatitis	
Overall	2.09 (1.84–2.38)
Males	2.06 (1.78–2.39)
Females	1.79 (1.55–2.08)
≥20–49 years	1.78 (1.55–2.04)
≥50 years	2.18 (1.85–2.56)

[a]Adjusted for time trend and smoking prevalence
[b]Age and gender standardized according to census population figures for 2010
[c]Including high and intermediate exposure zones, control exposure zone as reference
RR risk ratio; CI confidence interval; ARD acute respiratory diseases

Table 4 Multivariate Analysis[a] of acute respiratory disease[b]. Classification by three SES parameters

SES classification	RR[c] (95 % CI)
≤50 % 'no education' strata	1.90 (1.80–2.01)
>50 % 'no education' strata	2.11 (1.95–2.28)
≤50 % 'high education' strata	2.21 (2.06–2.38)
>50 % 'high education' strata	1.73 (1.63–1.84)
≤50 % 'employment' strata	2.33 (2.20–2.48)
>50 % 'employment' strata	1.62 (1.51–1.73)

[a]Adjusted for time trend and smoking prevalence
[b]Age and gender standardized according to census population figures for 2010
[c]Risk ratio of combined exposure zones in reference to control exposure zone
RR risk ratio; CI confidence interval

Table 5 Multivariate Analysis[a] of acute respiratory diseases, asthma, MS and GID follow-up[b] frequencies[c]

	Combined[d] RR (95 % CI)
ARD	1.74 (1.52–1.98)
Asthma	2.23 (1.92–2.60)
MS	0.94 (0.86–1.02)
GID	0.94 (0.84–1.04)

[a]Adjusted for time trend and smoking prevalence
[b]Follow-ups were defined as any patient's visit to the doctor occurring within the defined period for the 'new event' definition
[c]Crude exposure zone population was used as the model offset according to census population figures for 2010
[d]Including high and intermediate exposure zones, control exposure zone as reference
RR, risk ratio; *CI*, confidence interval; *ARD*, acute respiratory diseases; *MS*, All musculoskeletal diseases; *GID*, Gastrointestinal diseases

of the industrial park. This extent of health effects is possibly due to the unfavorable geography of the area, also noted in a recent meteorological study by Al-Khadouri et al. [43]. The authors showed that the air quality in SIZ is prone to stagnation and recirculation, with no single episode of ventilation. These characteristics facilitate a stagnant pollutant mass in the area that was shown, by numerical simulation, to reach >10 km inland.

Supporting our study results, epidemiological studies have shown that living near a petrochemical complex is associated with around two folds increase in acute irritant symptoms of the respiratory tract and eye, and asthma [44–46]. A study in China showed that persistent toxic substances from these industries have doubled the risk of developing dermatitis in people living in proximity [47]. According to a Brazilian study, living near aluminium smelters has been associated with four folds increase respiratory disease admissions [48], whereas a Canadian study showed that living near iron smelters has been associated with acutely declining lung functions [49].

Petrochemical industrial complexes, like in SIZ, are sources of SO_2, NO_x and VOC [7]. These gases are shown to cause acute irritant effects of the lining of the respiratory tracts eyes and the skin [50]. The aluminum smelter potentially emits many hazardous chemicals to the atmosphere such as aluminum compounds, SO_2 and fluoride compounds; iron smelters emit SO_2, NO_x and heavy metals [7].

In our study, living within proximity of exposure source showed a greater risk of ARD and asthma amongst the ≥50 years old age group, and this finding may suggest increased vulnerability amongst the older age group [51]. The gender stratified exposure-disease associations, specifically for asthma and conjunctivitis, did not correspond to the overall RR. One explanation is the unequal distribution of smoking prevalence amongst these two groups in Oman [15, 16]. The effect of the unequal smoking prevalence between the gender groups was also verified after performing another modeling excluding the smoking prevalence which showed corresponding gender stratified exposure-disease associations with the overall RR (Additional file 2).

Some suggestion of unequal effects by SES group was observed, with disadvantaged showing greater effects of living in proximity to exposure source for events of ARD and asthma. This is potentially due to other unfavorable circumstances associated with disadvantaged SES such as general health habits (smoking and alcohol drinking), occupational and other environmental factors including disadvantaged air quality due to living near industrial sources [52].

To ensure that we were adequately capturing exposure effects, we compared the follow-up frequencies of the ARD, asthma, MS and GID. Unlike the effects in the ARD and asthma, which showed increased risks associated with exposure, the associations for MS and GID suggested no differences in the follow-up frequency between exposure zones. Hence, this confirmed that our exposure assessment approach could differentiate exposure effects.

The results showed that the number of young males (≥20–49 year old) was greater compared to the young females. This disproportionate gender distribution in the area was also observed for the entire Omani population pyramid, using census 2010. This phenomenon could be explained by the high number of working male expatriates in this age group as evident by the Omani population pyramid, also supported by higher relative proportions of young males in exposure zones compared to control zone.

Few limitations of this study need discussion. First, the use of a proximity method for exposure classification is subject to misclassification bias. This bias arises when there is uncertainty in the outline of the limit of exposure zones, as pollutants do not respect boundaries [53]. Therefore, villages within each exposure zone may experience heterogeneity in exposure levels. However, in our exposure classification, we used previous evidence from epidemiological and policy studies [10, 11] which supported the incremental distance used here. Additionally, analyses of wind roses and dispersion model confirmed the validity of the selected distances and have contributed to minimize this bias. Second, morbidity data likely have a less complete representation of the disease in a specific area, unlike the self-defining mortality data. This is because morbidity data rely on patient's threshold to seek medical help from the primary health care centers; this threshold is determined by the patient, his family, and the surrounding society's perception and attitude to the disease, and accessibility to health institutions [54]. While more perceptive factors could not be factored in this study, the uniform distribution of the health institutions in the area ensured an easy access to health care providers for the population under study. Third, only the state-related and not the private health institutions were considered in this study, which might introduce a selection bias. However, the low number of private clinics in the exposure zones, after excluding Sohar city from the analyses, minimized the occurrence of this bias. Last, morbidity data can be affected by the method used to distinguish between the new cases from the follow-ups. The definitions used in our study were determined based on previously tested comprehensive clinical and epidemiological definitions.

Our study is the first environmental epidemiologic study carried out in Oman, which investigates the health impacts of the country's rapid industrial development. Our findings suggest that the inevitable economic growth and rapid industrial development of Oman could, potentially, have adverse population health effects. This would signify the need for a more sustainable development in the country by implementing a powerful environmental health system to balance this rapid development. The necessity for an environmentally and socially sustainable development is being recognised in many rapidly developing economies around the world. For example, China has suffered tremendously from air pollution with an estimated 2.3 billion dollars annual loss due to morbidities and mortalities related to air pollution [55]. This triggered the Chinese government to implement more policies regarding environmental health. In 2004, the WHO has estimated that the burden of environmental diseases in Oman was about 17 % of the total burden of diseases [56]; this estimate will likely increase in relation to prospective planned industrial developments and urbanization trends in the country. Hence, it is essential that future policies should consider improvements of public and environmental health system and tracking, along with industrial development.

Conclusion

This study suggested an increase in adverse acute health effects in an adult population living near the newly developed Sohar industrial zone. As this is the first environmental epidemiologic study carried out in Oman, we hope that these findings will contribute to increasing awareness and further research on environmental health issues. These findings will hopefully encourage the initiation of preventive actions and public health intervention programs in the country.

Availability of supporting data

Health data are available from the Omani Ministry of Health only after Institutional Data Access/Ethics Committee for researchers who meet the criteria for access to confidential data.

Additional files

Additional file 1: Examples of international housing policies for the minimum acceptable distance from industry to residential areas.

Additional file 2: A table of Multivariate Analysis of asthma and conjunctivitis incidence adjusted for time trend but not for smoking prevalence.

Abbreviations

ARD: Acute respiratory disease; CALPUFF: California Puff; CI: Confidence interval; GAM: Generalized additive model; GID: Gastrointestinal diseases; ICD-10 code: International Classification of Diseases 10th Revision; MoH: Ministry of Health; MM5: Meteorologic Mesoscale Model; MS: All musculoskeletal diseases; NB: negative binomial distribution; NO_x: nitric oxides; RR: Risk ratios; SES: Socio-economic status; SIE: Sohar Industrial Estate; SIP: Sohar Industrial Port; SO_2: Sulphur dioxide; SIZ: Sohar Industrial Zone; US EPA: United States Environmental Protection Agency; WHO: World Health Organisation..

Competing interests

The author(s) declare that they have no competing interests.

Authors' contributions

Al-Wahaibi, A: carried out literature review, data collection, design methodology, analysis and paper drafting. Zeka, A: supervised and made substantial contributions to the design of the study, analysis, drafting the paper and revising it critically. All authors read and approved the final manuscript.

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