Making Visible the Invisible

Health risks from environmental exposures among socially deprived populations in Nairobi, Kenya

Thaddaeus Wandera Egondi

Department of Public Health and Clinical Medicine
Epidemiology and Global Health
Umeå University, Sweden 2015

Responsible publisher under swedish law: the Dean of the Medical Faculty

ISBN: 978-91-7601-306-9
ISSN: 0346-6612
Electronic version available at http://umu.diva-portal.org/
Tryck/Printed by: Print and Media
Umeå, Sweden 2015

I dedicate this dissertation work to my parents

"If it's invisible, I can't remember if it's there or not. And not only that, but I can't even remember what it is." ~ Jarod Kintz

Table of Contents

Abstract

Background Most countries of sub-Saharan Africa (SSA) are experiencing a high rate of urbanization accompanied with unplanned development resulting into sprawl of slums. The weather patterns and air pollution sources in most urban areas are changing with significant effects on health. Studies have established a link between environmental exposures, such as weather variation and air pollution, and adverse health outcomes. However, little is known about this relationship in urban populations of SSA where more than half the population reside in slums, or slum like conditions. A major reason for this is the lack of systematic collection of data on exposure and health outcomes. High quality prospective data collection and census registers still remain a great challenge. However, within small and spatially defined areas, dynamic cohorts have been established with continuous monitoring of health outcomes. Collection of environmental exposure data can complement cohort studies to investigate health effects in relation to environmental exposures. The objective of this research was to study the health effects of selected environmental exposure among the urban poor population in Nairobi, Kenya.

Methods We used the platform of the Nairobi Urban Health and Demographic Surveillance System (NUHDSS), including two nested research studies, to provide data on mortality and morbidity. The NUHDSS was established in two areas of Nairobi, Korogocho and Viwandani, in 2003 and provides a unique opportunity for access to longitudinal population data. In addition, we conducted real-time measurements of particulate matter ($PM_{2.5}$) in the areas from February to October in 2013. We obtained meteorological meausrements from the Moi Air Base and Nairobi airport weather stations for the study period. We also conducted a cross-sectional survey to establish the communities' perceptions about air pollution and its related health risks. Time series regression models with a distributed lag approach were used to model the relationship between weather and mortality. A semi-ecological study with group level exposure assignment to individuals was used to assess the relationship between child health (morbidity and mortality) and the extent of $PM_{2.5}$ exposure.

Results There was a significant association between daily mean temperature and all-cause mortality with minimum mortality temperature (MMT) in the range of 18 to 20 °C. Both mortality risk and years of life lost analysis showed risk increases in relation to cold temperatures, with pronounced effect among children under-five. Overall, mortality risks were found to be high during cold periods of the year, rising with lower temperature from MMT to about 40% in the 0–4 age group, and by about

20% among all ages. The results from air pollution assessment showed high levels of $PM_{2.5}$ concentration exceeding World Health Organization (WHO) guideline limits in the two study areas. The air pollution concentration showed similar seasonal and diurnal variation in the two slums. The majority of community residents reported to be exposed to air pollution at work, with 66% reporting to be exposed to different sources of air pollution. Despite the observed high level of exposure, residents had poor perception of air pollution levels and associated health risks. Children in the high-pollution areas ($PM_{2.5} \geq 25$ µg/m3) were at significantly higher risk for morbidity (OR = 1.30, 95% CI: 1.13-1.48) and cough as the only form of morbidity (OR = 1.33, 95% CI: 1.15-1.53) compared to those in low-pollution areas. In addition, exposure to high levels of pollution was associated with high child mortality from all-causes (IRR=1.15, 95% CI: 1.03-1.28), and indicated a positive association to respiratory related mortality (IRR=1.10, 95% CI: 0.91-1.33).

Conclusion The study findings extend our knowledge on health impacts related to environmental exposure by providing novel evidence on the risks in disadvantaged urban populations in Africa. More specifically, the study illustrates the invisible health burden that the urban poor population are facing in relation to weather and air pollution exposures. The effect of cold on population is preventable. This is manifested by the effective adaptation to cold conditions in high-latitude Nordic countries by housing standards and clothing, as well as a well functioning health system. Further, awareness and knowledge of consequenes, and reductions in exposure to air pollution, are necessary to improve public health in the slum areas. In conclusion, adverse health impacts caused by environmental stressors are critical to assess further in disadvantaged populations, and should be followed by development of mitigation measures leading to improved health and well being in SSA.

Abbreviations

APHEA	Air Pollution and Health: A European Approach
ARI	Acute Respiratory Infection
CI	Confidence Interval
COPD	Chronic Obstructive Pulmonary Disease
DALYs	Disability-Adjusted Life Years
DLNM	Distribued Lag Non-linear Models
DPSEEA	Driving Forces-Pressures-States-Exposures-Effects-Actions
DPSIR	Driving Forces-Pressures-States-Impacts -Responses
GAM	Generalized Additive Models
GBD	Global Burden of Diseases
GLM	Generalized Linear Models
ICD	International Classification of Diseases
INDEPTH	International Network for Demographic Evaluation of Populations and their Health
IRR	Incidence Risk Ratio
IVP	INDEPTH Vaccination Project
JKIA	Jomo Kenyatta International Airport
LMIC	Low-and-Middle Income Countries
MAB	Moi Airforce Base
MCH	Maternal and Child Health
MEME	Multiple-Exposures-Multiple-Effects
MMT	Minimum Mortality Temperature
NOAA	National Oceanic and Atmospheric Administration
NUHDSS	Nairobi Urban Health Demographic Surveillance System
OR	Odds Ratio
PM	Particulate Matter
SD	Standard Deviation
SSA	Sub-Saharan Africa
UCL	Upper Confidence Limit
UNEP	United Nations Environmental Program
UN-HABITAT	United Nations Human Settlements Programme
VA	Verbal Autopsy
WHO	World Health Organization
YLL	Years of Life Lost

Contributing Papers

This thesis is based on the papers I-V. The published papers I, II and V were published in open access journals so no permission was required to reprint.

I. Egondi, T., Kyobutungi, C., Kovats, S., Muindi, K., Ettarh, R., & Rocklöv, J. (2012). Time-series analysis of weather and mortality patterns in Nairobi's informal settlements. Global Health Action, 5.

II. Egondi, T., Kyobutungi, C., & Rocklöv, J. (2015). Temperature Variation and Heat Wave and Cold Spell Impacts on Years of Life Lost Among the Urban Poor Population of Nairobi, Kenya. International Journal of Environmental Research and Public Health, 12(3), 2735-2748.

III. Egondi, T., Muindi, K., Kyobutungi, C., Gatari, M., Rocklöv, J. (Submitted). Measuring exposure levels of inhalable airborne particles ($PM_{2.5}$) in two socially deprived areas of Nairobi, Kenya.

IV. Egondi, T., Ettarh, R., Kyobutungi, C., Rocklöv, J. (Submitted). Child morbidity and mortality associated with exposure to inhalable particles ($PM_{2.5}$) among the urban poor in Nairobi, Kenya.

V. Egondi, T., Kyobutungi, C., Ng, N., Muindi, K., Oti, S., van de Vijver, S., Ettarh, R., Rocklöv, J. (2013). Community Perceptions of Air Pollution and Related Health Risks in Nairobi Slums. International Journal of Environmental Research and Public Health, 10, 4851-4868.

Introduction

This research investigates the effects of exposure to temperature variation and air pollution on health among urban poor populations. Initially, the introduction section provides the background on the situation that give rise to the vulnerability of the urban population to environmental exposure. Next, the section reviews the existing evidence on the effects of exposure to temperature and air pollution on human health. A description of the mechanisms by which temperature and air pollution exposures affect health follows. The section extends by providing a description of the framework used to guide the interpretation and reporting of environmental exposure and health effects. In addition, populations' perception of environmental exposure and associated risks is introduced. Finally, the section describes the study objectives of the research conducted.

Background

High rates of urbanization are being experienced around the world with more than half of the global population living in urban areas in 2014 [1]. By 2050, the world's urban population may exceed 10 billion representing about 66% of the population. Approximately 30-40% of urban dwellers in low- and middle-income countries live in socially deprived slum areas; in Africa this figure is higher, and it is estimated 62% live in slums [2]. Most of the world's population growth is occurring in cities and towns of poor countries [3]. These rapid, unplanned and unsustainable patterns of urban development make developing cities focal points for many emerging environmental and health risks [4]. Most low-and-middle income countries (LMIC) are not presently laying the required foundations to deal with the environmental emerging risks and epidemiological transitions that are being experienced in urban areas. Such neglect is likely to adversely affect the general well-being of billions of people as the urban slum populations remain invisible and/or uncounted [5]. Thus, urban poor populations in LMIC face multiple health burdens, which continue to be a public health challenge [6].

The changing environmental conditions are likely to influence change in disease patterns particularly in urban areas [7]. It is well recognized that a great burden of respiratory diseases is attributable to air pollution [8]. According to World Health Organization (WHO), 7 million people died in 2012 as a result of air pollution exposure, which doubles previous estimates and confirms air pollution as the world's largest single environmental health risk [9]. The largest health burden is borne by people living in cities in poor regions facing double exposure burden, from traditional and modern sources

[10]. In addition, effective environmental policies are lacking in most of the LMIC to protect the public. The levels of air pollutants are thought to significantly exceed WHO guideline values [11]. However, the reported levels and health burden attributable to air pollution exposure in LMICs is uncertain due to lack of data on both exposure and health outcomes [12].

Environmental conditions related to weather, such as those characterized by heat and cold waves, has been shown to contribute to considerable excess mortality in high-income countries. Particularly, heat waves are a problem in urban areas where there is additional heat, urban heat islands, caused in interactions with the urban environment [13, 14]. Evidence also exists on cold-related mortality with sometimes greater effect observed in warmer regions [15-18]. The excess cold-related mortality can be substancially reduced through personal protective measures against cold and improvement in housing conditions[15, 19]. In recent times, most studies on temperature-related mortality have been conducted in temperate regions, and little is known about this relationship in sub-tropical and tropical LMIC, especially in sub-Saharan Africa (SSA). Furthermore, it is expected that in urban areas, the local weather situation is likely to influence the outdoor air pollution levels, and, potentially, also modifying the health effects of air pollution [20]. Poor housing conditions, a common feature of slum settlements, are likely to be associated with thermal discomfort due to temperature variation. In addition, there are several links between poverty and poor health in general [21, 22].

Kenya, a low-income country, faces rapid urbanization resulting in the development and growth of slums [23]. Kenya's annual slum growth rate is the highest in the world at 5%, and it is expected to double in the next 30 years if no proper interventions are put in place [24]. A third of Kenya's total population lives in urban areas, and of this, more than 71% is confined in slum like areas [25]. Nairobi, Kenyas Capital city, is one of the fast growing cities in SSA [26]. The population of Nairobi has grown over the years from 1.3 in 1990 to about 3.8 million in 2010 [27]. More than half of Nairobi´s population live in informal settlements, commonly refered to as slums, occupying less than 5% of Nairobi's residential area [28]. UN-HABITAT defines slum as an urban area occupied by people with lack of one or more of: durable housing, sufficient living space, easy access to safe water, access to adequate sanitation and security of tenure [29]. At present, very little is known on the role of environmental exposure on the disease burden among the urban population residing in slum like areas. The lack of studies and evidence to raise awareness and propose policies on these matters persists, despite several studies showing evidence of high burden of diseases attributable to ambient environmental exposure [30-34].

According to the Global Burden of Disease Study 2010 (GBD 2010), lower respiratory infections were ranked amongst the highest causes of premature deaths [35]. In addition, Kenya is ranked the highest in terms of burden of disability-adjusted life years (DALYs) in chronic obstructive pulmonary disease (COPD) among similar comparator countries [31]. Similarly, previous studies in Nairobi indicate high prevalence of respiratory illnesses and asthma among children in slums [30], and acute respiratory illness (ARI) as the leading contributor of the mortality burden among under-five children [32]. In addition, a seasonal pattern of pneumonia related to under-five mortality was observed in the same population, and is thought to be associated with exposure to air pollution [36]. A study by the United Nations Environmental Program (UNEP) among children living near the Dandora dumpsite in Nairobi revealed a high incidence of diseases linked to environmental pollution [34]. As with other developing countries in Africa, Kenya has no air quality management and lacks data on air pollution, despite having the fastest growing urban population [37]. A few short-term studies on air pollution in Nairobi have shown that the levels of pollutants in most parts of Nairobi City, especially particulate matter, are above the 24-hour WHO limit of 25 mg/m^3 [26, 37, 38]. However, none of these were conducted in slum like residential areas, and only one study established the health association to the observed level of pollution [34].

In an effort to reduce air pollution, most air quality management bodies have focused on the emissions-based control programs [39]. Although regulations targeting emissions have led to a decrease in levels of pollution, inclusion of interventions targeting individuals, reducing exposure regardless of environmental stressors, will greatly mitigate health impacts from environmental exposure [39-42]. A new framework that incorporates strategies at regulatory, community, and individual levels to reduce emission, exposure and health impacts of air pollution has been suggested [39]. However, strategies targeting either the community or individual level require knowledge of the perceptions of exposure, and knowledge of associated risk in the target group. Therefore, understanding the people's perception and knowledge is crucial in activities aimed at promoting ill health from air pollution. Research on environmental risk assessment has established a relationship between exposure and health risk. However, little attention has been given to understanding community perceptions of environmental risk particularly in SSA. Consequently, governments are grappling with how to empower citizens to promote action and local participation to interventions [43]. Whereas it is commonly accepted that dangers and hazards do exist, the public does not necessarily view them equally. However, the public's concerns about risks cannot necessarily be attributed to ignorance or irrationality. It has been maintained that risk has generally been discussed through a "paradigm of rational choice" and to consider risk assessment independent of culture is incomplete [44]. Research has also shown that much of the public's reactions to risk can be attributed to how they respond to hazards in terms of technical, social, and perception elements that are not normally well addressed in risk assessments [45]. There is relatively little research on the general public's perceptions of specific environmental factors related to health [46, 47].

Epidemiology of temperature and air pollution

Associations between temperature and mortality has been established [17], and particularly the influence of thermal stress on health has been proven [48]. Although many climate and weather variables such as humidity and rainfall influence human performance and health [49, 50], the combined effect of different weather variables on mortality is less widely examined [51]. Hence, no clear evidence exists that these variables have an independent effect apart from temperature [52-56]. Generally, most epidemiological studies have shown temperature-mortality relationship to be either J or U-shaped indicating increased risks in cold and hot weather [57, 58]. Studies have also demonstrated that the effects of extreme temperatures may last for days or weeks, especially for cold weather where the effects can be delayed by several weeks [59, 60]. Extended periods of extreme temperatures have also been investigated and found to be associated with peaks in mortality [61, 62]. It has also been documented that respiratory health is largely affected not only by air pollution but also by weather conditions [16, 63-66]. Evidence of temperature-mortality relationship exist for sub-tropical countries that experience moderate temperature variations [67, 68]. In addition, there is evidence of adaptation to usual temperatures [53, 69, 70], and as a result, cold and heat effects have different thresholds for the onset of risk for different regions. Despite the existence of the evidence in various parts of the world, little is known in SSA countries.

Significant association between air pollution and adverse health outcomes including increased mortality has been clearly established [71, 72]. Respiratory diseases that are known to be highly attributable to air pollution are on the rise worldwide and the trend has been observed in both high and low income countries [73, 74]. High frequency of respiratory disease has been reported more in urbanized areas [75], and outdoor air pollution is one possible explanation for the observed trends [76]. Very few studies in developing countries, particularly in Africa, have assessed the association between urban air pollution and health outcomes. Lack of consistent air monitoring data and health outcome data is the common hindrance to studies in developing countries [77].

An interaction between air pollution and temperature has been suggested by a number of time-series and case-crossover studies [78-80]. The multicentre APHEA study demonstrated evidence of effect-modification, not only by season, but also according to typical temperature of the area [81]. Potential interaction between air pollution and temperature has been studied by several studies and found consistent evidence of synergy between the two exposures [82-88]. A positive interaction was also found between cold temperatures, and air pollution concentration, on respiratory mortality [89, 90]. The type of pollutant was found to influence the observed temperature-air pollution interaction, indicating that the underlying mechanisms are dependent on local conditions [7]. Similarly, two multicentre studies suggested that the synergistic effect might vary across regions according to climate, human activities and physical adaptation of an area [82, 91]. The next section discusses the different mechanisms of temperature and air pollution on human health, and the possible actions needed to reduce the impacts.

Mechanisms of temperature and air pollution effects on health

Exposure to temperature variation and air pollution may affect human health in different ways. However, the respiratory system is a main target of particulate matter present in the air. Still the underlying mechanisms are different for the different pollutants [7]. Air pollution has both acute and chronic effects on human health ranging from minor irritation of eyes and the upper respiratory system to chronic respiratory disease, heart disease, lung cancer, and death [92]. Air pollution has been shown to cause both acute respiratory infections and chronic bronchitis. It also worsens the condition of people with pre-existing chronic illness [93]. Both short-term and long-term exposures have been linked with premature mortality and reduced life expectancy [94]. In addition, the type of pollutant, its concentration, duration of exposure, presence of other pollutants and individual susceptibility influence the health impact of air pollution [95]. Causal biological mechanisms about effects of air pollution on mortality are not fully understood. Air pollution has been linked with compromised pulmonary immune defense mechanisms in both animals and humans. The effects of acute air pollution exposure on mortality occur primarily among people more susceptible to adverse effects, due to pre-existing poor health [95]. The environmental pathways, from source to health effects, from air pollution provides understanding where action can be taken to reduce the impact on health [96, 97].

On the other hand, cold weather is associated with a variety of involuntary responses in humans, including: contraction of skin blood vessels, shivering, and increases in blood pressure and heart rate. Therefore, exposure to cold may cause a decrease in blood flow among patients with heart problems leading to coronary spasm, chest pain, and even myocardial infarction [98-100]. The cold weather also interferes with lung mechanisms, and sufficient evidence exist that exposure to cold is a risk factor for pneumonia in all ages [101]. Cold air causes serious damage on ciliary motility, and, consequently, reduce the immune system's resistance to respiratory infections [102, 103]. Exposure to cold air may also increase the number of granulocytes and macrophages in the lower airways in healthy subjects [104], and induce bronchoconstriction [105, 106], which suggests that cold exposure could be involved in the pathogenesis of asthma-like conditions. The indirect effect of cold weather is with corresponding increased exposure to air pollution causing both higher indoor and outdoor air pollution levels.

On the contrary, exposure to heat has been found to induce physiologic changes such as an increase in blood viscosity and cardiac output leading to electrolyte imbalance, dehydration, hypotension and fatigue [107, 108]. In fact, exposure to extreme temperatures in general (both cold and heat) can act as a trigger for cardiovascular events due to changes in blood pressure, viscosity, cholesterol, and heart rate [109-111]. The health effects from exposure to heat are mainly in patients affected by chronic illnesses. In these patients, it is thought that responses to heat stress, particularly, those involving the respiratory system, may fail to release excess heat, and, thus, increase the risk of developing health conditions related to heat stress. However, this postulate is still not fully supported by the existing evidence [112]. A different pathway linking heat exposure to respiratory health outcomes involves the clinical course of heat-related illnesses. Acute lung inflammation and damage might occur [113], and heat may trigger a series of physiological changes in the lung leading to a severe respiratory distress syndrome [66, 114].

Environment and health framework

In general, a conceptual framework helps organize the concepts, ideas and notions of actions [115] in order to recognize and interpret complex links between elements of the response [116]. Various frameworks have been developed in the area of environment and health. The different frameworks are: Driving forces-Pressure-State-Impact-Responses (DPSIR), Driving forces-Pressure-State-Exposure-Effect-Action (DPSEEA), and Multiple Exposure Multiple Effects (MEME). Liu et al. [117] provides a detailed review of the four frameworks. The DPSIR focuses mainly on the environment and was designed to develop environmental indicators [118, 119]. The major limitation of this framework is the inability to identify within its route multiple entry points for action due to lack of description of exposure routes. In addition, it portrays the interaction between human activity and environment as unidirectional and linear. The DPSEEA framework was developed on behalf of WHO by Carvalan et al. [120] to support the development of environment and health indicators. Compared to DPSIR, there are advantages associated with DPSEEA. First, it recognizes the links between exposures and health effects [120]. Second, it allows for several entry points in the cause-effect chain. Third, it extends the concept of driving forces to more remote, contextual factors such as social and economic development [115, 121, 122]. Further, it is flexible and can be adapted and modified according to changing requirements and circumstances[118]. This frameworks has been adopted to monitoring health impacts of climate change in Europe [123], as well as developing environment and health indicators to assess, and monitor, human health vulnerability, and measuring the effectiveness of climate change adaptation and mitigation [118]. The framework was developed to link environmental policy and health. However, a limiations is that it assumes a linear flow from exposures and contexts to health [115, 121, 122]. WHO developed a simplified MEME (multiple-exposures multiple-effects) framework to provide a conceptual basis for development, collection and use in the context of children environment and health indicators [115, 124]. The framework is an extension of DPSEEA describing the link bewtween many different environmental settings and many different individual health outcomes. In this framework, both exposures and health effects are influenced by contextual conditions. Actions can be taken at different levels as has been demonstrated in North America [125]. The similarities between MEME and DPSEEA mean that it is relatively simple to switch between them according to the need [118]. We adopted the MEME framework to identify and interpret the link between temperature, air pollution and health. The framework is illustrated in Figure 1.

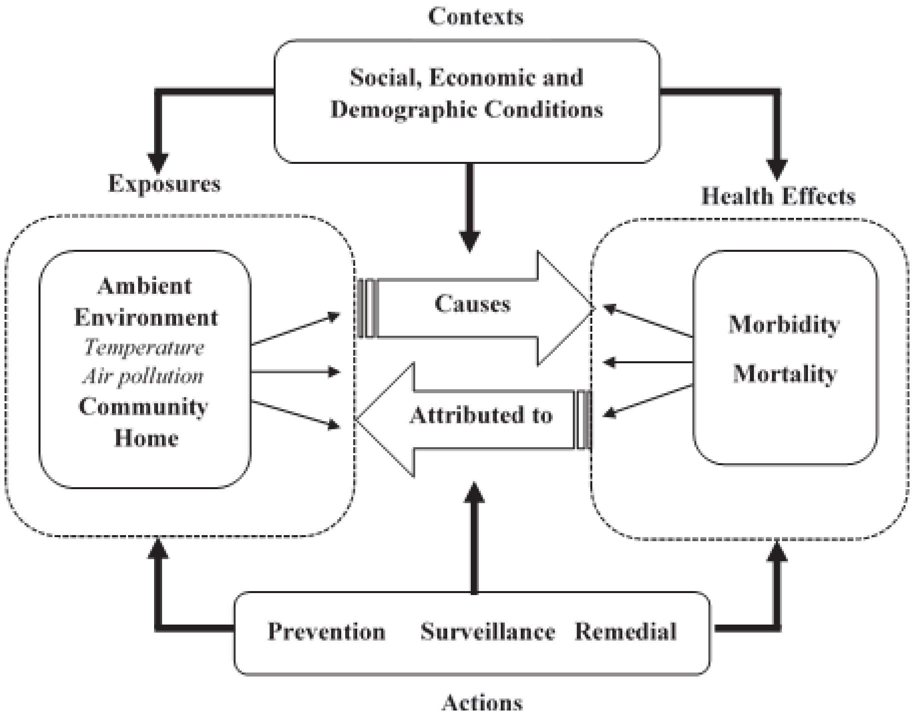


Figure 1: The Multiple Exposure Multiple Effects (MEME) framework for temperature, air pollution and health

Urban slum is the overarching context to different environmental risks because of poverty and proximity to sources of pollution, such as industries and garbage dumpsites. Poor housing condition is an important additional feature of the urban slums determining population health consequences of temperature and air pollution. The small sizes of houses with no ventilation increases the concentration of air pollution, and the housing materials also make the temperature inside more extreme than outside temperature. The model is also useful in highlighting potential exposures, but in this case we only consider temperature and air pollution as environmental exposure in both community and houses. The model highlights the potential health outcomes generated by the associated exposures. It also emphasizes, in addition to preventive and remedial actions, that surveillance is essential in monitoring the progress.

Perception of risk from environmental exposure

We adopted the definition of perception as subjective assessment of exposure level to environmental hazard, and the concern with the consequences of the exposure [126]. Perception is an important component of behaviour change, which plays a major role in public response to environmental exposures [127-129]. Therefore, increasing people's perception and knowledge is a cornerstone in promoting protective behaviour. The role of perception on exposure risk reduction can be explored following a community-based social marketing strategy [130]. The strategy involves addressing two behaviours simultaneously: 1) the behaviour to be encouraged; and 2) the behaviour to be discouraged. Figure 2 illustrates how the strategy could be adopted towards prevention and control of exposure to air pollution and temperature in residential areas.

The essential initial steps to a community-based social marketing strategy goes by identifying the environmental activities to be promoted, and the barriers that impede individuals from taking action. Although, the benefits for pollution prevention are evident, certain barriers, such as a general lack of concern or awareness, can inhibit implementation. Engaging individuals in discussions about pollution prevention, or protection from extreme weather is an important step to positive change. Common barriers can be overcome by availing information, developing partnership, and building support. Understanding public perception and attitude towards exposure rsisk, and regulations or actions, will be critical for successful involvement of citizens [131]. Promoting behaviour change by lowering barrier attitude and increasing motivation among residents leads to the desired social change and taking appropriate response.

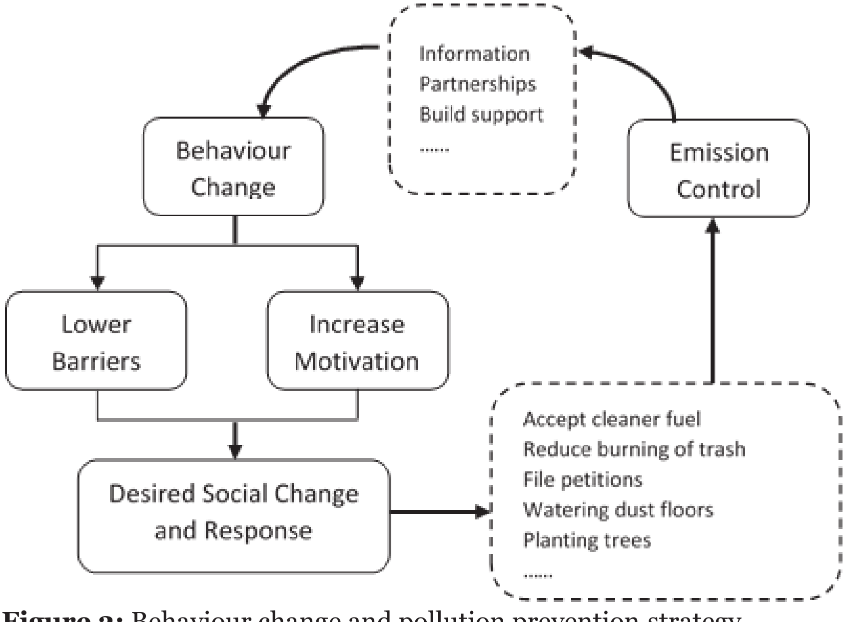


Figure 2: Behaviour change and pollution prevention strategy

Study objectives

There is relatively little research on health effects associated with exposure to temperature and air pollution in Sub-Saharan Africa (SSA), particularly, among socially deprived urban populations. In addition, little evidence exists on the general public perceptions on environmental pollution and related health risks. Understanding peoples' perception is important for actions targeting individuals, or for community participation in solving existing environmental risks. The aim of this research was to investigate health effects from environmental exposure among slum residents in Nairobi, Kenya. The specific study objectives were to:

1) investigate the relationship between daily temperature and all-cause and cause-specific mortality, and years of life lost;
2) establish the daily concentration level and variability of fine particulate matter in two slum areas, and its association to on child health indicators and mortality; and
3) explore community perceptions and knowledge to air pollution exposure and related health risks.

The following chapter provides the description of the methodology and data sources used in this study to address the specified objectives.

Methods and analysis

This section starts with the description of the study location and the population. It follows by detailing the data and their sources for the different study objectives. Subsequently, the different approaches for analysis of the data are described.

Study location and population

The study was conducted in two informal settlements of Korogocho and Viwandani in Nairobi, the capital city of Kenya. Kenya is located in east Africa, bordering the Indian Ocean to the east, Somalia to the northeast, Ethiopia to the north, Sudan to the northwest, Uganda to the west, and Tanzania to the south. Nairobi city is situated slightly south of the center point of the country. The country lies on the equator between latitudes 5°N and 5°S, and longitudes 34°W and 42°E as shown. Kenya has a warm and humid tropical climate on its Indian Ocean coastline, but the climate becomes cooler as you move inland through the wildlife-rich savannah grasslands towards the capital due to the change in altitude. Nairobi city is situated about 1700 meters above sea level and is characterized by a sub-tropical climate. The city has a predominantly a relatively cool climate and experience two rainy seasons in a year. A longer rainy season (March-May), and a shorter rainy season (October-December) [132, 133]. The climate of Nairobi is illustrated in Figure 3.

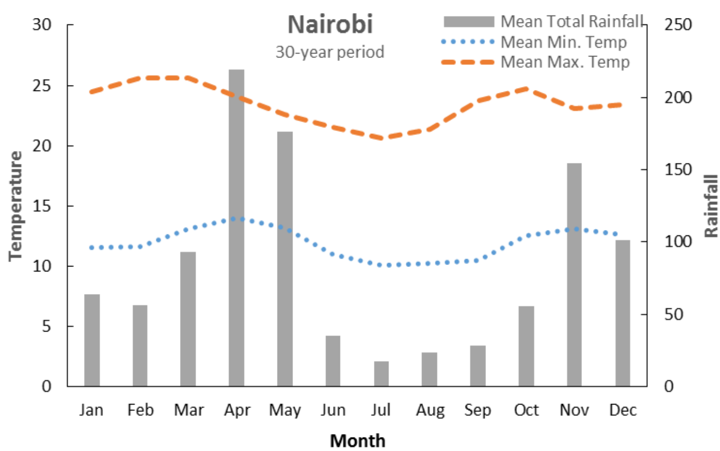
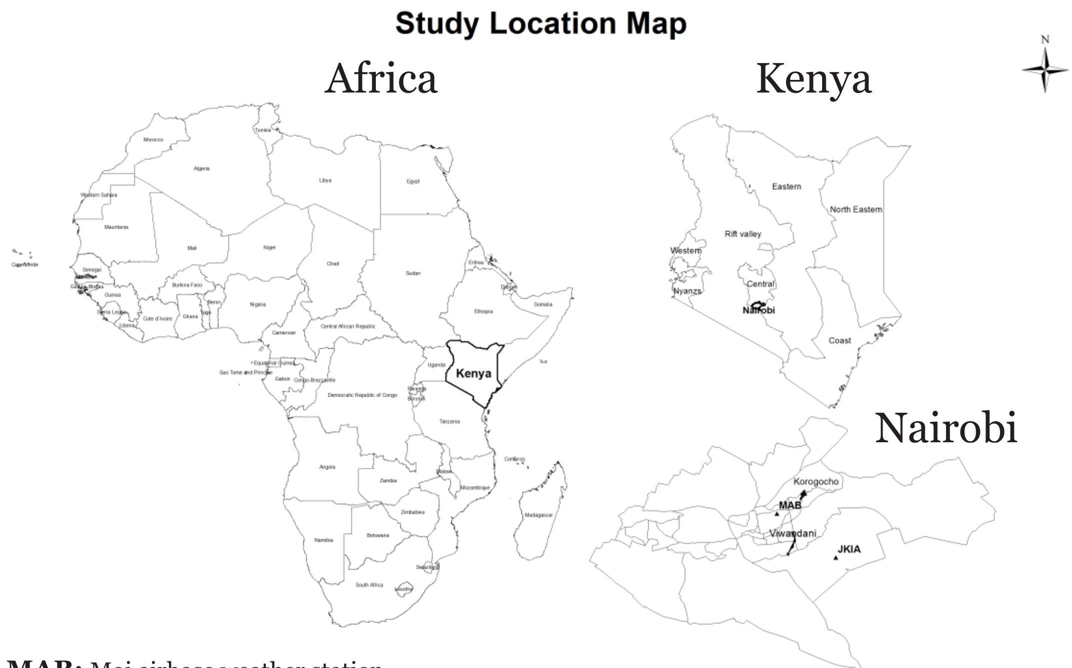


Figure 3: Climatological information for Nairobi city over a 30-year period. (Source: World Meteorological Organization http://worldweather.wmo.int/en/city.html?cityId=251)

The Nairobi Urban Health and Demographic Surveillance System (NUHDSS) covers two study areas, and has been run by the African Population and Health Research Center (APHRC) since 2003. Approximately 60,000 people from about 28,000 households are under surveillance in the open cohort, and are visited three times every year with a four month interval between each visit. The slum areas of Korogocho and Viwandani are located 12 and 7 kilometres from Nairobi City center respectively. Each slum area occupies a land area of about 0.5 km^2. Both are located close to dumpsites. There are industries situated on the North of Viwandani area where a majority of the residents work. A larger proportion of the population in the two study areas work as casual laborers in the informal sector [134]. Overcrowding, poor sanitation, and poor access to basic health care services characterize the two areas and residents are facing a high burden of disease, similar to other slums [32]. Housing structures in Korogocho are mainly made of mud or timber with roofing composed of tin waste, while in Viwandani structures are mainly made of iron sheets. Lack of proper garbage disposal remains a huge challenge in both areas.

Ethical consideration

The ethical approval for the NUHDSS was obtained from Kenya Medical Research Institute (KEMRI). Our study analysed data from NUHDSS without the need for identifying information, and therefore, additional approval was not required for use of NUHDSS data. We obtained ethical approval for collecting air pollution measurements, and for performing the community perceptions study from African Medical Research Foundation (Amref) ethical and scientific research committee.



MAB: Moi airbase weather station
JKIA: Jomo Kenyatta International Airport weather station

Figure 4: Map illustrating the location of study sites and weather stations.

Data

The NUHDSS provided the platform for health outcome (morbidity and mortality) and individual level demographic information of the study population. Morbidity data were available for under-five children through nested studies on maternal and child health from 2007 to 2013. Demographic events - birth, in-migration, out-migration and deaths - are routinely collected. Cause of death is ascertained through a verbal autopsy procedure. Oti et al. [135] provides a detailed description of the process of verbal autopsy used. Causes of death are classified according to the International Classification of Diseases, 10th Revision (ICD-10) using a modified and shortened code list [136]. The first and second papers of the thesis used mortality data for all ages, while the fifth paper used mortality and morbidity data for under-five children. Years of life lost (YLL) calculations for the second paper were generated using mortality data and life tables for NUHDSS population [137].

Exposure data obtained and collected consist of meteorological (Papers 1 and 2) and air pollution (Papers 3 and 4) data. Weather data were obtained from the Meteorological Department of Kenya for the period of 2003-2008 and additional data up to 2012 were obtained from the National Oceanic and Atmospheric Administration (NOAA) website [138]. The Moi Airbase Eastleigh weather station was the main source of daily meteorological data, and for days with missing data, Jomo Kenyatta International Airport (JKIA) measurements were used. The Moi Airbase Eastleigh weather station is located in between the two study sites (about 4 kilometres from each study area and 9 kilometers from JKIA station) [137, 139]. The location of the two stations in relation to study sites is shown in Figure 4.

Air pollution measurements of fine particulate matter ($PM_{2.5}$) were conducted in the period February-October 2013. Two handheld DustTrak, II Model 8532 samplers were used to record real-time measurements of $PM_{2.5}$ in two study areas. Two research assistants (one in each site) were trained on using of the equipment and conducted all the field measurements. We identified a fixed sampling route, including 15-20 minutes point stopovers. The activities and the number of people in an area informed our choice of the stopover points. The sampling points (stop-overs) of the two study areas are shown in Figure 5.

A cross-sectional study was conducted to collect data on community perceptions and knowledge regarding the air pollution and related health risks through questionnaire interviews. The questionnaire contained sections on: perception of air quality, air pollution-related health effects, annoyance with air pollution, sources of information on air pollution and individual demographic characteristics. Egondi et al. [140], provides a comprehensive description of the measures and the process of generating composite measures. The set of questions on the perceived air pollution and related health risks are summarized in Table 1.

Figure 5: Map of two study areas with air pollution sampling locations

Statistical analysis methodology

Different epidemiological analysis techniques were used for different papers in this thesis to address the study objectives. The main statistical analyses used were; time series analysis approach, regression analysis (linear, logistic and Poisson), and descriptive summary measures specifically for the third paper of air pollution measurements. The below section describes how the methods were used in the different papers.

Analysis of temperature-mortality relationship

The time series approach was applied under the general framework of generalized linear model (GLM) and generalized additive models (GAM). The general model formulation is given by;

$$y_t \sim \exp(\mu_t) \quad and \quad \mu_t = E(y_t)$$

$$g(\mu_t) = \alpha + \sum_{i=1}^{p} s(x_i, df) + s(season, df) + s(trend, df)$$

The formulation assume daily observed values y_t to be of some exponential family and $g(\mu_t)$ is a link function relating mean μ_t to a set of predictors incorporating smooth functions $f(x_i)$ for non-linear predictors. The last two terms in the equation represent short-term seasonal and long-term trend variation in the outcome. The two terms can be combined into a single term with high number of degrees for freedom able to capture both seasonal and long-term trend. Daily mortality count was modelled assuming Quasi-Poisson distribution for allowing overdispersion with a log link function and expected years of life lost was modelled using a Gaussian distribution with identity link. We used time-series data analysis adapting Poisson regression model to estimate the relationship between temperature, rainfall and daily mortality. This approach compares the daily observed and expected outcome based on time trends, so as to analyze the deviations from the expected outcome values related to variation in the exposure variable, in this case temperature.

Delayed effect

The delayed effect of exposure was modelled through distributed lag models framework [141-143]. The main effect of temperature on day i is described by the function *k* of the series of lagged temperatures t_{1-l}, with l=0, 1 … l_k = 21, where 21 as maximum lag considered for this study. The lag formulation can be interpreted in two perspectives: a forward perspective, an exposure event on day *i* determines the risk in the future at days *+l;* a backward perspective, the risk on day *i* is determined by a series of exposures experienced in the past days *i-l*. To allow flexibility, *k* is specified as a two-dimensional spline function, defining a DLNM that allows the main effect to vary smoothly along both dimensions of temperature and lags [141].

Creation of temperature extreme indicators

We used percentiles to define relative thresholds for extreme cold and heat over a period of a consecutive number of days [144]. These definitions describe heat wave and cold spells that are area specific depending on temperature variation and climate regimen [145, 146]. We considered different intensities and duration for cold and heat waves measured by different percentiles and the number of days of sustained temperature extreme respectively [147, 148]. The indicator variables for cold or heat were expressed as:

$$I_C = \begin{cases} 1 \; if \; temperature < \tau_c \\ 0 \; otherwise \end{cases} \quad \text{and} \quad I_H = \begin{cases} 1 \; if \; temperature > \tau_H \\ 0 \; otherwise \end{cases}$$

Where I_C and I_H represent indicators for cold spell and heat wave days, respectively. The percentiles of 90th, 95th and 98th were used for different intensities of heat waves. The cold spell was defined based on 10th, 5th and 2nd percentiles. Cold spell and heat wave were defined as indicators for at least two days of consecutive days with temperatures below, or above, the identified temperature thresholds for cold or heat. A detailed description with an example is provided by Egondi et al. [137].

Analysis of air pollution and child health

The association between air pollution and morbidity was examined using a cohort of under-five children observed during the period of 2012-2013. The analysis was conducted considering three different analyses: prevalence; episode at individual level; and episode at household level. The prevalence analysis, which was conducted using logistic regression at individual level, corrected for standard errors to account for multiple observations per child. Poisson regression was used for episode analysis to morbidity counts at individual and household levels. The morbidity was analysed separately for cough only, and for cough, fever and convulsion combined.

We examined the association of exposure to air pollution and mortality among under-five children for the period 2003-2013. However, we used exposure data collected in 2013 with assumption that sources and activities for air pollution in two study areas were stable. Poisson regression was used compare the incidence (mortality) risk ratio (IRR) for all-cause and respiratory related mortality adjusting for household wealth index, sex and age of the child. Mortality analysis related to the exposure level was conducted for all-cause and respiratory related mortality. The mortality was collapsed by aggregating deaths and person-years of observation by sex, age group and wealth index.

Analysis of community perception of air pollution

The composite perceived measures were generated using a Cronbach alpha algorithm implemented in STATA. The approach allows combining questions with different response scales. In our case we had binary as well as five-point ordinal scale responses. The final composite measure is obtained by averaging standardized individual items, and then transformed to a scale of 0 to 100 for ease of interpretation. The high scores represent high-perceived air pollution level or high-perceived health risk. To measure level of annoyance, the respondents were asked to assume that people's level of annoyance due to indoor and outdoor air pollution from any source could be stacked on a ladder or staircases of five steps, with low level (1) representing 'No Annoyance' and high level (5) representing 'Extreme Annoyance'. Then, respondents were asked to place themselves on the ladder that corresponds to their level of annoyance due to outdoor or indoor air pollution. Questions were adopted from studies that used similar scales [149, 150], though we reduced scales from 11-point scales to 5-point scales.

Table 1: List of questions for the composite indices of perceived level of pollution and perceived related health risk

Perceived air pollution	
	How would you rate the quality of air in the community where you live (Viwandani/Korogocho)? Would you say it is (Very Low, Low, High, Very High)
	How would you rate the quality of air in your house? Options (Very Low, Low, High, Very High)
	Which of the following would you say are the sources of outdoor or indoor air pollution within Korogocho/Viwandani (Dust, Vehicle emissions, Industrial emissions, Cooking fuels, Burning trash, Smelly sewage, Cigarette smoking, Other sources)? Options (Yes or No)
	How severe would you say is air pollution in Korogocho/Viwandani from (Dust, Vehicle emissions, Industrial emissions, Cooking fuels, Burning trash, Smelly sewage, Cigarette smoking, Other sources)? Options (None, Low, Moderate, High and Very High)
Perceived health risks	
	How much health risk do you think each of the following is to you and your family (dust, vehicle emissions, industrial emissions, cooking fuels, burning trash, smelly sewage, cigarette smoking, and other sources)? Options (None, Low, Moderate, High and Very High)
	What health problems do you think are brought about by air pollution ('cough/cold, difficulty breathing, eye problems, asthma, cancer, heart problems, headache, other)? Options (Yes/No)

The distribution of study participants' characteristics of the two study sites was compared using descriptive statistics. The perceived measures were summarized in terms of averages by demographic characteristics to assess the distribution of the perception levels across key characteristics. The association of perceived air pollution and related health risks, with different characteristics, were assessed using linear regression analysis. Bivariate analysis was conducted first to determine independent relationship between each characteristic and outcome measure. Then multiple regression analysis was conducted to assess the association of different factors controlling for other potentially confounding factors.

Results

The chapter presents study findings according to the study objectives. The first part of the chapter summarizes the results focusing on the relationship between temperature variation and mortality. The second part of the chapter gives the findings on air pollution exposure levels and the associated health impacts on child health. The last part of the chapter describes the results on community perception of air pollution and associated health risks.

Deaths and Years of Life Lost in NUHDSS

The distribution of deaths and years of life lost (YLL) during the study period 2003-2012 is presented in Table 1. During this period, there were a total of 4,671 deaths recorded with a total YLL of 206,712.3. There were more male deaths compared to females (57% vs 43%), and 32% of deaths occurred below the age of five years. Daily average of YLL was higher for male deaths (32 years) compared to female deaths (25 year).

Table 2: Distribution of deaths and years of life lost in NUHDSS

	Daily average deaths (SD)	Total deaths (%)	Daily average YLL (SD)	Total YLL
Sex/Gender				
Male	0.7 (1.3)	2651 (56.8)	31.9 (56.7)	116 349,4
Female	0.6 (0.9)	2020 (43.2)	24.7 (42.6)	90 362,9
Age group				
0-4 years	0.4 (0.7)	1487 (31.8)	25.6 (44.1)	93 460,2
5-14 years	0.0 (0.2)	146 (3.1)	2.4 (12.0)	8 601,5
15-24 years	0.1 (0.4)	415 (8.9)	5.5 (19.4)	20 049,3
25-49 years	0.5 (1.2)	1966 (42.1)	19.8 (19.8)	72 263,4
50+ years	0.2 (0.5)	657 (14.1)	3.4 (9.5)	12 337,9
Overall	**1.3 (1.9)**	**4,671**	**56.6 (82.0)**	**206 712,3**

The average daily temperature over the study period was 19.4 ^oC and ranged from 13.3 ^oC to 25.5 ^oC. The daily maximum temperature averaged to 25.8 ^oC with a range of 15.0 ^oC to 38.2 ^oC. Daily minimum temperature ranged from 5.0 ^oC to 19.0 ^oC and averaged 13.9 ^oC. The seasonal variation of all-cause mortality and temperature is displayed in Figure 6. Mortality fluctuations were observed with high peaks occurring during the periods with low temperatures. The peak in mortality seemed to be followed by an immediate drop in the number of deaths.

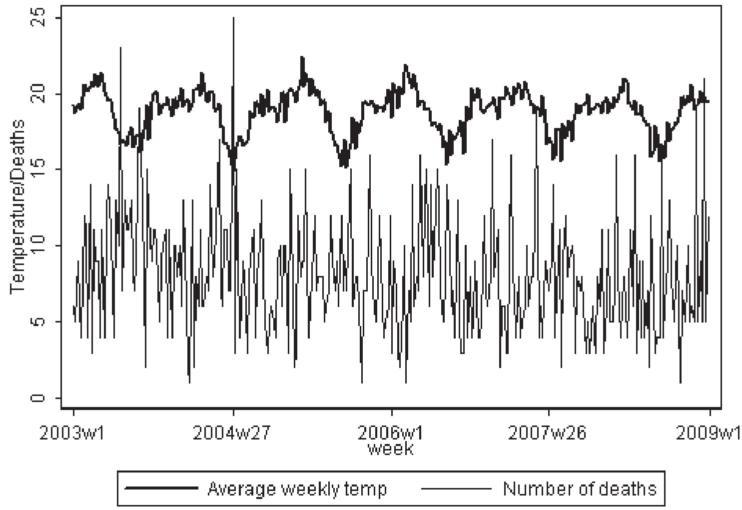


Figure 6: Weekly time series of all-cause mortality and temperature

Temperature and Mortality Risk

The association of temperature and mortality was assessed using average daily temperature as the temperature variable. The results from time series analysis of temperature-mortality relationship showed presence of seasonality (Figure 7). High mortality was observed in the month of July, which corresponds to a cold period of the year. The seasonal mortality was significant among under-five children, but is masked when considering all-ages together. This implies that the seasonal mortality is driven by under-five mortality in our study population.

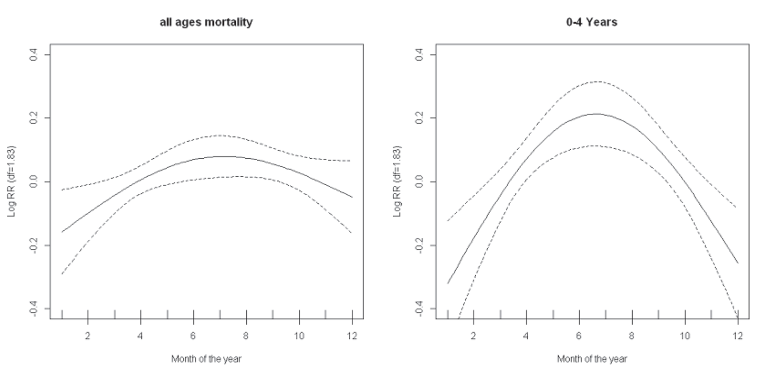


Figure 7: Seasonal variation in mortality among populations of all-ages (left), and under-five years of age (right). The dotted lines show a 95% confidence interval.

Exponentiation of the log relative risk estimates from the two plots, shows that mortality relative risk change from the lowest to the highest by about 40% for deaths among populations under-five years of age and 20% for all-ages. Temperature-mortality plots from the time series model revealed a non-linear relationship for temperatures away from the average temperature (Figure 8). The pattern of temperature and mortality showed a J-shape for all-ages and a U-shape for under-five mortality. The observed relationship shows that a change in temperature from the optimal temperature was associated with increased mortality risk. A strong cold effect is observed from the two plots for the same day, and with a one-day lag. The mortality risk was quantified by age, gender and cause of death using 25th and 75th percentiles as lower and upper temperature thresholds. This quantification produced no statistically significant results. Possibly due to the limited size of the population studied. However, there was 13% increase in mortality due to acute infections associated with low temperatures.

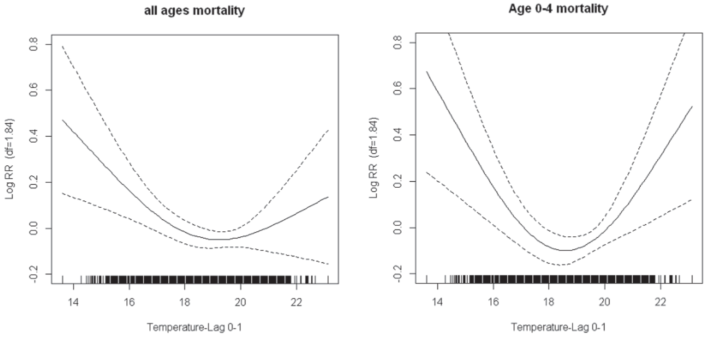


Figure 8: Smooth functions of temperature for all-ages, and for under-five mortality. Dotted lines are corresponding to 95% confidence intervals.

Temperature and Years of Life Lost

Daily maximum temperature was used to evaluate the relationship between temperature and YLL. The general association of temperature and YLL showed a J-shaped curve similar to the temperature-mortality relationship. The temperature-YLL relationship was lowest for daily maximum temperatures between 24-30 °C. The relationship illustrate an apparent cold association on YLL, but no significant effect from heat. The results also indicate that exposure to temperature of 21 °C (representing 5th percentile) for two weeks, relative to temperatures of 26 °C (minimum mortality temperature) was associated with an increase of 27.4 in YLL (95% CI, 2.7 – 52.0). The minimum mortality temperature was obtained from the fitted exposure-response curve. To explore the lag effect of cold, we used temperature corresponding to 25th percentile (24 ^{o}C). The results of the lag-response for the temperature of 24 ^{o}C showed a significant effect within 3 days after exposure, and diminished completely after 6 days.

Table 3: Heat wave and cold spell temperature thresholds and number of consecutive days with corresponding association to YLL

	Threshold (^{o}C)	No. of days	Main Effect		
			YLL	95 % CI	
Cold Spell intensities					
≤ 2nd percentile	20.0	24	56.7	4.4	109.1
≤ 5th percentile	21.1	67	35.8	2.3	69.2
≤ 10th percentile	22.4	169	26.1	0.6	51.6
Heat wave intensities					
≥ 98th percentile	29.0	23	3.4	-20.7	27.5
≥ 95th percentile	29.6	88	1.3	-25.5	28.2
≥ 90th percentile	30.4	221	8.1	-28.0	44.2

We explored graphically the delayed effects of cold spells and heat wave on YLL, and observed significant cold spell signals varying by lag and intensities. Separate models for different lags were used to explore lag associations. A cold spell as defined as the 5th or 2nd percentiles showed significance at lag 5 and 14 days. A less intense definition of cold spell defined as 10th percentile showed significance at lag 3 and 6 days. Therefore, this exploration of lags shows that the cold spell association indicates to be of significance within two weeks of exposure. The cumulative effect of cold spell, or heat wave, is presented in Table 3. The effect of either cold spell, or heat wave, was evaluated relative to normal conditions during the defined days of cold or heat. We observed a significant association between cold spells and YLL, with stronger effect following more intense cold spells (10th, 5th and 2nd percentiles). Cold spells, defined by these percentiles, were associated with 26.1, 35.8 and 56.7 YLLs respectively. There were no significant heat wave association on YLL observed in this study.

Air Pollution Exposure Assessment

The $PM_{2.5}$ readings showed seasonal patterns over the measurement period (February-October 2013) in both areas. The highest levels of $PM_{2.5}$ were measured during the month of July. However, measurements in July for Viwandani were largely missing. During the study period, Korogocho site displayed the highest concentration of $PM_{2.5}$ with a daily average level of 166 μg/m³ (Table 4). The lowest average $PM_{2.5}$ concentrations of 53 μg/m³ and 66 μg/m³, in Viwandani and Korogocho respectively, were recorded in the month of April. Moreover, the Viwandani area had daily average $PM_{2.5}$ concentration of 67 μg/m³ with marked smaller variation over the months. Excluding the measurements taken in the month of July, the average level of $PM_{2.5}$ in Korogocho dropped to 96 μg/m³, but still higher than in Viwandani.

Table 4: Observed $PM_{2.5}$ concentration for entire daily measurement periods, for defined time periods of the day, and 8-h average concentrations with 95% upper confidence limit (UCL)

	Korogocho				Viwandani	
	Entire period		Excluding July		Entire period	
	Average	UCL	Average	UCL	Average	UCL
All measurements (Entire period)	166.4	171.9	95.6	97.8	67.2	67.7
Parts of the days						
Morning period (0700-1000)	213.6	230.1	104.8	110.3	76.4	77.5
Mid-day period (1000-1700)	146.0	153.3	86.6	89.7	58.5	59.2
Evening period (1700-2100)	164.9	172.1	104.7	108.8	81.9	83.3
8-h Measurements (0600-1800)	183.6	258.1	97.0	121.8	62.9	68.1

Daily and Diurnal Variation of $PM_{2.5}$

Figure 9a shows the variation in $PM_{2.5}$ concentration for different parts of the day in the two study areas. We observed that $PM_{2.5}$ concentration was higher in the morning and evening compared to the afternoon period. A similar pattern was observed in both slums though the concentration was higher in Korogocho during all three periods of the day. An average $PM_{2.5}$ concentration of 214 and 165 μg/m³ was observed in the morning (0700-1000) and in the evening (1800-2100) respectively in Korogocho, while in Viwandani the observed concentration was 76 and 82 μg/m³ the morning and evening respectively (Table 4). The mid-day (1000-1700 hours) concentration level was 146 μg/m³ in Korogocho and 59 μg/m³ in Viwandani. A variation in $PM_{2.5}$ concentration by day of the week was observed in the Korogocho area (Figure 9b), with Mondays, Wednesdays and Saturdays having higher concentration levels. The concentration levels in Viwandani on average showed little variation across days of the week. The two plots show higher spikes of $PM_{2.5}$ in Korogocho compared to Viwandani for most hours of the day, and for all days of the week.

Eight-hour concentrations

The eight-hour (8-h) concentration presented in Table 4 was obtained for days with measurements for at least 8 hours from 6.00am to 6.00 pm. The 8-h average concentration was 183 µg/m^3 (median 91 µg/m^3) ranging from 24 µg/m^3 to 716 µg/m3 in Korogocho and 63 µg/m^3 (median 60 µg/m^3) with a range of 30 µg/m^3 to 133 µg/m3 in Viwandani. The 95% upper confidence limit (UCL) was 258 µg/m^3 and 68 µg/m^3 for Korogocho and Viwandani respectively. Excluding the month of July, the 8-h average $PM_{2.5}$ concentration was 97 µg/m^3 with UCL of 122 µg/m^3. The 95% UCL of the measurements in Viwandani was closer to the average concentration showing little variation.

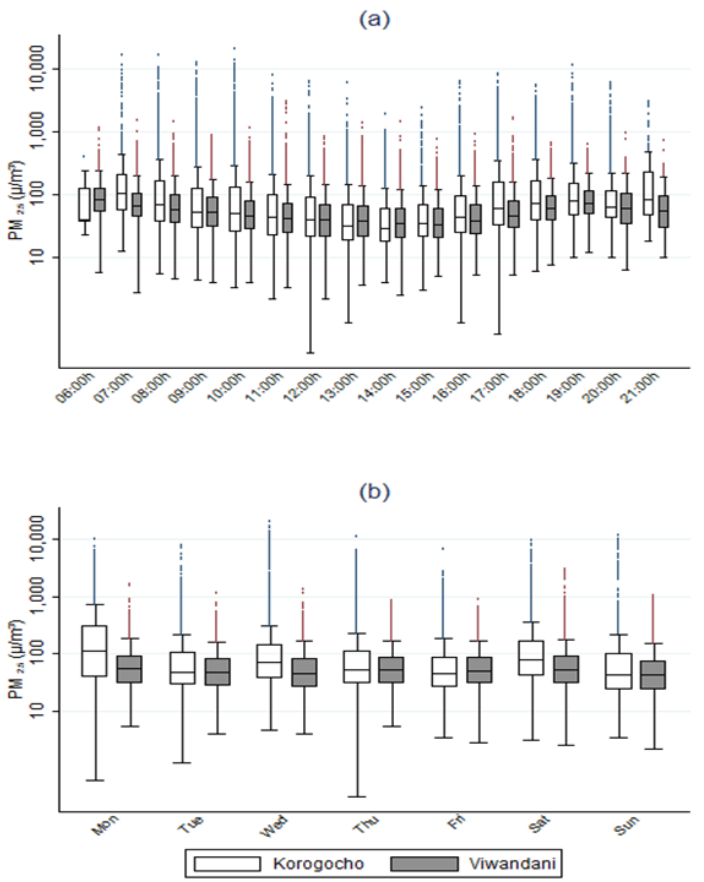


Figure 9: The distribution of $PM_{2.5}$ concentration by time of the day (a) and the day of the week (b)

Level of Exposure to $PM_{2.5}$ and Child Morbidity

A cohort of 4,529 children aged below five years were followed up during the period 2012-2013 and was included in the morbidity analysis. We used a longer retrospective period of follow up for mortality analysis given the lower mortality incidence compared to morbidity incidence.

Table 5: Distribution of individual characteristics of the two study cohorts by the exposure level

	Morbidity Cohort†		Mortality Cohortᶧ	
	$PM_{2.5} < 25$ µg/m³ n (%)	$PM_{2.5} \geq 25$ µg/m³ n (%)	$PM_{2.5} < 25$ µg/m³ n (%)	$PM_{2.5} \geq 25$ µg/m³ n (%)
Sample (n)	**1,583**	**2,946**	**8,353**	**13,288**
Gender				
Male	798 (50.4)	1485 (50.4)	3937 (46.9)	6416 (48.4)
Female	785 (49.6)	1461 (49.6)	4456 (53.1)	6832 (51.6)
Age (months)				
0-11	323 (20.4)	598 (20.3)	2330 (27.8)	3470 (26.2)
12-23'	411 (26.0)	704 (23.9)	1664 (19.8)	2434 (18.4)
24-35	279 (17.6)	546 (18.5)	1102 (13.1)	1702 (12.9)
36-47	301 (19.0)	595 (20.2)	786 (9.4)	1225 (9.3)
48-60	269 (17.0)	503 (17.1)	2511 (29.9)	4417 (33.3)
Wealth Index				
Poorest	399 (25.2)	1324 (44.9)	1427 (17.0)	4554 (34.4)
Poor	553 (34.9)	830 (28.2)	2586 (30.8)	3841 (29.0)
Least poor	557 (35.2)	640 (21.7)	3450 (41.1)	3418 (25.8)
Missing	74 (4.7)	152 (5.2)	930 (11.1)	1435 (10.8)
All-Cause Morbidity				
Yes	550 (34.7)	1252 (42.5)		
No	1033 (65.3)	1694 (57.5)		
Cough*				
Yes	424 (77.1)	1030 (82.3)		
No	126 (22.9)	222 (17.7)		
All-Cause Mortality				
Yes	-	-	473 (5.6)	857 (6.5)
No	-	-	7915 (94.4)	12396 (93.5)
Respiratory-related mortality**				
Yes	-	-	133 (28.1)	224 (26.1)
No	-	-	340 (71.9)	633 (73.9)

†*The morbidity cohort is from MCH/IVP projects for the period 2012-2013*
ᶧ*The mortality cohort is from NUHDSS for the period 2003-2013*
* *Sample total based on All-Cause Morbidity cases*
***Sample total is based on All-Cause Mortality cases*

The main characteristics of the two cohorts for both morbidity and mortality analysis are described in Table 5 according to the level of exposure (low=

$PM_{2.5}$< 25 µg/m³ vs high= $PM_{2.5} \geq$ 25 µg/m3). The distribution of gender and age classes was similar over the exposure categories. However, people living in areas with high concentrations $PM_{2.5}$ were more often poorer households for both cohorts. Among children of the morbidity cohort, about 45.0% of children in the poorest households were from highly polluted areas compared to 25.2% from less polluted areas. The proportion of participants with missing information on wealth index for the two cohorts was similarly distributed between the two levels of pollution categories. Among the morbidity cohort, a total of 1,802 children (39.8%) experienced morbidity with 1,454 (80.7%) of them reported to have had cough during 2012-2013. Both morbidity and cough cases were equally distributed by gender: female cases were 890 and 731 (50.3%) for morbidity and cough respectively.

Table 6: Association between $PM_{2.5}$ and child morbidity adjusting for gender, age and socio-economic status

	Prevalence analysis		Episode analysis-individual		Episode analysis-Household	
	OR (95% CI)	p-value	IRR (95% CI)	p-value	IRR (95% CI)	p-value
Gender (ref: Male)						
Female	0.99 (0.87;1.12)	0.87	1.03 (1.00; 1.05)	0.02	1.00 (0.98;1.02)	0.88
Age in months (ref: 0-11)						
12-23	1.17 (0.97;1.40)	0.09	1.45 (1.38;1.52)	0.00	1.21 (1.18;1.24)	0.00
24-35	0.87 (0.71;1.05)	0.14	1.14 (1.09;1.19)	0.00	1.10 (1.07;1.13)	0.00
36-47	0.58 (0.48;0.71)	0.00	1.25 (1.18;1.32)	0.00	1.14 (1.11;1.18)	0.00
48-60	0.41 (0.33;0.51)	0.00	1.09 (1.01;1.17)	0.03	1.05 (1.01;1.09)	0.02
Wealth Index(ref: Poorest)						
Poor	0.67 (0.58;0.78)	0.00	0.97 (0.95;1.00)	0.03	1.02 (1.00;1.03)	0.02
Least Poor	0.63 (0.54;0.74)	0.00	0.98 (0.95;1.01)	0.16	1.01 (0.99;1.03)	0.32
Air Quality*						
Poor	1.30 (1.13;1.48)	0.00	1.36 (1.22;1.51)	0.00	1.45 (1.30;1.62)	0.00

**Poor air quality refers fine particulate matter ($PM_{2.5}$) $\geq$ 25 µg/m³*

We found significant association between high level of exposure ($PM_{2.5} \geq$25 µg/m³) and child morbidity (cough, fever and convulsion). A similar relationship with slightly higher estimates was observed when considering cough as the only form of morbidity. Therefore, we present the results for morbidity related to the three symptoms (cough, fever and convulsion) combined in Table 6. Children in areas with higher exposures were 30% more likely to report morbidity (OR =1.30, 95% CI = 1.13 – 1.48). Morbidity cases were more often reported among children from poorer households compared to children from less poor households whom were 37% less likely to report morbidity (OR =0.63, 95% CI = 0.54 – 0.74). The results show that morbidity prevalence was higher among the younger children compared to older children with a somewhat linear trend. However, there was no difference in the morbidity prevalence between male and female children.

The results of morbidity episodes at individual level show that children from areas with high level of pollution had an incidence rate, IRR, of 1.36 (95% CI = 1.22 – 1.51) times greater than those from areas of low level of pollution. The results showed higher incidence rate for older children compared to children aged 0-11 months. Females compared to male children, were expected to have a rate of 1.03 times greater for morbidity episodes. High level of $PM_{2.5}$ concentration was also found to be significantly associated with morbidity episodes at household level. The results indicate that households in highly polluted areas were 45% more likely to experience high morbidity cases compared to households from less polluted areas (IRR=1.45, 95% CI=1.30 – 1.62).

Level of Exposure to $PM_{2.5}$ and Child Mortality

A total of 21,641 children under five years of age were observed for a period of 2003-2013 forming a cohort for mortality analysis. We used a longer period of follow up for mortality analysis to have enough number of deaths for the analysis.

Table 7: Association between $PM_{2.5}$ and child mortality adjusting for gender, age and socio-economic status

	All-Cause Mortality		Respiratory Related Mortality	
	IRR (95% CI)	p-value	IRR (95% CI)	p-value
Female (ref: Male)	0.98 (0.89;1.09)	0.76	0.96 (0.80;1.15)	0.66
Age in months (ref: 0-11)				
12-23	0.26 (0.23;0.30)	0.00	0.25 (0.20;0.33)	0.00
24-35	0.10 (0.07;0.12)	0.00	0.10 (0.06;0.15)	0.00
36-47	0.07 (0.05;0.10)	0.00	0.05 (0.02;0.10)	0.00
48-60	0.03 (0.02;0.05)	0.00	0.04 (0.02;0.09)	0.00
Wealth Index (ref: Poorest)				
Poor	0.87 (0.76;0.99)	0.03	0.98 (0.79;1.23)	0.89
Least Poor	0.88 (0.77;1.00)	0.04	1.01 (0.80;1.26)	0.96
Poor Air Quality*	1.15 (1.03;1.28)	0.02	1.10 (0.91;1.33)	0.34

**Poor air quality refers fine particulate matter ($PM_{2.5}$) $\geq 25\ \mu g/m^3$*

The characteristics of the cohort for mortality analyses are described in Table 5 according to the level of exposure (low vs high). There was a similar distribution for the mortality cohort where 34.4% of children in the poorest households were from highly polluted areas compared 17.0% from less polluted areas. The proportion of participants with missing information on wealth index for the two cohorts was similarly distributed between the two levels of pollution categories. During the study period (2003–2013) we observed 1,330 under five all-cause deaths (6.2%), among those 357 deaths were related to respiratory infections (26.7%). There were 710 male all-cause deaths (53.0%), and 194 male respiratory related deaths (54.2%). The majority of deaths occurred within 12 months of life; 1,103 (82.4%), and 310 (86.6%) for all-cause and respiratory-related respectively.

A significant relationship between high levels of $PM_{2.5}$ with under-five mortality was observed (Table 7). The incidence mortality ratio for children in highly polluted areas was 1.15 compared to children in less polluted areas (95% CI = 1.03 – 1.28). The mortality rate was higher among the poorest households, and among the 0-11 months age group. However, there was no difference in mortality by the gender of the child. The analysis of association of exposure to $PM_{2.5}$ on respiratory related mortality showed that children from high exposure were 10% more likely to die from respiratory related infections compared to those from low exposure areas. Though, the result was not statistically significant (95% CI = 0.91 – 1.33). However, the insignificant results for the respiratory related mortality might be due to the few number of deaths for the population studied in this cause of death category.

Community Perceptions of Air Pollution

The survey on community perception was conducted in 2012 among 5,317 residents (3887 in Korogocho and 1430 in Viwandani). All socio-demographic characteristics significantly differed between the two study sites at 5% significance level (Table 8). Participants in Viwandani were mainly male and younger compared to Korogocho. About a half of the residents in Korogocho had lived there for at least 20 years and majority of residents in Viwandani (84%) had lived for less than 20 years. Most respondents were married in both study areas. A higher proportion of respondents were not married in Korogocho (30%) compared to Viwandani (15%). Majority of residents in Korogocho had low level of education compared to Viwandani. Informal business and casual labour were the two main occupations of the residents in the two sites of Korogocho and Viwandani respectively.

Table 8. Description (%) of the sample by the two study sites

	Viwandani (n=1430)	Korogocho (n=3887)
Sex		
Female	36.1	49.1
Male	63.9	50.9
Respondent's Age		
35-40 years	41.9	26.3
41-50 years	41.5	37.7
51-60 years	13.3	21.4
60+ years	3.3	14.6
Duration of stay		
0-10 years	41.0	17.5
11-20 years	43.3	33.9
21-30 years	14.4	30.9
30+ years	1.2	17.8
Marital status		
Married	85.3	70.5
Not married	14.7	29.5
Education level		
Less than primary	15.2	38.0
Primary	50.8	46.2
Secondary+	34.0	15.8
Current Occupation		
Business	29.4	43.0
Informal	35.1	34.5
Formal	27.0	3.9
Other	8.6	18.6

Location of Work and Sources of Pollution

A majority of respondents in both study areas reported their daily work was located next to either a busy road or in a dusty place (Table 9). Working near a place where cooking takes place was reported by about half of the respondents in both sites. More than a half of the participants in Viwandani reported not to be working in a fixed place. In addition, 13% of respondents reported working in four areas known to be highly polluted compared to only 3% in Korogocho. These areas were: next to a busy road, in a dusty place, near a place where cooking is taking place, and in a factory where air is bad.

Smelly trenches perceived as the main source of air pollution by most of respondents (81%) in both areas, although this is not scientifically considered a source of air pollution (Table 9). Dust and burning of trash were most common mentioned sources of outdoor air pollution. Respondents in Korogocho compared to Viwandani mentioned them more frequently. Industrial emissions were reported to be a major source of pollution in Viwandani and vehicles were also mentioned as contributors to outdoor air pollution in Korogocho. Cooking fuels and cigarette smoking were perceived as sources of indoor air pollution by only a small proportion of the respondents.

Table 9. The percentage distribution of respondent's location of work and perceived sources of air pollution by study site

	Viwandani %	Korogocho %	Total p-value
Location of respondent's daily work			
Next to a busy road	72.0	68.1	0.02
Near a place where cooking takes place	46.9	52.8	0.00
In a dusty place	70.2	68.4	0.26
In a factory where air is bad	40.6	10.4	0.00
Not in a fixed place	56.4	38.1	0.00
At least one of the above	71.3	68.6	0.06
Perceived sources of air pollution			
Outdoor air pollution sources			
Dust	47.5	63.0	0.00
Vehicles	7.7	20.3	0.00
Industries	55.5	5.0	0.00
Burning of Trash	50.5	66.6	0.00
Indoor air pollution sources			
Cooking fuels	13.8	22.1	0.00
Cigarette Smoking	11.6	18.5	0.00
Other			
Smelling of Trenches	81.1	81.8	0.57
Other sources	9.5	13.1	0.00

Health Risks and Information on Air Pollution

Table 10 shows the results on perceived health risks from air pollution and sources of information on air pollution. Cough/cold, difficulties in breathing, headache and eye problems were the common health risks mentioned related to air pollution. High proportion of Korogocho residents had knowledge on health risks related to air pollution compared to Viwandani residents. It was surprising that some respondents did not know anything about health problems related to air pollution. This proportion was estimated at 10% in Viwandani and 6% in Korogocho. More than half of the respondents in Viwandani, and more than a third in Korogocho, had never received any information related to harm or mitigation of air pollution exposures. For those that had, common sources of information on air pollution in Korogocho were radio, barazas (community meetings) and health workers, while the radio was the dominant information channel in Viwandani.

Table 10. The percentage distribution of self reported health risks and sources of information on air pollution by study site

	Viwandani %	Korogocho %	Total p-value
Perceived health risks from air pollution			
Cough/Cold	61.5	74.4	0.00
Difficulty breathing	39.9	46.4	0.00
Eye problem	15.2	27.7	0.00
Asthma	10.2	14.7	0.00
Cancer	6.4	6.5	0.90
Heart problem	15.1	13.3	0.09
Headache	16.5	30.1	0.00
Don't know	10.2	6.3	0.00
Other health risks	24.5	17.6	0.00
Sources of information on air pollution			
Radio	32.3	39.1	0.00
Television	12.5	14.6	0.06
Newspapers	5.7	6.1	0.63
Barazas (Community meetings)	5.4	18.4	0.00
Health workers/facilities	9.7	25.1	0.00
Never heard	55.0	35.1	0.00

Perceptions of Air Pollution

Outdoor air quality was considered poor compared to indoor air quality and a majority of residents felt that the quality of air inside their houses was moderate or better. Thus, they were mostly not annoyed by the quality of air in their households. Annoyance level about outdoor air quality may directly relate to the perceived air quality. The variation in perceived air quality and annoyance level in Korogocho and Viwandani is illustrated in Figure 10.

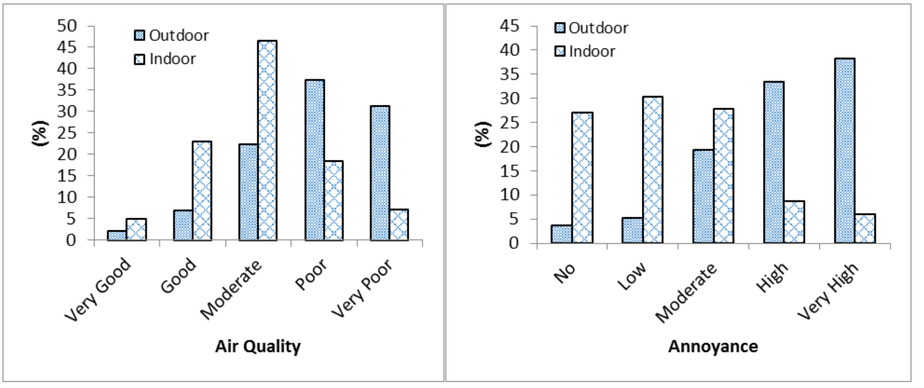


Figure 10. The percentage rating of air quality and the level of annoyance from air pollution for outdoor and indoor environments

Bivariate analysis was performed to assess independent association of respondent characteristics and perceived pollution level (results not shown). The results from bivariate analysis showed that the perceived air pollution level was associated with duration of stay in the slum, age of the respondent, education level, occupation, received information on air pollution, number of work locations of poor air quality, and the slum residence. Respondents who had stayed longer in the study area, or who were older, had lower perception of air pollution when considered independently. However, this was not significant when controlled for other factors. Residents in Korogocho perceived a lower air pollution exposure level compared to residents in Viwandani in the bivariate analysis. Therefore, the final regression analysis for perceived air pollution was performed separately for each slum area of residence (Table 11).

Individual's level of education was associated with perception about air pollution levels. Those with at least primary level of education perceived higher exposure to air pollution compared to those with no or less than primary level education. However, the relationship between education and perceived air pollution was statistically significant among residents of Viwandani. Occupation was significantly associated with perceived air pollution, and the relationship varied by the study site. In Viwandani, people engaged in formal form of occupation had low perceived air pollution, and the perception of those in the informal, or other forms of occupation, were not significant compared to those in business. Those in informal, formal and other form of occupations had high-perceived air pollution compared to those in business among Korogocho residents. Respondents who never heard information on air pollution had significantly low levels of perceived air pollution in Korogocho. Surprisingly, those who never heard information about air pollution in Viwandani had higher levels of perceived air pollution.

Exposure to air pollution in working environments was positively associated with perceived poor air quality. Perceived poor air quality was positively associated with annoyance level among residents in both areas.

Table 11. Characteristics associated with perceived level of pollution and health risks of air pollution (estimates represent linear regression coefficients)

	Air pollution		Health Risk	
	Viwandani	Korogocho	Viwandani	Korogocho
Perceived pollution level			0.44*	0.48*
Duration stay (ref: <10 years)				
11-20 years	-1.16	0.63	1.32	-0.47
21-30 years	-2.17	0.77	2.13	-0.96
30+ years	-3.70	0.09	3.14	1.47
Age (ref: 35-40 years)				
41-50 years	0.46	-0.54	-0.27	0.20
51-60 years	1.11	-1.37	0.28	-0.11
60+ years	4.43	-1.46	2.21	0.20
Male	-0.23	-0.85	-1.86	0.30
Married (ref: Not married)	0.49	-0.20	0.21	1.09*
Education (ref: No education)				
Primary	3.80*	0.80	-0.78	1.60*
Secondary +	3.44*	0.38	-0.71	1.29
Occupation (ref: Business)				
Informal	-0.50	1.25*	-0.87	-0.89
Formal	-3.20*	4.88*	-1.26	-1.87
Other/None	2.42	5.12*	3.85*	-1.50*
Never heard any information	2.31*	-2.19*	-5.06*	-1.4*
Number of polluted work locations	9.61*	5.40*	10.05*	0.97
Annoyance level	0.38*	0.07*	0.07*	0.21*

** Statistically significant at 5% level*

Perception of Health Risks related to Air Pollution

A positive association between perceived self-reported health risk and perceived air pollution in both areas was observed. Duration of stay, age and gender were not significantly associated with perceived health risk related to air pollution after controlling for other individual characteristics. Perceived health risk was associated with marital status, education level, and occupation in multivariate analysis. Married people, and those with at least primary level of education, had high-perceived health risk among respondents in Korogocho. Other occupation, or no occupation, was associated with high-perceived health risk among residents in Viwandani, and low perceived health risk among Korogocho residents. Those who had not heard information about air pollution, in general reported low perceived risk in both areas. A similar positive association of high-perceived exposure to air pollution at working environments with more frequent annoyance was observed.

Discussion

The main goal of this research was to tease out, describe, analytically assess, and, thus, make visible health risks from exposure to temperature variation and air pollution among slum residents in Nairobi, Kenya. In addition, the study explored the community's perceptions of the sources, knowledge and health risks of air pollution. We examined the association between temperature and all-cause mortality, cause-specific mortality risk, and years of life lost. We found evidence of seasonal and temperature-associated risk of mortality particularly for children below five years. In particular, we found that cold temperatures increased mortality rates in the population of Nairobi. We also determined the level of fine particulate matter concentration and the associated risk to child health. Our study showed strikingly high level of pollution in the two slums, and that children from highly polluted areas associated to have higher risk of morbidity and mortality. Despite the exposure levels and the associated health effects, it was found that many individuals in the study areas knew little about air pollution. This novel and pioneering study provides a great opportunity to understand the health burden and situation of environmental exposures among the socially deprived urban population in SSA, and is a first step to increase knowledge in the community, and globally, and to development of protective measures.

The discussion of the study finding is organized in four sub-topics of; temperature and mortality, air pollution and health, community perceptions and the policy implications guided by the MEME framework. The discussion of each sub-topic includes the possible response actions to mitigate the exposure effects.

Temperature and mortality

We observed temperature effect on both mortality risk and YLL to have a J-shaped relationship with a U-shaped for the under-five child mortality risk. The observed similar pattern of mortality risk and years of life lost indicate that temperature related mortality was more among children. The observed relationship was consistent with previous studies on temperature and all-cause mortality in sub-tropical climate regions [68, 151, 152] and also many studies conducted in developed countries [153]. A study in Brisbane, Australia examined the impact of temperature on years of life lost and found a U-shaped relationship, with increased YLL for cold and hot temperatures. Our findings showed that the minimum mortality risk was observed between 25th and 75th percentiles of the mean daily temperature corresponding to 18

°C and 20 °C respectively. Similar finding of the change point for both heat and cold related deaths of 20 °C was made in Brazil [67]. Another study in China found a minimum mortality temperature associated with cold of 23 °C [154]. However, a range of favourable temperatures that were associated with lowest mortality varied across cities in a multi-city study in China [68]. Areas characterized by hot summers experienced higher thresholds and colder areas had a lower threshold [68]. The climate pattern was suggested to influence the temperature–mortality relationship, which reflected behavioural and physiological adaptation to climate for the local population.

A significant seasonal mortality with greater effect among children below five years was observed during the cold period of the year. The result of increased mortality during the cold season of the year of June, July and August was consistent with findings of studies in Tanzania [155], and Australia [156]. Mrema et al. [155] showed that mortality increased during mid of the year when the temperatures were relatively low and the effect was greater among under-five children. Similarly, Bi et al. [156] found high mortality rate in colder period of the year in the general population. A relatively limited number of studies looked at cold-related mortality in children, and those that did often reported effects of heat. The relative risk of high temperature was found to be high in children aged under one year [157], below five years [155, 158, 159], and among children aged 0-15 yeas [67, 158, 160]. The effect of cold on child mortality has been shown among children aged 0–9 years in Madrid [161], among children aged 0-15 years in Brazill and 0-4 years in Tanzania [155]. Studies in sub-tropical regions have generally reported more pronounced cold effects. Gouveia et al. [67], observed greater cold effect on mortality in Brazil, while Kan et al. [154] found a cold related mortality for non-accidental, cardiovascular and respiratory related mortality in China. In Shanghai, China, significant interaction between particulate matter pollution and extreme low temperature for both all-cause and cause-specific mortality was observed [162]. Guo et al. [163] found greater cold effect than heat effects after controlling for season, pollution and humidity in Thailand. Lindeboom et al. [164] also found hot and cold related mortality with greater effect during colder season in Banglad. The cold effect observed in Nairobi lasted for 3 days and the cumulative effect diminished completely after 6 days. The gradually increased cold effect with lag day was consistent with previous studies [151, 165, 166]. However, we found varying lag days of significant effect, which could be due to the different mechanisms and interactions with environments underlying the results in various studies. Interestingly, our findings show that cold remain an important public health problem, even in sub-tropical regions, which should not be overlooked.

Temperature stress conditions are predictable thus mortality related to cold exposures is preventable [62]. Personal protection measures such as layering and selecting appropriate clothing are simple, but effective in conserving body heat [15]. The use of Kangaroo Mother Care might be the only effective, affordable and available method to prevent neonatal hypothermia in most resource poor settings [167]. Heat exposure effects can also be reduced through personal measures, such as drinking a lot of water, avoiding strenuous work and wearing light clothing. In addition, community actions such planting trees can be taken which increase solar energy reflection from the earth back to space and also act as wind breakers to air pollution [168]. Long-term investment in proper housing conditions would be better protection action against temperature health effects.

The observed cold effect does not necessarily lead to the postulation that mortality would be reduced due to climate change. There is likely to be continued cold exposure effects even with climate change as some studies have demonstrated greater cold effect in wamer regions [15, 68]. Overall, the cold impacts are avoidable by investment in housing, heating and protective behaviour and health systems. The discussion, comparing heat to cold, should be handled rather separately as mechanism and protective strategies are often quite different. Also, more studies are needed to shedlight on climate change impacts in the slum population in respect to heat and cold exposure. The results on mortality risk and YLL provides relevant knowledge on temperature association to both scientific community and decision makers. The results on YLL is useful in comparing the relative of importaance of different risk factors within our study population.

Air pollution and child health

A significantly high concentration of particulate matter was observed in two slums with seasonal variation. The period of high level of pollution coincided with the period of peak mortality also corresponding a period of low temperatures. This indicates a potential synergistic effect of cold weather and air pollution. However, our study was not designed to assess the interaction effect of the two exposures. There was also significant difference in the level of pollution for the two study areas that are not far apart. The observed difference in pollution levels clearly underscores the consideration of local sources in reducing health effects from exposure to air pollution. In addition, there was variation in the level of pollution for different parts of the day with high concentrations during morning and evening hours. However, we can assume that colder conditions give rise to increased exposure to indoor and ourdoor air pollution from fires made for heating.

Compared to other studies conducted in Nairobi, a number of studies were conducted for shorter periods either along the major roads, or within central business district of Nairobi [26, 169-171]. These prior studies offer a starting point in understanding air quality in general, but may offer little information on the exposures individuals. Our study offers an explanation of the air pollution situation in a socially deprived residential area, where majority of residents work and live. The street level PM2.5 concentration observed by Kinney et al. [26] in Nairobi was lower than that observed in Korogocho area. Compared to background measurements from the University of Nairobi [169], the concentrations observed in the two study areas were higher by at least a factor of 3. The PM2.5 concentration in Korogocho was higher compared to studies in Ghana [172-174], and in the city of Ouagadougou [175]. However, the PM2.5 concentrations in Viwandani were similar to studies in Accra [172, 173].

We examined the effect of exposure to PM2.5 on child health, and we found high child morbidity rate was reported among children in highly polluted areas. This risk was higher among the poorest households. Recent studies in China [176] and India [177] have found similar results. Two studies have demonstrated significant association between child morbidity and the level of exposure to particulate matter. Higher prevalence rates of child morbidity were consistently found among children living in areas of high pollution. Incidence of cough, which is a sign of pulmonary irritation that could be caused by exposure to air pollution, was a common health outcome across these studies. The study by Ghosh et al. [177] showed that the burden of air pollution is disproportionately larger on children in slums than other non-slum urban areas. However, our study was not designed to provide comparison between slum and non-slum, but reinforce the evidence of the burden faced by slum population from from air pollution. Previous studies in Nairobi have showed a high disease burden of respiratory illnesses among children in slums [30, 32]. A study by UNEP among children living near the Dandora dumpsite next to one of our study site revealed a high incidence of diseases linked to environmental pollution [34]. The study found that half of the children examined had respiratory ailments. Therefore, our study provides significant contribution in quantifying the health impacts of poor ambient air quality as potential determinant of poor health outcomes among the slum population. We also found the risk of under-five child mortality from all-causes was high in those areas that were highly polluted areas. Although not statistically significant, more respiratory related mortality was also observed in the more polluted areas. Overall, the direct effects of air pollution on human health are well known, studies investigating the effects of air pollution on under-five child mortality are limited [178]. Therefore, there was no similar study to make direct comparisons with our mortality results.

Community perception on air pollution

In addition to observed air pollution levels, the study on perception and knowledge showed that residents were exposed to air pollution from multiple sources. Despite the situation on air pollution level, most of the residents had not heard information on air pollution and a number of them did not know any health risks associated with air pollution. However, localized sources of pollution, as in the case of our study sites, education and awareness programmes can help people take measures to avoid exposure [179]. Education and occupation were associated with the perception on either air pollution level or health related risks. The relationship between level of education and air quality perception remains unclear. Previous studies have reported positive [180, 181] and negative [182, 183] association of education with perceived air quality. Some studies [184, 185] found that health education only, as an intervention, showed little effectiveness. Therefore, it is important to understand the barriers and motivational behaviour that should be targeted for behaviour change [130]. Awareness or receiving information on air pollution was associated with perception on air pollution level. It was surprising that the relationship was opposite in the two study areas. Knowledge obtained through social interactions, play an important role in the shaping of perceptions [186], and we observed this in one of the study areas where community barazas (gatherings) were source of information on air pollution.

Study limitations

This study has a number of limitations that we acknowledge. First, the use of the opportunity to combine data from studies that were not initially designed for our study objectives limited our ability to assess synergestic effect of temperature and air pollution. It has been shown that air pollution level can modify health effects of temperature[90]. Hence, we treated the two exposures to have independent effect on health. Secondly, verbal autopsy (VA) could also face challanges of recall bias and uncertainty introduced by physician coding cause of deaths. However, the VA process provides an opportunity to conduct cause-specific analysis. Third, the temperature measurements were obtained from a monitoring station located outside the study area about 4 km, which may not represent well the actual individual exposures, creating a potential misclassification of exposure. Fourth, lack of 24-hour continuous measurements of PM2.5 renders our comparison to WHO guideline limits difficult. However, our study measured during the daytime hours when the exposure to air particles concentration is greatest. Additionally, individuals can have different exposure than those assigned according exposure measured at their housing. The use of group level PM2.5 measurements to assess the effect of air pollution and child health could introduce exposure misclassification error. Assuming same exposure back in time could also introduce some level of misclassification error. Despite these study limitations, the study provides novel evidence to demonstrate the need for measures to mitigate the effects from environmental exposures. More importantly, the study contributes to novel understanding the health burden from environment exposure among urban poor populations.

Policy implications of study findings

The results of this research naturally raise a practical question; perhaps the most obvious is, given the observed association between cold weather, air pollution and ill health, what are preventive measures that can be taken to avert health effects. Thus, we suggest possible actions through MEME framework of addressing environmental health issues. The study shows exposure risks from cold and air pollution on mortality and morbidity. The preventive strategies to these exposures, as well as other weather related health hazards, can be implemented at various scales of the framework.

The findings have multiple potential policy implications for the low-income countries, and highlight the need for multisectoral collaboration of different stakeholders to tackle the challenges of environmental exposures in urban areas. First, the need to create preventive health care awareness amongst the child caregivers regarding the risks of exposure to temperature and air pollution to child health. Secondly, infrastructural development, such as better housing is necessary for preventing exposure to temperature variations. At the same time, national efforts should be undertaken to create awareness of the health effects of environmental exposure to the larger population through initiatives like campaigns involving institutions such as schools, community groups, social and sports groups. Involvement of local decision makers is critical in recognizing the risk to their communities and effectively deploying preventive measures at community level. The short-term measures at community level could include education and public health response systems such as education campaigns regarding temperature variation related symptoms, reducing exposure and behaviour change campaigns on environmental pollution. In addition, long-term local actions could include infrastructure improvements that reduce concentration, or exposure, in communities. These actions include tree planting and proper waste managemet, which help in reducing the level of air pollution.

Establishment of waste recycle management programs is critical for reducing the level of air pollution in urban poor settlements.

At national level, the findings also suggest the need for the public policy-makers to formulate appropriate national environmental health regulations and policies. It will be beneficial to incorporate environmental pollution prevention into basic education curriculum. The interlinkages between weather and air pollution, mutual benefits can be achieved with policies that integrate both exposures. Therefore, policy makers need to review relevant policies that are likely to deliver the greatest public health benefits. In order to support this policy, the framework also emphasizes the need for surveillance to provide information from epidemiological analysis and qualitative studies to guide decision-making.

In addition, policies addressing the high rate of urbanization will also reduce the problems of environmental pollutions. For instanse, making agricultural livelihood more attractive and creating economic opportunities in rural areas. Through such policies there will lower pull towards urban oppotunities thus reducing the rate of urban population growth. However, countries should be prepared in improving urban inrastructure as the urban population will continue to grow.

Conclusion

This study provides important contribution in understanding the health risks posed by the ambient environment among socially deprived urban populations. The study utilizes the unique opportunity offered by Nairobi Urban Health and Demographic Surveillance System to study unseen health problems mainly because of a lack of data. The findings on weather variation suggest that cold exposure can be an important public health problem in poor populations in subtropical regions, with the most severe effect on children. Policies, and preventive actions are needed to protect populations, particulary from cold exposure.

The exposure to air pollution is high in the slum areas studied, and frequently exceed the WHO guideline limits. The slums are not homogeneous in exposure levels, and the levels of exposure associate to poor child health. It is critical to develop a monitoring system to support the overall air pollution management strategy and develop policies to protect the public health. Further studies with refined exposure estimates and outcomes measures are needed to guide policy and prevention initiatives to address air pollution.

Perception of air pollution is influenced by the individual's knowledge and occupation, which could be used as proxy of socio-economic indicator. This relationship differs by the location implying that interventions may need to be modified to specific communities within the urban population.

Acknowledgements

First of all, I acknowledge the opportunity provided by APHRC to pursue my doctoral studies. I am grateful to Dr. Alex Ezeh who made initial conduct to Prof. Stig Wall on the collaboration between APHRC and Umeå University, division of Epidemiology and Global Health. I thank Dr. Joacim Rocklöv to accept me as his PhD student.

I appreciate my supervisors Dr. Joacim Rocklöv, Dr. Nawi Ng, Dr. Michael Gatari and Dr. Remare Ettarh for their guidance throughout the journey of my doctoral studies. I express my deepest gratitude to my supervisor, Dr. Joacim Rocklöv, for his excellent guidance, caring, patience, and providing me with an excellent atmosphere for doing research. He always showed confidence in my ability to work independently and also provided opportunity to join him in facilitating training workshops. I acknowledge the support from Dr. Remare Ettarh, who promptly gave feedback to my work and was always available for skype call to clarify issues that were not clear. I thank Dr. Catherine Kyobutungi, who patiently corrected my writing and provided guidance at every stage of my research.

I acknowledge the support for research in this thesis by the Umeå Centre for Global Health Research at Umeå University, with support from FAS, the Swedish Council for Working Life and Social Research (Grant no. 2006-1512) and the generous core funding to APHRC by Swedish International Development Cooperation Agency (grant no. 2012-7612) and William and Flora Hewlett Foundation (grant no. 2011-001578). I acknowledge the scholarship support from Swedish Research School for Global Health. The school provided opportunity to interact with other doctoral students and attending of courses related to global health. I am grateful to International Science Programme for their research support at Institute of Nuclear Science and Technology (INST), University of Nairobi. I acknowledge the support from Amsterdam Institute for Global Health and Development (AIGHD) for the SCALE-UP study in which we nested the study on understanding the community perceptions.

I thank those who participated in the study and field workers of different projects that provided data for the thesis work. I thank all APHRC staff who made it possible to have data or in other way for this research to succeed. I also acknowledge those who conceptualized the idea of NUHDSS, which provided opportunity for this work.

I appreciate the support and encouragement received from fellow PhD colleagues from Epidemiology and Global Health, Umeå University. Thanks to my academic twin sister, Kanyiva Muindi whose support made things look much easier. I thank my colleagues Sewe, Mikkel, Osama, Vijendra, Ryan and others who made my stay in Umeå enjoyable.

I thank my wife Maureen and my children Emmah, Eric and Kelly for their moral support and encouragement. Maureen always assured me not to worry about our children while away which was greatest motivation. Finally, I thank God for his guidance and protection to the work. I would also like to thank my parents, siblings and colleagues. They were always supporting me and encouraging me with their best wishes.

References

1. United Nations, Department of Economic and Social Affairs, Population Division,, *World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352)*, 2014.

2. United Nations (UN), *The Millennium Development Goals report 2013*, 2013, UN: New York.

3. Montgomery, M.R., et al., eds. *Cities transformed: demographic change and its implications in the developing world*. 2004, Earthscan: London.

4. Health Effects Institute, *Health effects of outdoor air pollution in developing countries of Asia; a literature review*, 2004, Boston, MA.

5. Agarwal, S., et al., *Urbanization, Urban Poverty and Health of the Urban Poor:Status, Challenges and the Way Forward*. Demography India, 2007. **36**(1): p. 121-134.

6. Barbiero, V.K., *Urban health: it's time to get moving!* Glob Health Sci Pract, 2014. **2**(2): p. 139-144.

7. Sario, M.D., K. Katsouyanni, and P. Michelozzi, *Climate change, extreme weather events, air pollution and respiratory health in Europe*. European Respiratory Journal, 2013. **42**(3): p. 826–843.

8. American Thoracic Society, *What constitutes an adverse health effect of air pollution? Official statement of the American Thoracic Society*. Am J Respir Crit Care Med 2000. **161**(2 Pt 1): p. 665–673.

9. World Health Organization. *7 million premature deaths annually linked to air pollution*. 2014 23 June 2014; Available from: http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/

10. Johnson, I. and K. Lvovsky, *World Bank special: Double burden*. Our Planet, 2001. **12**(2).

11. World Health Organization. *Ambient (outdoor) air quality and health* 2014 23 June 2014; Available from: http://www.who.int/mediacentre/factsheets/fs313/en/

12. Petkova, E.P., et al., *Particulate matter pollution in African cities*. Air Quality, Atmosphere & Health, 2013. **6**(3): p. 603-614.

13. Goggins, W.B., et al., *Effect modification of the association between short-term meteorological factors and mortality by urban heat islands in Hong Kong*. Plos One, 2012. **7**(6): p. e38551.

14. Smargiassi, A., et al., *Variation of daily warm season mortality as a function of micro-urban heat islands*. J Epidemiol Community Health, 2009. **63**(8): p. 659-64.

15. *Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe*. The Lancet, 1997. **349**(9062): p. 1341-1346.

16. Analitis, A., et al., *Effects of cold weather on mortality: results from 15 European cities within the PHEWE project*. Am J Epidemiol, 2008. **168**(12): p. 1397-408.

17. Anderson, B.G. and M.L. Bell, *Weather-Related Mortality How Heat, Cold, and Heat Waves Affect Mortality in the United States*. Epidemiology, 2009. **20**: p. 205-213.

18. Barnett, A., et al., *Cold and heat waves in the United States*. Environmental Research, 2012. **112**: p. 218–224

19. Wilkinson, P., et al., *Cold comfort: the social and environmental determinants of excess winter deaths in England, 1986–1996*. 2001: York:Joseph Rowntree Foundation.

20. Denman, K.L., et al., *Couplings Between Changes in the Climate System and Biogeochemistry*, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon, et al., Editors. 2007, Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA.

21. McMichael, A.J., *The urban environment and health in a world of increasing globalization: issues for developing countries*. Bulletin of the World Health Organization, 2000. **78**(9).

22. World Health Organization, *The World Health Report 1995: Bridging the Gaps*, 1995, The World Health Organization: Geneva.

23. Mutisya, E. and M. Yarime, *Understanding the Grassroots Dynamics of Slums in Nairobi: The Dilemma of Kibera Informal Settlements* International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 2011 **2**(2).

24. United Nations Development Programme, *Human Development Report 2007/2008* in *Fighting Climate Change: Human Security in a Divided World*2007, United Nations Development Programme: New York.

25. UN-Habitat, *State of the World's Cities 2008/2009 - Harmonious Cities*, 2009.

26. Kinney, P.L., et al., *Traffic impacts on $PM_{2.5}$ air quality in Nairobi, Kenya*. Environmental Science & Policy, 2011. **14**: p. 369 - 378.

27. Kenya National Bureau of Statistics (KNBS 2010), *Republic of Kenya Population and Census Survey*, 2009, Ministry of Planning.

28. Mitullah, W., *Understanding Slums: Case Studies for the Global Report on Human Settlements, 2003 – The Case of Nairobi, Kenya*, 2003.

29. © United Nations Human Settlements Programme (UN-HABITAT), *State of world's cities*, 2006/7.

30. Gulis, G., et al., *Health status of people of slums in Nairobi, Kenya*. Environmental research, 2004. **96**: p. 219-227.

31. Institute for Health Metrics and Evaluation, *GBD Profile: Kenya*. http://www.healthdata.org/sites/default/files/files/country_profiles/GBD/ihme_gbd_country_report_kenya.pdf, 2010.

32. Kyobutungi, C., et al., *The burden of disease profile of residents of Nairobi's slums: Results from a Demographic Surveillance System*. Popul Health Metr, 2008. **6**: p. 1.

33. Lozano, R., et al., *Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010*. The Lancet. **380**(9859): p. 2095-2128.

34. United Nations Environment Programme (UNEP), *Environmental Pollution and Impacts on Public Health: Implications of the Dandora Municipal Dumping Site in Nairobi, Kenya*, 2007. United Nations Environment Programme (UNEP): Nairobi.

35. Lim, S.S., et al., *A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010*. Lancet, 2012. **380**(9859): p. 2224-2260.

36. Ye, Y., et al., *Seasonal pattern of pneumonia mortality among under-five children in Nairobi's informal settlements*. American Journal of Tropical Medicine and Hygiene, 2009. **81**: p. 770-775.

37. Mulaku, G.C. and L.W. Kariuki. *Mapping and analysis of air pollution in Nairobi, Kenya*. in *International Conference on Spatial Information for Sustainable Development*. 2001. Nairobi.

38. Odhiambo, G.O., et al., *Motor vehicles air pollution in Nairobi, Kenya*. Research Journal of Environmental and Earth Sciences, 2010. **2**(4): p. 178-187.

39. Giles, L.V., et al., *From Good Intentions to Proven Interventions: Effectiveness of Actions to Reduce the Health Impacts of Air Pollution*. Environmental Health Perspective, 2011. **119**(1): p. 29-36.

40. Ballard-Tremmer, G. and A. Mathee, *Review of Interventions to Reduce Exposure of Women and Young Children to Indoor Air Pollution in Developing Countries*, 1999, World Health Organization/USAID Global Consultation: Washington, DC.

41. Barnes, B.R., et al., *A Behavioral Intervention to Reduce Child Exposure to Indoor Air Pollution: Identifying Possible Target Behaviors* Health Education Behavior, 2004. **31**(3): p. 306-317.

42. von Schirnding, Y., et al., *Addressing the Impact of Household Energy and Indoor Air Pollution on the Health of the Poor*, 2001, World Health Organization: Geneva, Switzerland.

43. Wakefield, S.E., et al., *Taking environmental action: the role of local composition, context, and collective*. Environmental Management, 2006. **37**(1): p. 40-53.

44. Douglas, M., *Risk and Blame: Essays in Cultural Theory*. 1992, London, UK: Routeledge.

45. Slovic, P., *Public perception of risk*. Journal of Environmental Health, 1997. **59**: p. 22-23.

46. Grason, H.A. and D.P. Misra, *Reducing exposure to environmental toxicants before birth: moving from risk perception to risk reduction*. Public Health Reports, 2009. **124**(5): p. 629-641.

47. Watterson, A., et al., *Integrating environmental health into nursing and midwifery practice* Journal of Advanced Nursing, 2005. **49**(6): p. 665-674.

48. Bettaieb J, et al., *Relationship between temperature and mortality in the city of Tunis: 2005-2007*. Archives de l'Institut Pasteur de Tunis, 2010. **87**: p. 25-33.

49. White, M.R. and I. Hertz-Picciotto, *Human health: Analysis of climate related to health*, in *Characterization of information requirements for studies of CO2 effects: Water resources, agriculture, fisheries, forests and human health*, White M.R, Editor. 1985, Department of Energy: Washington, D.C. p. 172-206.

50. Alberdi, J.C., et al., *Daily mortality in Madrid community 1986-1992: relationship with meteorological variables*. European Journal of Epidemiology, 1998. **14**: p. 571-578.

51. Yan, Y.Y., *Association between daily mortality and weather in Hong Kong*. The Internet Journal of Public Health, 2011. **1** (2).

52. Abe, T., et al., *The relationship of short-term air pollution and weather to ED visits for asthma in Japan*. The American journal of emergency medicine, 2009. **27**(2): p. 153-159.

53. Braga, A.L., A. Zanobetti, and J. Schwartz, *The time course of weather-related deaths*. Epidemiology, 2001. **12**(6): p. 662-7.

54. Jamason, P.F., L.S. Kalkstein, and P.J. Gergen, *A synoptic evaluation of asthma hospital admissions in New York City*. American Journal of Respiratory and Critical Care Medicine, 1997. **156**(6): p. 1781-1788.

55. Keatinge, W. and G. Donaldson, *Mortality related to cold and air pollution in London after allowance for effects of associated weather patterns*. Environmental Research, 2001. **86**(3): p. 209-216.

56. Mireku, N., et al., *Changes in weather and the effects on pediatric asthma exacerbations*. Annals of Allergy, Asthma & Immunology, 2009. **103**(3): p. 220-224.

57. Hajat, S. and T. Kosatky, *Heat-related mortality: a review and exploration of heterogeneity*. Journal of Epidemiology and Community Health, 2010. **64**: p. 753–760.

58. O'Neill, M. and K. Ebi, *Temperature extremes and health: impacts of climate variability and change in the United States*. Journal of Occupational Environmental Medicine, 2009. **51**: p. 13–25.

59. Goldberg, M., et al., *The short-term influence of temperature on daily mortality in the temperate climate of Montreal, Canada*. Environmental Research, 2011. **111**: p. 853–860.

60. Rocklöv, J. and B. Forsberg, *The effect of temperature on mortality in Stockholm 1998–2003: a study of lag structures and heatwave effects*. Scandinavian Journal of Public Health, 2008. **36**: p. 516–523.

61. Le Tertre, A., et al., *Impact of the 2003 heatwave on all-cause mortality in 9 French cities*. Epidemiology, 2006. **17**: p. 75–79.

62. Revich, B. and D. Shaposhnikov, *Excess mortality during heat waves and cold spells in Moscow, Russia*. Occup Environ Med, 2008. **65**: p. 691–696.

63. Baccini, M., et al., *Heat effects on mortality in 15 European cities*. Epidemiology, 2008. **19**(5): p. 711-719.

64. D'Ippoliti, D., et al., *Research The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project*. Environmental Health, 2010. **9**.

65. Marino, C., et al., *Effects of cold weather on hospital admissions: results from 12 European cities within the PHEWE project*. Epidemiology, 2009. **20**(6): p. S67-S68.

66. Michelozzi, P., et al., *High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities.* American journal of respiratory and critical care medicine, 2009. **179**(5): p. 383-389.

67. Gouveia, N., S. Hajat, and B. Armstrong, *Socioeconomic differentials in the temperature–mortality relationship in São Paulo, Brazil.* International Journal of Epidemiology, 2003. **32**: p. 390–397.

68. Wu, W., et al., *Temperature–mortality relationship in four subtropical Chinese cities: A time-series study using a distributed lag non-linear model.* Science of the Total Environment 2013. **449**: p. 355–362.

69. Keatinge, W.R., et al., *Heat related mortality in warm and cold regions of Europe: observational study.* BMJ, 2000. **321**: p. 670-673.

70. Pope, C.A.I., *Mortality effects of longer term exposures to fine particulate air pollution: review of recent epidemio¬logical evidence.* Inhalation Toxicology, 2007. **19**(suppl 1): p. 33-38.

71. Kan, H., et al., *Part 1. A time-series study of ambient air pollution and daily mortality in Shanghai, China.* Research Report Health Effects Institute 2010. **154**: p. 17-78.

72. Samet, J. and D. Krewski, *Health effects associated with exposure to ambient air pollution* Journal of Toxicology and Environmental Health Part A, 2007. **70**(3-4): p. 227-242.

73. Björkstén, B., et al., *Worldwide time trends for symptoms of rhinitis and conjunctivitis: Phase III of the International Study of Asthma and Allergies in Childhood.* Pediatric Allergy and Immunology, 2008. **19**(2): p. 110-124.

74. Pearce, N., et al., *Worldwide trends in the prevalence of asthma symptoms: phase III of the International Study of Asthma and Allergies in Childhood (ISAAC).* Thorax, 2007. **62**(9): p. 758-766.

75. Douwes, J. and N. Pearce, *Asthma and the westernization 'package'.* International Journal of Epidemiology, 2002. **31**(6): p. 1098-1102.

76. Anderson, H.R., *Air pollution and trends in asthma*, in *The rising trends in asthma*. 1997, Wiley Chichester. p. 190-203.

77. Huang, W., et al., *Visibility, air quality and daily mortality in Shanghai, China* Science of the Total Environment, 2009. **407**: p. 3295-3300.

78. Anderson, H.R., et al., *Particulate matter and daily mortality and hospital admissions in the west midlands conurbation of the United Kingdom: associations with fine and coarse particles, black smoke*

and sulphate. Occupational and Environmental Medicine, 2001. **58**(8): p. 504-510.

79. Stafoggia, M., et al., *Does Temperature Modify the Association between Air Pollution and Mortality? A Multicity Case-Crossover Analysis in Italy*. American Journal of Epidemiology, 2008. **167**(12): p. 1476-1485.

80. Zmirou, D., et al., *Time-series analysis of air pollution and cause specific mortality*. Epidemiology, 1998. **9**(5): p. 495-503.

81. Katsouyanni, K., et al., *Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project*. Epidemiology, 2001. **12**(5): p. 521-531.

82. Filleul, L., et al., *The relation between temperature, ozone, and mortality in nine French cities during the heat wave of 2003*. Environmental Health Perspectives, 2006: p. 1344-1347.

83. Hu, W., et al., *Temperature, air pollution and total mortality during summers in Sydney, 1994–2004*. International journal of biometeorology, 2008. **52**(7): p. 689-696.

84. Li, G., et al., *Does temperature enhance acute mortality effects of ambient particle pollution in Tianjin City, China*. Science of the Total Environment, 2011. **409**(10): p. 1811-1817.

85. Lin, C.-M. and C.-M. Liao, *Temperature-dependent association between mortality rate and carbon monoxide level in a subtropical city: Kaohsiung, Taiwan*. International journal of environmental health research, 2009. **19**(3): p. 163-174.

86. Mohr, L.B., et al., *Influence of season and temperature on the relationship of elemental carbon air pollution to pediatric asthma emergency room visits*. Journal of Asthma, 2008. **45**(10): p. 936-943.

87. Nawrot, T.S., et al., *Stronger associations between daily mortality and fine particulate air pollution in summer than in winter: evidence from a heavily polluted region in western Europe*. Journal of Epidemiology and Community Health, 2007. **61**(2): p. 146-149.

88. Qian, Z., et al., *High temperatures enhanced acute mortality effects of ambient particle pollution in the "oven" city of Wuhan, China*. Environ Health Perspect, 2008. **116**(9): p. 1172-1178.

89. Carder, M., et al., *Interacting effects of particulate pollution and cold temperature on cardiorespiratory mortality in Scotland*. Occupational and Environmental Medicine, 2008. **65**(3): p. 197-204.

90. Katsouyanni, K. and A. Analitis, *Investigating the synergistic effects between meteorological variables and air pollutants: results from the*

European PHEWE, EUROHEAT and CIRCE projects. Epidemiology, 2009. **20**(6): p. S264.

91. Pattenden, S., et al., *Ozone, heat and mortality: acute effects in 15 British conurbations*. Occupational and Environmental Medicine, 2010. **67**(10): p. 699-707.

92. Kampa, M. and E. Castanas, *Human health effects of air pollution*. Environmental Pollution, 2008. **151**(2): p. 362-367.

93. Pope, C.A., *Epidemiology of fine particulate air pollution and human health: Biologic mechanisms and who's at risk?* Environmental Health Perspectives, 2000. **108**: p. 713-723.

94. Gurjar, B.R., L.T. Molina, and C.S.P. Ojha, eds. *Air pollution: health and environmental impacts*. 2008, CRC Press.: Boca Raton, FL.

95. Vichit-Vadakan, N., et al., *Part 3. Estimating the effects of air pollution on mortality in Bangkok, Thailand*. Res Rep Health Eff Inst, 2010(154): p. 231-68.

96. McGranahan, G. and F. Murray, *Air Pollution and Health in Rapidly Developing Countries*, G. McGranahan and F. Murray, Editors. 2003, Earthscan Publications Ltd: London. Sterling, VA.

97. Smith, K.R., *Fuel combustion, air pollution exposure and health: the situation in developing countries'* Annual Review of Energy and Environment, 1993. **18**: p. 529-566.

98. Mercer, J., B. Østerud, and T. Tveita, *The effect of short-term cold exposure on risk factors for cardiovascular disease*. Thrombosis Research, 1999. **95**: p. 93–104

99. Sun, Z., *Cardiovascular responses to cold exposure*. Frontiers in bioscience (Elite edition) 2010. **2**: p. 495–503.

100. Wolf, K., et al., *Air temperature and the occurrence of myocardial infarction in Augsburg, Germany*. Circulation, 2009. **120**: p. 735–742

101. Pio, A., B.R. Kirkwood, and S. Gove, *Avoiding Hypothermia, an Intervention to Prevent Morbidity and Mortality From Pneumonia in Young Children*. The Pediatric Infectious Disease Journal, 2010. **29**(2): p. 153-159.

102. Clary- Meinesz, C., et al., *Temperature effect on the ciliary beat frequency of human nasal and tracheal ciliated cells*. Biology of the Cell, 1992. **76**(3): p. 335-338.

103. Eccles, R., *An explanation for the seasonality of acute upper respiratory tract viral infections*. Acta oto-laryngologica, 2002. **122**(2): p. 183-191.

104. Larsson, K., et al., *Inhalation of cold air increases the number of inflammatory cells in the lungs in healthy subjects*. European Respiratory Journal, 1998. **12**(4): p. 825-830.

105. Amirav, I. and M. PUT, *Temperature and Humidity Modify Airway Response to Inhaled Histamine in Normal Subjects1, 2*. Am Rev Respir Dis, 1989. **140**: p. 1416-1420.

106. Koskela, H. and H. Tukiainen, *Facial cooling, but not nasal breathing of cold air, induces bronchoconstriction: a study in asthmatic and healthy subjects*. European Respiratory Journal, 1995. **8**(12): p. 2088-2093.

107. Cheng, X. and H. Su, *Effects of climatic temperature stress on cardiovascular diseases*. European Journal of Internal Medicine, 2010. **21**: p. 164–167.

108. Donaldson, G., W. Keatinge, and R. Saunders, *Cardiovascular responses to heat stress and their adverse consequences in healthy and vulnerable human populations*. International Journal of Hyperthermia, 2003. **19**: p. 225–235

109. Bhaskaran, K., et al., *Short term effects of temperature on risk of myocardial infarction in England and Wales: time series regression analysis of the Myo¬cardial Ischaemia National Audit Project (MINAP) registry*. BMJ, 2010. **341**: p. 3823

110. Halonen, J., et al., *Outdoor temperature is associated with serum HDL and LDL*. Environmental Research, 2011. **111**: p. 281–287.

111. Ren, C., et al., *Ambient temperature, air pollution, and heart rate variability in an aging population* American Journal of Epidemiology, 2011. **173**: p. 1013–1021.

112. Kenny, G.P., et al., *Heat stress in older individuals and patients with common chronic diseases*. Canadian Medical Association Journal, 2010. **182**(10): p. 1053-1060.

113. Hsi-Hsing, Y., et al., *Inhibition of acute lung inflammation and injury is a target of brain cooling after heatstroke injury*. Journal of Trauma and Acute Care Surgery, 2010. **69**(4): p. 805-812.

114. El-Kassimi, F., et al., *Adult respiratory distress syndrome and disseminated intravascular coagulation complicating heat stroke*. CHEST Journal, 1986. **90**(4): p. 571-574.

115. Briggs, D., *Making a difference. Indicators to improve children's environmental health*, 2003, World Health Organisation: Geneva.

116. Council, e., *Developing national environmental health indicators*, 2002, Department of Health and Ageing: Canberra.

117. Liu, HY., et al., *Approaches to integrated monitoring for environmental health impact assessment*. Environmental Health, 2012. **11**(1): p. 88.

118. Hambling, T., P. Weinstein, and D. Slaney, *A review of frameworks for developing environmental health indicators for climate change and health*. Int J Environ Res Public Health, 2011. **8**: p. 1 - 22.

119. World Health Organization, *Framework for linkages between health, environment and development* in *Health in Sustainable Development Planning: The Role of Indicators* Y. von Schirnding, Editor 2002, World Health Organization: Geneva.

120. Corvalan, C., D. Briggs, and T. Kjellstrom, *Development of environmental health indicators*. Linkage methods for environment and health analysis, 1996: p. 19 - 53.

121. Briggs, D., *Environmental health indicators: framework and methodologies*, 1999, World Health Organization: Geneva.

122. Farchi, S., et al., *Defining a common set of indicators to monitor road accidents in the European Union*. BMC Publ Health, 2006. **183**: p. 1-12.

123. World Health Organization, *Monitoring health impacts of climate change in Europe*, 2001, World Health Organization: London.

124. Organisation for Economic Co-operation and Development (OECD), *Children's environmental health indicators: A survey*. http://www.oecd.org/greengrowth/tools-evaluation/35381349.pdf, 2005.

125. Commission for Environmental Cooperation (CEC), *Feasibility Study for the Development of Indicators of Children's Health and the Environment in North America*. http://www3.cec.org/islandora/en/item/1941-feasibility-study-development-indicators-childrens-health-and-en.pdf, 2003.

126. Sjöberg, L., B.E. Moen, and T. Rundmo, *Explaining risk perception. An evaluation of the psychometric paradigm in risk perception research*, 2004, Norwegian University of Science and Technology. p. 1-33.

127. Berry, P., et al., *The Role of Rosk Perception and Health Communication in Adapting to the Health Impacts of Climate Change in Canada*, in *Climate Change Impacts and Adaptation Program*2009, Earth Sciences Sector, Natural Resources Canada.

128. Elliott, S.J., et al., *The Power of Perception: Health Risk Attributed to Air Pollution in an Urban Industrial Neighbourhood*. Risk Analysis, 1999. **19**(4).

129. Hillier, D., *Communicating health risks to the public: A global perspective*, ed. D. Hillier. 2006, Aldershot: Gower.

130. McKenzie-Mohr, D. and W. Smith, *Fostering Sustainable Behavior: An Introduction to Community-Based Social Marketing* Education for Sustainability Series. 1999: Education for Sustainability Series. 176.

131. Saksena, S., *Public perceptions of urban air pollution with a focus on developing countries*, in *Environmental change, vulnerability, and governance*2007, East-West Center.

132. *"World Weather Information Service - Nairobi". World Meteorological Organization (UN)*. 19-05-2012; Available from: http://www.worldweather.org/071/c00251.htm - climate.

133. *"Climatological Normals of Nairobi". Hong Kong Observatory*. 19-05-2012; Available from: http://www.hko.gov.hk/wxinfo/climat/world/eng/africa/ken_madg/nairobi_e.htm.

134. Zulu, E.M., et al., *Overview of migration, poverty and health dynamics in Nairobi City's slum settlements*. J Urban Health, 2011. **88**(Suppl 2): p. 185–199

135. Oti, S.O. and C. Kyobutungi, *Verbal autopsy interpretation: a comparative analysis of the InterVA model versus physician review in determining causes of death in the Nairobi DSS*. Population Health Metrics 2010. **8**(21).

136. Organization, W.H., *WHO: International Classification of Diseases (ICD)*, World Health Organization.

137. Egondi, T., C. Kyobutungi, and J. Rocklöv, *Temperature Variation and Heat Wave and Cold Spell Impacts on Years of Life Lost Among the Urban Poor Population of Nairobi, Kenya*. International Journal of Environmental Research and Public Health, 2015. **12**(3): p. 2735-2748.

138. National Oceanic and Atmospheric Administration (NOAA). *Land-Based Datasets and Products*. Available from: (http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets).

139. Egondi, T., et al., *Time-series analysis of weather and mortality patterns in Nairobi's informal settlements*. Global health action, 2012. **5**.

140. Egondi, T., et al., *Community Perceptions of Air Pollution and Related Health Risks in Nairobi Slums*. International Journal of Environmental Research and Public Health, 2013. **10**: p. 4851-4868.

141. Gasparrini, A., B. Armstrong, and M. Kenward, *Distributed lag non-linear models*. Statistics in Medicine, 2010. **29**: p. 2224--2234.

142. Schwartz, J., *The distributed lag between air pollution and daily deaths*. Epidemiology, 2000. **11**(3): p. 320-326.

143. Zanobetti, A., et al., *Generalized additive distributed lag models: quantifying mortality displacement*. Biostatistics, 2000. **1**(3): p. 279-292.

144. Peng, R., et al., *Towards a quantitative estimate of future heat wave mortality under global climate change*. Environmental Health Perspective, 2011. **119**: p. 701–706

145. Meehl, G.A. and C. Tebaldi, *More Intense, More Frequent, and Longer Lasting Heat Waves in the 21st Century*. Science, 2004. **305**(5686): p. 994-997

146. Robinson, P.J., *On the definition of a heat wave*. Journal of Applied Meteorology, 2001. **40**(4): p. 762-775.

147. Gasparrini, A. and B. Armstrong, *The impact of heat waves on mortality*. Epidemiology, 2011. **22**(1): p. 68-73.

148. Rocklöv, J., A.G. Barnett, and A. Woodward, *On the estimation of heat-intensity and heat duration effects in time series models of temperature-related mortality in Stockholm, Sweden*. Environmental Health, 2012. **11**(23).

149. Atari, D.O., I.N. Luginaah, and K. Fung, *The Relationship between Odour Annoyance Scores and Modelled Ambient Air Pollution in Sarnia, "Chemical Valley",Ontario*. International Journal of Environmental Research and Public Health, 2009. **6**: p. 2655-2675.

150. Oglesby, L., et al., *Validity of annoyance scores for estimation of long term air pollution exposure in epidemiologic studies: the Swiss Study on Air Pollution and Lung Diseases in Adults (SAPALDIA)*. American Journal of Epidemiology, 2000. **152**: p. 75-83.

151. Lin, Y.-K., T.-J. Ho, and Y.-C. Wang, *Mortality risk associated with temperature and prolonged temperature extremes in elderly populations in Taiwan*. Environmental research, 2011. **111**(8): p. 1156-1163.

152. Yang, J., et al., *Daily temperature and mortality: a study of distributed lag non-linear effect and effect modification in Guangzhou*. Environ Health, 2012. **11**(1): p. 63.

153. McMichael, A.J., et al., *International study of temperature, heat and urban mortality: the 'ISOTHURM' project*. International Journal of Epidemiology, 2008. **37**(5): p. 1121-1131.

154. Kan, H., et al., *Diurnal temperature range and daily mortality in Shanghai, China*. Environmental Research, 2007. **103**(3): p. 424-431.

155. Mrema, S., et al., *The influence of weather on mortality in rural Tanzania: a time-series analysis 1999–2010*. Global health action, 2012. **5**.

156. Bi, P., et al., *Temperature and Direct Effects on Population Health in Brisbane, 1986-1995*. J Environ Health, 2008. **70**(8): p. 48-53.

157. Basagana, X., et al., *Heat waves and cause-specific mortality at all ages*. Epidemiology, 2011. **22**(6): p. 765-772.

158. Kyselý, J. and J. Kim, *Mortality during heat waves in South Korea, 1991 to 2005: how exceptional was the 1994 heat wave?* Climate research, 2009. **38**(2): p. 105-116.

159. Nitschke, M., et al., *Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis*. Environmental Health, 2011. **10**(42).

160. Hajat, S., et al., *Mortality displacement of heat-related deaths: a comparison of Delhi, São Paulo, and London. Epidemiology*. Epidemiology, 2005. **16**: p. 613–620.

161. Díaz, J., et al., *Impact of temperature and air pollution on the mortality of children in Madrid*. Journal of Occupational and Environmental Medicine, 2004. **46**(8): p. 768-774.

162. Cheng, Y. and H. Kan, *Effect of the Interaction Between Outdoor Air Pollution and Extreme Temperature on Daily Mortality in Shanghai, China*. Journal of Epidemiology, 2012. **22**(1): p. 28-36.

163. Guo, Y., et al., *Effects of temperature on mortality in Chiang Mai city, Thailand: a time series study*. Environ Health, 2012. **11**(36): p. 10.1186.

164. Lindeboom, W., et al., *The association of meteorological factors and mortality in rural Bangladesh, 1983–2009*. Global health action, 2012. **5**.

165. Braga, A.L.F., A. Zanobetti, and J. Schwartz, *The effect of weather on respiratory and cardiovascular deaths in 12 U.S. cities*. Environmental Health Perspectives, 2002. **110**(9): p. 859-863.

166. Guo, Y., et al., *The Impact of Temperature on Mortality in Tianjin, China: A Case-Crossover Design with a Distributed Lag Nonlinear Model*. Environmental Health Perspectives, 2011. **119**: p. 1719-1725.

167. Tunell, R., *Prevention of neonatal cold injury in preterm infants*. Acta Paediatrica, 2004. **93**(3): p. 308–310.

168. O'Neill, M.S., et al., *Preventing heat-related morbidity and mortality: New approaches in a changing climate*. Maturitas, 2009. **64**(2): p. 98-103.

169. Gaita, S.M., et al., *Source apportionment and seasonal variation of $PM_{2.5}$ in a Sub-Sahara African city: Nairobi, Kenya*. Atmospheric Chemistry and Physics Discussion, 2014. **14**(7): p. 9565-9601.

170. Gatari, M.J., J. Boman, and A. Wagner, *Characterization of aerosol particles at an industrial background site in Nairobi, Kenya*. X-Ray Spectrometry, 2009. **38**(1): p. 37–44.

171. Kinney, P.L., et al., *Airborne concentrations of $PM_{2.5}$ and diesel exhaust particles on Harlem sidewalks: a community based pilot study*. Environmental Health Perspectives, 2000. **108**(3): p. 213-218.

172. Dionisio, K.L., et al., *Within-neighborhood patterns and sources of particle pollution: mobile monitoring and geographic information system analysis in four communities in Accra, Ghana*. Environmental Health Perspectives, 2010. **118**(5).

173. Zhou, Z., et al., *Household and community poverty, biomass use, and air pollution in Accra, Ghana*. Proceedings of the National Academy of Sciences, 2011. **108**(27): p. 11028-11033.

174. Aboh, I.J.K., et al., *Identification of aerosol particle sources in semi-rural area of Kwabenya, near Accra, Ghana, by EDXRF techniques*. X-RAY SPECTROMETRY 2009. **38**(4): p. 348-353.

175. Boman, J., et al., *On the elemental composition of $PM_{2.5}$ in central Cairo, Egypt*. X-RAY SPECTROMETRY, 2013. **42**(4): p. 276-283.

176. Gao, Y., et al., *Chronic effects of ambient air pollution on respiratory morbidities among Chinese children: a cross-sectional study in Hong Kong*. BMC Public Health, 2014. **14**(105).

177. Ghosh, A. and A. Mukherji, *Air Pollution and Respiratory Ailments among Children in Urban India: Exploring Causality*. Economic Development and Cultural Change, 2014. **63**(1): p. 191-222.

178. Gani, A., *Air Quality and Under-five Mortality Rates in the Low-income Countries*. The Journal of Development Studies, 2015: p. 1-14.

179. Barnes, B.R., *Behavioural Change, Indoor Air Pollution and Child Respiratory Health in Developing Countries: A Review*. Int. J. Environ. Res. Public Health 2014. **11**: p. 4607-4618.

180. Jacquemin, B., et al., *Annoyance due to air pollution in Europe*. International Journal of Epidemiology, 2007. **36**(4): p. 809-820.

181. Kim, M., O. Yi, and H. Kim, *The role of differences in individual and community attributes in perceived air quality*. Science of the Total Environment, 2012. **425**: p. 20-26.

182. Klaeboe, R., et al., *Oslo traffic study—part 1: an integrated approach to assess the combined effects of noise and air pollution on annoyance*. Atmospheric Environment, 2000. **34**(27): p. 4727-4736.

183. Semenza, J.C., et al., *Public perception and behavior change in relationship to hot weather and air pollution.* Environment Research, 2008. **107**: p. 401– 411.

184. Barnes, B.R., *Why do caregivers protect their children from indoor air pollution in rural South Africa?* Mila: a journal of the Institute of African Studies, 2010. **11**: p. 1-16.

185. Jin, Y., et al., *The China Rural Energy and Health Research Group. Exposure to indoor air pollution from household energy use in rural China: The interactions of technology, behavior, and knowledge in health risk management*. Soc. Sci. Med, 2006. **62**: p. 3161-3176.

186. Howel, D., et al., *Public views on the links between air pollution and health in Northeast England.* Environmental Research, 2003. **91**(3): p. 163-171.