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Faculty of Social Sciences

Sociology, Social Policy & Criminology

Mortality trends on the road towards environmental sustainability: A case study with a focus on ambient air pollution effect in China

by

Duygu Cihan

Thesis for the degree of Doctor of Philosophy

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Abstract

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China experienced rapid economic growth following the introduction of a series of open market reforms in 1978, leading in turn to considerable societal and health transformation in the country. While the resultant economic growth, spurred by the establishment of special economic zones and infrastructure development in cities and urban areas, benefitted the country in terms of elevating millions out of poverty, it also widened income and health inequalities and augmented environmental degradation driven by unprecedented industrialisation and urbanisation. This thesis investigates the regional inequalities and trends in mortality and exposure to ambient air pollution in China and quantifies their potential association within a broader context of regional economic and social development. Mortality is widely acknowledged as a robust indicator of socioeconomic development. The UN Sustainable Development Goal SDG-3.9 specifically calls for urgent efforts to reduce the number of deaths and diseases attributed to environmental hazards including ambient air, water and soil pollution. This is particularly relevant in China where the growth of mega and large cities has been unprecedented over the last two decades with substantial population movements and infrastructural development. On the other hand, with a growing number of pollution prone industries and the steady increase in the use of motor vehicles, cities and urban areas in China have become increasingly exposed to air pollution and congestion. The extent of the impact of these external environmental factors on human health and survival in China has not been systematically analysed or quantified.

This thesis presents findings from three interrelated analyses of different sources of aggregate data, investigating how mortality in China has been influenced by changes in environmental conditions. First, we explain the trends and factors underlying regional differences in the relationship between mortality and economic growth in China. Second, we investigate the extent of environmental inequalities by analysing the differential effect of selected economic and industrial factors on air pollution levels in cities. Third, we analyse the effect of long-term ambient air pollution exposure, measured in terms of $PM_{2.5}$, on mortality at the regional and provincial levels. The level of relationship between economic growth and mortality is found to be to be unexpected and, in some cases, indirect.

Results indicate that mortality trends have been on decline and the macro factors that are the most significant in explaining the improvement in mortality are adult illiteracy, rural-urban economic inequality and health care provision. On the other hand, economic growth has a diminishing effect on mortality outcomes across different geographical regions in China, but it has contributed indirectly to reducing inequalities in mortality through better health care for children and adults. While examining the environmental inequalities and the underlying effect of economic and industrial factors on ambient air pollution in cities, we observed substantial regional disparities. Although regional environmental inequalities were stark, economic conditions and economic inequalities between cities and regions had no perceptible effect on ambient air pollution. Industrial activities turned out to be more relevant in explaining regional differences in air pollution. According to China National Ambient Air Quality Standards (CNAAQS), 78.6 % of cities exceeded annual $PM_{2.5}$ standards in 2015. Our estimations show as high as 2.8 million deaths associated with long-term exposure to $PM_{2.5}$ in the same year. The results indicate that highly polluted central provinces suffer the most in terms of air pollution exposure attributed to mortality.

The thesis concludes by highlighting the urgent need to address environmental inequalities underlying region-specific mortality differences in China, with a reflection on recent policy and legislation measures to tackle ambient air pollution in cities and urban areas. Despite the rigorous policy making, China seems to continue its struggle in reducing environmental and health inequalities. The findings call for improvement in mechanisms to monitoring implementation of health and environment policies. Inequalities are both a cause and outcome of environmental problems, and local governments should be encouraged to prioritise addressing environmental equalities over GDP growth.

Keywords: Mortality; Life expectancy; Ambient air pollution; Regional inequality; Environmental inequality; Sustainable Development; China

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Research Thesis: Declaration of Authorship

Print name:	Duygu Cihan
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I declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
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3. Where I have consulted the published work of others, this is always clearly attributed;
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6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;

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Definitions and Abbreviations

API	Air Pollution Index
AQG	World Health Organization’s Air Quality Guidelines
AQI	Air Quality Index
CMS	Rural Cooperative Medical Scheme
CO	Carbon monoxide
CPC	Communist Party of China
EPA	The Environmental Protection Agency
FYP	Five-Year Development Plan of China
GBD	Global Burden of Disease
GDP	Gross Domestic Product
IAR	Indirect Age Adjusted Mortality Rate
IER	Integrated Exposure-Response Function
IHD	Ischaemic Heart Disease
IPUMS	Integrated Public Use Microdata Series
MDG	Millennium Development Goals
NBS	National Bureau of Statistics of China
NCRMS	New Rural Cooperative Medical Scheme
NO_2	Nitrogen dioxide
O_3	Ozone
OECD	The Organisation for Economic Co-operation and Development
PAF	Population Attributable Fraction

PMx	Particulate Matter (i.e. PM2.5 refers to particles equal or smaller than 2.5 microns where as PM10 refers to particles equal or smaller than 10 microns)
RR	Relative Risks
SDG	Sustainable Development Goals
SDH	Social Determinants of Health
SMR	Standardized Mortality Ratio
SO_2	Sulphur dioxide
TSP	Total Suspended Particles
UEBMI	Urban Employees’ Basic Medical Insurance
UN	United Nations
UNESCO	The United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children’s Fund (originally United Nations International Children’s Emergency Fund)
URBMI	Urban Residents’ Basic Medical Insurance
US	United States
USD	United States Dollar
VOC	Volatile Organic Compounds
WHO	World Health Organization

Chapter 1 INTRODUCTION

This thesis examines inequalities in mortality over time in China and associated environmental impact as reflected in substantial increase in ambient air pollution particularly during the period when China achieved immense economic growth. More specifically, this thesis aims to present a comprehensive analysis of mortality trends, and the relationship between socioeconomic and environmental aspect of development. The dynamic relationship underlying these three dimensions is quite complex and required to be understood for policy-making.

1.1. Rationale and scientific relevance

People seek for longer and healthier lives. Understanding mortality change offers better explanation of demographic and epidemiological transitions, achieving mortality reduction and improved longevity have always been central to the development agenda of low- and middle-income countries. As Amartya Sen states (1998), mortality is a crucial indicator of economic development and reflects the inequalities in socioeconomic development dynamics. Since mortality is a key element in planning, implementing and evaluating health programmes and policies, its significance continues to be heavily stressed in major national and international developmental plans including the United Nations Millennium Development Goals (MDG4) and subsequently the United Nations Sustainable Development Goals (SDG3).

Sustainable development balances the aspects of economic growth, as well as environmental, social and physical wellbeing of a nation that goes through the development process. Sustainable development, as first defined in Brundtland Commission in (1987), addresses meeting the current needs while taking into consideration of the needs of future generations. Therefore, it strongly emphasizes the equity and redistribution of wealth to poor people instead of promoting only economic growth. However, it is difficult to maintain the balance of various aspects of development while pursuing economic growth. Current economic systems and policies seem to encourage economic growth and rapid urbanization, but any imbalance in development often leads to inequality and environmental degradation. As a result, maintaining balanced improvement in health, environment and economy is quite complex and difficult.

Good health is essential for sustainable development (United Nations, 2015). There is a need for research to understand the broader contextual factors that influence health outcomes, particularly in the light of sustainable development. There are indeed several studies that on health, environment and socioeconomic development in the development and wellbeing literature (Gangadharan & Valenzuela, 2001; Costantini & Monni, 2008; Chuang, Huang, Hu, Chen, & Tseng, 2015) . However, both the subject of development and wellbeing are very inclusive, they can be applicable to various fields, for example urbanisation, air pollution, climate change and so on. On the other hand, there are not many studies that integrate health, socioeconomic development and environmental aspect of development all together. Global Burden Disease (GBD) studies are one of the most comprehensive studies that analyse social and environmental aspects of health. It is essential to understand the interlinkages between health (mortality), socioeconomic development and environment. This thesis makes an attempt to address this research gap, especially in the context of China where there are only limited studies that incorporate the overall dynamics at the macro-level.

1.2. Research context

Longevity and individual wellbeing have been deeply engrained in Chinese culture, as reflected in their societal norms. Confucius strongly advocated the pursuit of a long and healthy life to become people’s habit. Although China has traditionally put a significant emphasis on living a longer and healthy life, it has not always been successful in achieving this desire. During the reconstruction of the country under Chairman Mao Zedong in 1950s, life expectancy was 40.8 years whereas the average life expectancy of the world and developed countries were 46.9 and 64.7 years respectively (United Nations, 2013). China during this period experienced high death rates and this resulted in low life expectancy in the early years of the People's Republic of China around 1950s. Since then, China has had notable success in improving mortality rates and life expectancy, and even managed to achieve its Millennium Development Goals (MDG) targets before the target year. In 2015, China's life expectancy was 75.9 years, which was four years higher than the world's average, and close to the level observed in developed countries (Worldbank, 2017).

Moreover, the country has witnessed an economic miracle in the last few decades, becoming the fastest growing economy in the world (Congressional Research Service, 2019). With the rapidly growing economy, China has been also going through a societal transformation. Those dynamic transitions as well as its growing political strength, make China an interesting case study for social sciences research.

Since 1980, China's rapid economic growth has resulted in lifting millions of people out of poverty; as well as increasing people's capability of supporting better lives such as diet quality and diversity, improved housing and sanitation, and access to better education and health care. However, economic growth alongside has also brought other challenges such as rising inequality, declining government's support on basic health, increased consumption, and environmental degradation and so on (Knight, 2016). Rapid economic growth and the urbanization that has accompanied it have undoubtedly availed populations of the benefits of increased economic conditions, but they have brought harm too. Income inequality rose sharply with economic growth; and although it began decreasing after late 2000s, it is still relatively high in comparison to high-income countries (OECD, 2017). Not only did income inequality became a challenge for developing China, so too did environmental inequality. To illustrate, China has four cities such as Baoding, Dezhou, Liaocheng and Xingtai on the top 15 of WHO's most polluted cities in the world list in 2015 (WHO, 2016). The provinces and administrative regions of China are shown on the map, see Figure 1.1. A recent study found that the under-five year old children are at the most risk of suffering from respiratory diseases, while the older populations are at risk of cardiovascular diseases (Zhao, Zhang, & Fan, 2014).

Figure 1.1 **Map illustrating province and administrative boundaries of China**

Source: Retrieved from https://geology.com/world/china-satellite-image.shtml on 28 September 2019

Moreover, the Zhao et al (2014) study claims that rural populations are the biggest victims of the environmental inequality in China due to the shift of heavy industries from urban to rural areas – as a strategic move towards reducing pollution in cities and urban areas.

China with 1.371 billion population which corresponds to 19% of global population, is the world's second biggest economy after the United States (Ministry of Foreign Affairs People's Republic of China, United Nations System in China, 2015). With the introduction of open market reforms in 1978, China's economic growth escalated to the levels that surpassed developed countries. However, rapid growth in economy does not translate into immediate development of the overall country. China is still considered as a transition economy despite the immense growth that no developed country has experienced in recent decades. For example, GDP per capita, with 8033.4 USD (i.e. 50,027.9 yuan or RMB), is still below the high-income countries but is around upper-middle income countries level (Table 1.1). Although rapid economic growth elevated millions of people out of poverty, 27% of total population is still under international poverty line of 5.50 USD a day which equals more than 370 million Chinese citizens (World Bank, 2019). Compared to high-income (i.e. 2%) and upper-middle income countries (i.e. 24%), China suffers more from poverty. Therefore, economic growth still is the major drive for China's development but instead of excessive growth, China aims for sustainable growth where the government could achieve balanced improvement in every sector.

Table 1.1 Economic, social and demographic indicators, China, 2015

Population (persons)	1,371,220,000
Surface Area (sq.km)	9,562,911.3
GDP per capita (current $)	8,033.4
GDP per capita (current LCU, yuan)	50,027.9
GDP growth, annual (%)	6.9
Life Expectancy, at birth (years)	75.9
Fertility rate (births per woman)	1.7
Crude Death Rate (per 1000 persons)	7.11
Under-five mortality rate (per 1000 persons)	10.7
Probability of dying between 15 - 60 years m/f (per 1 000 population, 2015)	100.1/64.5
Total expenditure on health as % of GDP (2014)	5.5
Agriculture, forestry and fishing, value added (% GDP)	8.4
Industry (construction included), value added (% GDP)	41.1

Source: World Bank (World Bank, 2019). Note that World Bank values might show slight differences from data published by China Statistical Bureau.

China has shown a strong determination towards sustainable development recently. Rather than growing uncontrollably, China has slowed down the pace of growth and focused on balancing each aspect of development, including social and environmental. In 2015, China announced its national plan to implement the Sustainable Development Goals (SDG) for 2030. China was successful in meeting the targets of MDG for 2015, and they want to display the same success story with the new SDG plan. In the last five-year development plan, China stressed the importance of sustainable growth in their new agenda. In order to reduce mortality, China has to inevitably take a sustainable approach. Therefore, it is important to examine mortality trends of the country, as well as the trends of the causes of mortality so that the country can learn from the past and plan better future for its citizens. In the light of China's new sustainable development agenda, the proposed study conducts a detailed investigation of mortality in a broader context addressing the changes in socioeconomic conditions and physical environment, from the time when market reforms were introduced.

1.3. Research objectives

The main aim of this thesis is to investigate mortality trends, and its underlying relationship between socioeconomic and environmental aspect of development.

The thesis is organised into a three-paper format. First, we analyse the mortality trends in Chinese provinces after market reforms in 1978. The objective is to assess the effect of rapid economic growth on mortality trends. Since data on mortality (and life expectancy) was not available at the provincial level during earlier years, we will employ life tables to estimate the key indicators such as life expectancy, under-five mortality and adult mortality for each province from 1981 until 2010.

Then we analyse recent trends in ambient air pollution and its association with economic growth. The objective of this chapter is to assess the environmental inequality in Chinese cities, addressing the factors that affect environmental inequality. Due to lack of inter-city data on ambient air pollution as well as other socioeconomic factors (such as income levels or other economic indicators like GDP per capita in district level), we defined environmental inequality in terms of regional differences in exposure to ambient air pollution. Ambient air pollution data was compiled in daily format and then aggregated to annual level. In addition, we evaluate the state's role in addressing environmental inequality across the Chinese cities by examining how well they implemented pollution abatement policies.

In the final analysis, we assess the impact of ambient air pollution on mortality across different Chinese provinces. Previously collected air pollution data was at city level, therefore we aggregated city level pollution concentrations to province level by population weighting. The reason for selecting provinces as case studies rather than cities is due to the lack of availability of death records in city level. Our objective is to find how provinces are affected by the ambient air pollution as well as how regional differences play role in defining pollution related deaths.

1.4. Research questions and hypothesis

The thesis addresses the following key questions in the designated chapters.

Mortality trends and differentials

i. To what extent does economic growth explain mortality and life expectancy trends over time? How are trends in socioeconomic development indicators related to mortality and life expectancy in China?
ii. Are there regional differences in mortality and economic growth? If so, what are the underlying explanations?

Environment inequality attributed to ambient air pollution

i. How does economic factors affect environmental inequality in China?
ii. What is the association between income inequality and environmental inequality? How does income inequality affect ambient air pollution in China?
iii. What is the role of state in addressing the environmental inequality?

Exposure to ambient air pollution and mortality

i. How does long-term exposure to ambient air pollution impact mortality in Chinese provinces? Are there any regional differences?
ii. How much does mortality decrease if China achieve its pollution abatement targets?

1.5. Policy relevance

China successfully achieved MDGs in 15 years since the goals launched in 2000. In meeting the targets, China made significant improvements in health, education, mortality reduction and poverty alleviation. However, the MDGs did not address the environmental problems in China. With the new SDGs, China not only continues being committed to global development agenda but also is proactive in implementing new policies that highlight the importance of sustainability in development process. SDGs addresses mortality reduction (SDG-3), poverty reduction (SDG-1) and economic growth (SDG-8), inequality reduction (SDG-10) and environmental protection (SDGs 6, 7, 11, 12 and 13). To achieve the targets by 2030, China launched its national policies through the 13th Five-Year-Plan (2016-2020).

The 13th Five Year Plan (FYP) highlights the importance of sustainable development. It addresses the need to provide equity in providing health care services and education, improve environmental conditions by reducing ambient air pollution according to set targets, doubling GDP from 2010 levels but stabilise annual economic growth to 6.5% in order to achieve sustainable development. Equity and sustainability are key elements in FYP. To implement such policies and achieve the set objectives require a deep understanding of the dynamics and the inter-relations of different aspects of development such as mortality, environment and economy. This thesis provides a comprehensive analysis of the relationships underlying these three dimensions and help understand the dynamics of the said relationships, moreover addresses the problems in implementing the policies as well as suggests policy recommendations. Therefore, the key policy contribution of this thesis is understanding how China progresses towards its sustainable development goals and addressing the challenges in terms of its current problems in policy implementations.

1.6. Structure of the thesis

The findings of the thesis are presented in three substantive analyses in research articles format. Following the introduction, the next chapter summarises the literature review addressing the broader theoretical aspects linked to mortality and health, and measurement of environmental inequality defined in terms of exposure to ambient air pollution. Chapter Three examines the mortality trends and the associated impact of socioeconomic factors in china. Chapter Four investigates the current ambient air pollution status and environmental inequality in China. The final analysis is presented in Chapter Five, which includes a detailed analysis of the effect of ambient air pollution on mortality in China. The thesis concludes in Chapter Six which summarizes the overall findings, with a discussion and an overview of research limitations, the key factors where policy makers should pay more attention to and considerations for future research.

Chapter 2 DEMOGRAPHIC CHANGE, INEQUALITIES AND ENVIRONMENTAL SUSTAINABILITY

This chapter presents a general literature review addressing the concepts and framework underlying demographic change, inequalities and environmental sustainability as well as the relationship between each other. Literature specific to each paper is included separately in respective chapters.

2.1. Mortality and development: Theoretical background

Mortality and development are two concepts that are closely interlinked. Mortality is often regarded as an important indicator of development. The well-known social scientist Amartya Sen (1998) suggests that mortality is a great instrument to measure the effects of development policies. However, the relationship between mortality and development is not one-way, but it is rather complex.

First attempts to describe the relationship, were to give an explanation to population growth and classify countries according to their similarities on the population growth. Thompson (1929) categorized countries based on their rate of population growths into three (i.e. Group A, B, C). The first category, Group A, consisted of the countries that displayed a decreasing natural population growth due to their decreasing birth rates while keeping low death rates. Developed countries like Western Europe and United States fit into this category. The second category, Group B, displayed a more rapid decline in death rates than the birth rates thus the natural population growth was not declining like Group A, rather there was still increase that could be observed. On the other hand, Group C did not display any sign of either decreasing birth rates or death rates, so increasing population growth had been going strong. These countries were mostly defined as developing and under-developed countries, and Thompson referred them as Malthusian countries. He espoused Malthus's principle of population (1798) that claims that populations increase exponentially whilst food production increases arithmetically and therefore people would face a resource scarcity inevitably in the future, so in order to prevent that happen, Malthus proposed controls on population growth. Based on this theory, Thompson (1929) claimed that the countries in Group C would continue in population growth unless there is enough resource to sustain life (i.e. clean drinking water, food, energy). He argued that the difference in the availability of the resources defines the differences the population growth. For example, he predicted that Russia would experience higher population growth than India. However, Russia is facing a serious depopulation risks because of declining birth rates and increasing death rates. Thompson (1929) predicted that vast lands and abundant resources would lead Russia's population to boom, but although those lands remained vast, the resources failed to accelerate the population as expected.

After Thompson, Adolphe Landry attempted to evaluate population growth in his book '*La Révolution Démographique*' that was published in 1934. He, similar to Thompson, classified countries in three groups: primitive, intermediate and contemporary (Kirk, 1996). He predicted that this three-staged demographic evolution has already occurred or will occur in every country in the world. The first stage is where there is high fertility and high mortality, and population growth is controlled with the change in mortality. In this case, fertility is not affected by the external economic conditions. In the second stage, people are conscious of achieving certain level of quality of life and so socioeconomic conditions start to influence fertility. However even at this stage, fertility and death rates regulate in equilibrium. On the other hand, in the third phase people are striving for even higher levels of quality of life. In this case, people take measures to limit fertility so therefore, the equilibrium of deaths and births break and thus population shrinking might be possibility (Landry, 1987).

Landry was one of the first commentators to formulate the notion of the demographic transition, however he used the term 'revolution' instead of transition as highlighted in his book published in 1934. Landry contributed to demographic transition literature even before the idea was theorized. However, Frank Notestein's presentation of the issue in 1945 became widely acknowledged as the first attempt to properly define demographic transition in the literature (see Box 1). Without prior knowledge of either works, he also described the transition in three stages. The first stage is where the populations just started their demographic transition and demonstrate "high growth potential" with high birth and death rates. The second stage, transitional growth, displays relatively earlier phase of demographic transition where death and birth rates started to decline but the decline in death rates began earlier than the decline in birth rates, so the population growth continued naturally. The third stage is the "incipient decline" and was described as the last stage of the transition where the birth rates fell beyond replacement level or close to that level (Notestein, 1945).

Box 1: Demographic Transition

The definition of demographic transition is that the change of the demography of a country from high fertility and mortality to low fertility and mortality along with the help of industrialization and modernization (Kirk, 1996).

Reasons for the decline in fertility and mortality according to Notestein (1953):

Fertility

- *Rapid urbanisation*
- *Reduction in family size*
- *Increasing cost of child-rearing*
- *Shift in roles of women in family and society*
- *Increased education and technology*

Mortality

- *Increased incomes*
- *Improvement in sanitate an medical knowledge*
- *Improvement in nutrition intake*
- *Elimination of deaths due to infectious diseases*

Demographic transition theory has been improved and elaborated by many other scholars into its latest form. According to the current demographic transition model, there are four phases of the transition: pre-transition, early transition, late transition and post transition. The first stage, pre-transition, described with high birth and death rates, and population growth was regulated by preventive (i.e. late marriages) and positive (i.e. war, famine, hazards etc.) measures. The second stage, early transition, displays population growth due to declining death rates while birth rates remain high. At the third stage, late transition, birth rates also begin to decrease, thus the rate of population growth slows down. At the last stage, post transition, population growth is either very small or non-existent and the population might be at the risk of decline due to low death and birth rates (Grigsby, 1991). Later, Blacker (1949) added a fifth stage where the countries have aging population and the fertility decreased below replacement level, so the depopulation begins.

Nevertheless, not every country has followed the same transition pattern as presumed (Figure 2.1). Szreter (1993) questioned the validity of the one directional linear transition assumption. Cleland (2001) further debated the demographic transition theory, which had always described transition with rapidly declining death rates, a lagged decline in fertility and as a result reaching population equilibrium eventually. However, not every country fit into this type of transition. Casterline (2001) stated that the regional/contextual difference plays a crucial role in pace of transition, so variations are observed in transitions. Difference in take-off timing for demographic transition of countries could be a significant element in determining development difference of countries (Cervellati & Sunde, 2015).

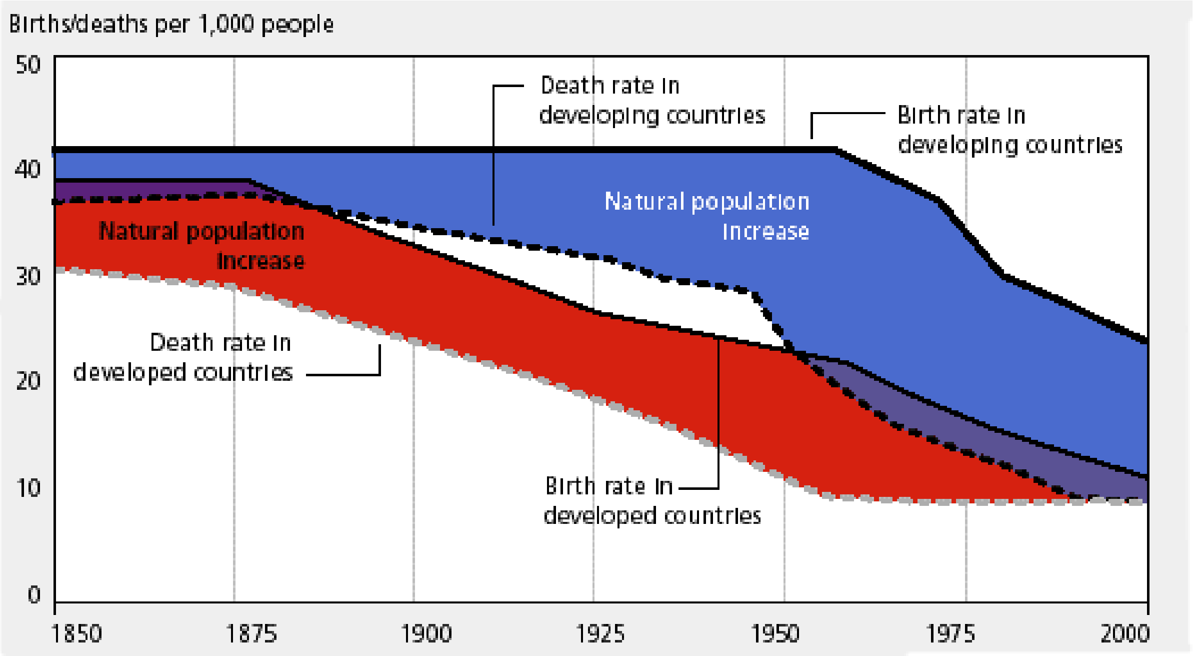


Figure 2.1 Death and birth rate trends between 1850 – 2000

Source: World Bank (Soubbotina, 2004)

2.2. Nexus between demographic change and environment sustainability

Demographic change and its link to environmental sustainability has been a subject to analysis for many years. One of the earliest studies that mentioned the links between population change and environmental sustainability was by Malthus (1798). He stated that population growth should be controlled because the population increase exponentially whilst food production increases arithmetically and thus people would face resource scarcity inevitably. He was not the only one that addressed the significance of demographic change on environment.

The United States National Academy of Sciences (1963) published a book called "The Growth of the World" where they highlighted the concerns regarding fast global population growth. Later, Paul Ehrlich made similar statements regarding population growth and its dynamic relationship between food production and environment in his book called "The Population Bomb" (1968). However, the famous neo-Malthusian Hardin stated in the "tragedy of commons" that people tend to overexploit commons (i.e. earth) as long as they see benefit but this freedom of overexploitation of shared commons would eventually become the tragedy and ruin the commons. Therefore, he vehemently promotes the idea of stopping breeding and thus overpopulation as he claims "freedom to breed will bring ruin to all" (Hardin, 1968). Later in 1972, The "Limits to Growth" by Club of Rome (1972) drew attention on how demographic change (i.e. population growth) accompanied with unprecedented economic growth impacts the environmental sustainability. The authors highlighted the concept of "carrying capacity". Some studies describe it as the maximum population that the given habitat can support indefinitely with the available resources to sustain life. According to Hui (2006) this definition could confuse with "population equilibrium" which indicates natural selection as in biological sense (Bellows & Hassel, 1999). According to Rees (Rees, 1992), carrying capacity is the number of people that a given environment can sustain without being irreversibly damaged. If the carrying capacity were exceeded, either the resources to sustain the given environment would be depleted beyond replenishment level or there would be over generated wastes due to over population and thus it would begin damaging the health of the population (Hui, 2006).

Carrying capacity effects population change in this way: if the population is below carrying capacity, the given population tends to increase. On the other hand, if the population is above the carrying capacity, population would collapse.

In an attempt to find the source of the environmental problems, Commoner (1972a) claimed that most of pollution problems in the US occurred after WWII where new technologies introduced to the country, therefore he blamed the new technology to be the reason of environmental pollution. However, Ehrlich and Holdren (1972a) disagreed with the idea and claimed that population size and growth are the major drivers of the environmental degradation. They presented a method that measures the human impact on environment which is called “I=PAT”. The impact “I” was directly influenced by population size “P” and the impact per capita “F” since the initial equation was formed as $I = P * F$ (Chertow, 2001). Since the variables were quite interlinked, they reorganised the equation to present them as interdependent. The new equation which was $I = P(I, F) * F$, stated that population is dependent on both the impact “I” and the impact fraction “F” where impact fraction “F” is also dependent on population. Despite disagreement with Ehrlich and Holdren, Commoner contributed to evolution of the formula as well. He defined “I” as the annual amount of pollution that is released to environment and still argued that new technology that focus on increasing productivity and cost efficiency during the post-war period is the one of the main causes of environmental pollution (1972a; 1972b).

However, Ehrlich and Holdren (1972b) still argued the position of technology on the impact on environment but they claimed that technological advancements may delay some environmental trends, but it cannot prevent them. Nevertheless, they took the Commoner’s interpretation of the impact formula (see Box 2) and finalize the current version of “I=PAT” formula (1972b). This function was utilized by different variety of studies (Dietz & Rosa, 1994; 1997; 1998; Greening, Davis, & Schipper, 1998; Waggoner & Ausubel, 2002). However, it is also heavily criticised. Because it is too simplistic and ignores the interactions between the indicators, as well as socio-cultural elements (Dietz & Rosa, 1998); Meyer and Turner (1992) claimed that it is mostly by biologist and ecologist and the terms in the equation does not relate to social science theory. Dietz and Rosa (1998) and

Waggoner and Ausubel (2002) improved the equation by re-formulating it as "STIRPAT" and "ImPACT".

Box 2: Definition of I=PAT (Ehrlich & Holdren, 1972b) **and its variations**

I-PAT aims to quantify the impact of human on the environment. The equation is as following: $I = P * A * T$

I: the impact of human on environment

P: Population

A: Affluence (usually GNP per capita or GDP per capita is used)

T: Technology factor

ImPACT is derived from I-PAT definition but includes consumption to the equation as following: $Im = P * A * C * T$

Im = Impact of human on environment

P = Population

A: Affluence (usually GNP per capita or GDP per capita is used)

T: Technology factor

STIRPAT is a stochastic model of I-PAT that utilizes regression analysis on population, affluence and technology to assess the impact of human on environment.

$I = aP_i{}^b * A_i{}^c * T_i{}^d * e_i$

a = constant

b, *c*, and *d = exponent* of P, A, and T where e is error term. According IPAT proportionality assumption; a = b = c = d = e = 1. The term "i" in the subscript refers to examined units.

Vicious Circle Model (VCM) is another neo-Malthusian model that intends to explain how fertility remains high during the depletion of environmental resources (Dasgupta, 1995). Meadows et al (1972) also incorporated this model into their World3 model for the "Limits to Growth" study. This model presents a scheme that population growth increase with high fertility as a replacement of high mortality rate in the societies where poverty rising due to low schooling, access to health care is decreasing and therefore mortality is increasing. High infant mortality rates, child dependency as a farm labour and women low status could be reasons for the high fertility (de Sherbinin, Carr, Cassels, & Jiang, 2007).

Meadows et al. (1972) attempted to create the first world model that captures the relationship between industrialization, population growth, malnutrition, depletion of non-renewable resources and environmental degradation. The model examines two scenarios; first scenario allows society to proceed along its historical path without major policy change. There is no effort to halt pollution or keep resources. So, it is a baseline scenario in which world runs as it is. In this scenario, population and industry grow until environmental and/or natural resource limits start to reduce the capacity of capital to sustain investment. As a result, industrial capital starts to deflate faster than a new investment can rebuild the capacity. At the end, food and health services begin to fail which leads reduction in life expectancy. The second scenario is "what if we double the resources" in the first scenario. In that case, industry can grow 20 more years, population rises to higher levels and this generates more pollution. The resources last longer in this scenario but the final behaviour is still overshoot and collapse. As a result, they predicted that if the current growth trends do not alter, the limits of growth will be reached in next hundred years. The result would be catastrophic and lead to uncontrollable deterioration in economy and human population. The authors states that the industrial output has been increasing more than human population. This means energy utilization is very high to sustain growing economy as well as human population. Javon Paradox assumes that technological advancements (i.e. improved efficiency) lead to increase the rate of consumption because either the saved-up income could be used for another consumption or it could lower the price of goods which means more consumption eventually (Alcott, 2008). This suggests a direct link between demographic change and environmental degradation as the major cause of the degradation was anthropogenic rather than natural causes (Shrinkhal, 2019). As Ripple et al. and more than 15 thousand scientists (Ripple, et al., 2017) claim that population growth is the main threat to environmental sustainability and urge stabilization of human population since it can overpower the sustainability efforts that has been made globally. They state that humans risk their future and the earth's future with overpopulation and overconsumption regardless of environmental degradation. However demographic transition models propose different view on the human impact on environment. According to the transition model, population growth would balance itself with the mortality and fertility reductions over the course of development process.

2.3. Environment inequalities due to ambient air pollution and mortality

Wilkenson and Pickett (2010) stressed the importance of equality in their phenomenon book "The Spirit Level" and argued that development is only meaningful unless the country is equal. Improvement in any socioeconomic or health outcomes would only result better, when the inequality maintained at lower levels. Inequality is a crucial measure of the socioeconomic and health improvement performance of a country. Income inequality is one of most common used indicators in development studies. According to Paskov et al. (2013) inequality increases consumption because it encourages individualism and fulfils the feeling of status seeking. That is, people mimic the rich by consuming more in order to increase or maintain their status. Therefore, in relatively more unequal societies, consumption is potentially higher and thus impact on environment would be greater. A further aspect of inequality that is the poorer or less privileged group of people tend to be more influenced by the changes in environmental degradation because they are more exposed to the changes – such inequality has been termed environmental inequality (Narain, 2016; Laurent, 2013; Laurent, 2015).

Environmental inequality definition includes intentional racism and discriminatory outcomes of environmental actions (Downey, 2005). Intentional racism highlights the significance of hazardous facilities locations while discriminatory environmental outcomes highlight inequality in health, exposure, and social impacts due environmental actions.

Laurent (2013) states that environmental inequality is closely related to social inequalities, in fact social inequalities are one of the major causes of environmental inequalities. Studies show that there is a strong correlation between environmental conditions and income inequality (Dorling, 2010b; Holland, Peterson, & Gonzalez, 2009; 2003). Higher income disparity is observed to increase environmental degradation such as pollution and waste generation. In addition, Boyce (1994; 1999) argued that power inequality is crucial indicator for environmental inequality. He described power in 5 categories: purchasing power, decision power, agenda power (i.e. decisions regarding to the issues that never make into public sphere), value power (i.e. ability of influencing other people's decisions), and event power (i.e. ability to set circumstances where people make choices). He claimed that inequalities in any form of power correlates with the social choices related to environmental protection as in favouring people with the power. With the cross-sectional analysis of power distribution, public health, and environment in 50 US states, he found that the higher power inequality gets, the weaker environmental policies become thus environmental degradation increase and eventually this leads to health problems.

Environmental inequality is measured in many ways. Boyce et al.(2016) applied composite inequality indices such as Gini coefficient, Atkinson index and Theil index; others incorporated environmental outcomes like biodiversity (Qian, et al., 2019) as an indicator. However, the most common used environmental outcome indicator is population health disparities attributed, either directly or indirectly, to pollution. However the literature on pollution related inequalities in western world are mainly about environmental racism (Mitchell & Dorling, 2003; Bell & Ebisu, 2012; Zwickl, Ash, & Boyce, 2014). China does not have similar approach to the environmental inequality as western countries did because there is not much racial variation within the country. Chinese literature usually addresses the regional differences (i.e. rural-urban, west-east and coast-inland areas) and social classification of occupational groups that work in environmentally hazardous industry (Mah & Wang, 2017). Rural residents and particularly rural migrants are usually the focus of the Chinese literature since they are the group of population that are most affected by the pollution exposure (Ma C. , 2010; Schoolman & Ma, 2012; Zhao, Zhang, & Fan, 2014). According to Zhao et al. (2014), China's industry relocation from east to west has caused great environmental inequality as less developed areas started to get exposed to more pollution. Because people living in less developed regions such as rural areas, living worse conditions such as migrant workers, and children and elderly people are found to be the most vulnerable people to pollution related health risks.

Environmental inequalities in the form of air pollution and its link to health is studied thoroughly by many scholars (Brulle & Pellow, 2006; Finkelstein, Jerrett, & Sears, 2005). Impact of air pollution on health is extensively analysed by many studies. One of the earliest studies that focused on the relationship between air pollution and human health was the study where Pope (1989) examined the relationship between PM10 concentration and hospital admissions in Utah Valley, United States. Utah Valley was severely polluted because of a heavily emitting mill, so Pope took this region as a case study and examined the monthly hospital admissions and air pollution concentration over three years from 1985. The results show significant correlation between air pollution exposure and hospital admissions for bronchitis, asthma, pneumonia and pleurisy. Pope continued presenting strong evidence for the link between pollution exposure and respiratory dysfunctions (Pope, Dockery, Spengler, & Raizenne, 1991) as well as lung dysfunctions (Pope & Dockery, 1992).

In addition to general health, studies suggest that there is also a strong link between air pollution exposure and mortality (Dockery, et al., 1993; Samet, Dominici, & Curriero, 2000; Laden, Schwartz, Speizer, & Dockery, 2006). Air pollution literature are categorized in two group: short-term and long-term exposure impact on health. Short-term studies address the acute health outcomes by using daily air pollution exposure, but long-term studies address chronic health outcome by using longer period of pollution exposure. Short-term studies are more prevalent in the literature in comparison to long-term studies. In one of the most cited short-term studies, Samet et al. (2000) analysed link between daily mortalities and ambient air pollution in 20 large cities in the United States from 1987 until 1994. Results presented a significant evidence to the impact of daily exposure on all cause, cardiovascular diseases and respiratory disease mortality rates. For every $10\mu g/m^3$ increase in PM10, there is 0.51% in all-cause mortality and 0.68% increase in both cardiovascular disease and respiratory diseases mortality. On the other hand, long-term exposure studies in the literature are considerably lesser than short-term studies since they usually require larger data sets like cohort studies.

Dockery et al. (1993) used “Harvard Six Cities” cohort study of United States and examined the long-term exposure impact on the mortality of 8111 adults for 14 to 16 years starting from 1974 by using Cox proportional hazards regression. Comparisons between the least polluted and the most polluted cities showed that the most polluted cities have 1.26 times higher risks of deaths for all cause and cardiopulmonary mortality due to have pollution in comparison to the least polluted cities. Pope et al. (1995) analysed the long-term exposure impact on mortality of 552,138 adults in 154 United States cities for 7 years starting from 1982 by using “American Cancer Society” (ACS) cohort study. The results indicated that the most polluted cities have 1.17 times more risks of death attributed to fine particulate exposure in comparison to the least polluted cities. In addition, a strong correlation between air pollution and cardiopulmonary and lung cancer deaths are found. Krewski et al (2000) reanalysed the studies of Dockery (1993) and Pope (1995). After reanalysing, the results were observed to be close to original studies. Relative risks of death for all-cause deaths was found 1.28 in case of 18.6 μg/m^3 increase in fine particles for “Harvard Six Cities” study and 1.18 in case of 24.5 μg/m^3 increase in fine particles for ACS study.

Pope et al. (2002) re-estimated their original study from 1995 because previously they utilized linear function for pollution-mortality relation but in this new study they applied log-linear function which is observed to be a better fit for high polluted areas. This study included 1.2 million adults as of now remains to be one of the biggest studies in the field. The results showed that relative risks of death for every 10 μg/m^3 increase in PM2.5 as 1.06, 1.09 and 1.14 for all cause, cardiopulmonary disease and lung cancer cases, respectively. Laden et al. (2006) presented a follow-up study of ACS in order to assess the effect of improvement in pollution concentration on mortality. Extended by 8 years from the original study, the follow-up study found the relative risks of all-cause death as 1.16, cardiovascular deaths as 1.28 and lung cancer as 1.27. Another follow up of ACS study was presented by Krewski et al. (2009). This follow-up study observed increase in relative risks of deaths ranging from 3% to 15% depending on the cause of death. Also, it suggested that deaths due to Ischaemic Heart Diseases (IHD) which is closely linked to PM2.5 exposure, were affected the most when ecological covariates (i.e. socioeconomic elements like school attainment, income level, housing) are controlled. Relative risks of deaths for IHD increased by 7.5%.

A follow-up "Harvard Six Cities" study was conducted by Lepeule et al. (2012). They reanalysed the previous study with the additional 11 years with the same Cox Hazard regression. They found 14% increase in all-cause mortality, 26% increase in cardiovascular mortality and 37% increasing in lung cancer mortality for every 10 µg/m^3 PM2.5 increase. Unlike other studies, Burnett et al. (2014) introduced a new adaptation of log-linear function which is named integrated exposure response function. The function integrates various sources of emissions such as ambient air pollution, household solid cooking fuel, active smoking and second-hand smoking. This function assumes the shape of relation between pollution and mortality is supra-linear. As a result of this, the estimated number tends be lower than the log-linear functions.

Zhang and Kanbur (2005) states that the regional variation in health outcomes grew a lot after the market reforms. China has been going through a rapid economic growth since the market reforms and the government encouraged increasing urbanisation, the risk of having chronic diseases is observed to be increasing with locating in urban areas; moreover, the life style of richer groups worsens the health conditions by changed diet and less physical activities (Miao & Wu, 2016). With rapid economic growth, people have begun to consume more; this in turn has led to increasing environmental degradation. Studies show that environmental pollution has an immense impact on the incidence and prevalence of respiratory diseases, cancer and cardiovascular diseases (Chen, et al., 2017; Wu, Benjamin, & MacMahon, 2016; Wan, Ren, Ma, & Yang, 2017). Through the years of epidemiological transition of China, not only have urban areas shifted to a phase of having such chronic diseases that are associated with richer societies, but also rural areas have also started to show similar trends. (Zhao Z. , 2007).

2.4. Summary

Demographic change, development, and environment are closely interlinked. Demographic transition explains the demographic change that is induced by development process of a nation. It states that demographic shift from high fertility and mortality to low fertility and mortality are expected as the nation develops. Improvements in health care, women status, education cause reduction in fertility as well as mortality rates. However, if the development performance of a nation is poor, this nation observes high mortality and high fertility rates. VCM explains the system stating that high fertility increases the resource use and cause reduction in educational attainment as well as limited access to healthcare systems. It creates environments where highly dense population must share limited space and land source. According to United Nations Population Division (Montgomery, 2009), two-thirds of the global population will reside in urban areas by 2050. This transformation leads to significant health consequences. VCM mentions increase in infectious diseases as population density increases which is a concerning threat of high urbanisation rates in developing countries. Due to increasing disease and worsening lifestyle, VCM claims that mortality would increase. The increased mortality rates, particularly infant and children, would increase the fertility rate as a mechanism of replacement. However, demographic transition along with epidemiological transition by Omran (1971) which describes the change of trends in health and disease as well as the interactions between these trends and their demographic and socioeconomic elements, suggest that non-communicable chronic diseases would replace infectious diseases through the development process. The reason for increasing chronic and degenerative diseases could be the increasing industrialization and urbanisation during that period; however, the population's age distribution would change in this period too, due to increased socioeconomic conditions and health awareness.

As VCM and demographic transition indicates a natural population equilibrium according to development process, some ecologist and demographers have more fatalistic approach. They claim population growth will be continuous unless we limit the growth by preventive measures. They claim that population growth will overshoot the earth's carrying capacity and this will lead to great environmental degradation and eventually the destruction of earth beyond repair (Ehrlich P. , 1968; Ehrlich & Holdren, 1972a; 1972b; Hardin, 1968; Meadows, Meadows, Randers, & Behrens, 1972; Malthus, 1798). In order to assess the human impact on environment, some models like "I=PAT" is introduced (Ehrlich & Holdren, 1972a; 1972b). This model shares the same Malthusian perspective on population growth and claims that the population growth is the major driver of human impact on environment, therefore it suggests population growth to be controlled. Although there are less fatalistic approaches like “ecological footprint” that mainly focuses on overconsumption rather than overpopulation, there are many researchers that supports the Malthusian view. In 2017, more than fifteen thousand researchers pleaded urgent action to be taken against rapid population growth because it can overpower the global sustainability efforts (Ripple, et al., 2017).

Besides overpopulation, demand for consumption is acknowledged to be beyond the available global resources. Valentine (2010) shows that global consumption by the year 2001 exceeded world capacity by 21%. He claims that despite the exceeding sustainable carrying capacity of the earth, consumption is still perceived as the main driver of economic growth. There are many economic growth theories such as uneconomic growth (Daly, 1999), de-growth (Jackson, 2009; Kallis, Kerschner, & Martinez-Alier, 2012), a-growth (van der Bergh, 2011) presented for achieving sustainable growth. Common view of these approaches are human activities, particularly consumption should be within the carrying capacity of the earth. Otherwise there is serious consequences for human and environmental health. This is two end relationship. Besides the magnitude of human impact on environment, the impact of environment on human health is also evident. Environmental degradation, in this case air pollution, has significant effect on human health. There is a direct link between air pollution and mortality (Dockery, et al., 1993; Samet, Dominici, & Curriero, 2000; Laden, Schwartz, Speizer, & Dockery, 2006). Studies show that disadvantaged groups like poorer people and urban slums are more affected by the environmental degradation (Narain, 2016; Laurent, 2013; Laurent, 2015; Zhao, Zhang, & Fan, 2014). Therefore, environmental inequalities should be addressed as significant factor in human health.

Chapter 3 SOCIAL DETERMINANTS OF HEALTH: THE IMPACT OF SOCIOECONOMIC EXTERNALITIES ON MORTALITY IN CHINA

Abstract

Background: Longer life expectancy and mortality reduction is often attributed to development of a country. Despite the rapid economic growth beyond the level of developed countries, China remains behind in social development. However Chinese authorities have prioritized economic growth as the means of overall development of the country.

Objective: This study investigates the macro level effect of socioeconomic factors on mortality trends in Chinese provinces during the years where economic growth was at peak.

Methods: We conducted a time-series study with the data from Population censuses and statistical yearbooks. Life tables created for each province for the studied period.

Results: Findings suggest that rapid economic growth does not affect improvement in life expectancy as it affects under-five mortality and adult mortality. Eliminating adult illiteracy, particularly female adult illiteracy, plays a great role in mortality reduction. Consistent with the literature, we found that under-five mortality is more associated with social factors such as access to health care services which has immediate effect on health and mortality. However, adult mortality is more associated with economic factors. Inland-coastal disparities, as well as rural-urban disparities within provinces are observed in terms of mortality levels. Western provinces have the highest mortality rates and the lowest life expectancy levels in comparison to eastern provinces

Conclusion: Our findings suggest that despite great mortality reduction and life expectancy improvements, China still has room for further improvements. China should focus on eliminating inequality in health, education and income, and implement policies that would balance the development throughout all the regions in the country.

Contribution: The analysis enhances our knowledge and understanding of mortality trends of Chinese provinces during the peak of economic growth in China. It contributes to the limited mortality literature as well as social determinants of health literature in China based on the analysis of most recent mortality data.

3.1. Introduction

This chapter presents the analysis of recent mortality trends in China, and further examines the social determinants of health and reassesses their impact on mortality. We conducted a statistical analysis with time series data that covers the death records of provinces for last three decades until 2010. Although there exist mortality studies regarding China in the literature, only a few studies systematically addressed mortality trends in China due to lack of availability of published data. This implies that there are even limited studies published in English language. Moreover, the few existing studies are not up-to-date. This chapter contributes to the literature by providing an analysis of province level mortality trends with the most recent data, as well as to the social determinants of health (SDH) literature.

China has made exemplary progress in terms of mortality reduction and health development since the establishment of the Republic of China. Since longer life span and reduction in mortality are often associated with economic growth, China's mortality and life expectancy improvement may be associated with rapid economic growth. Despite the unprecedented economic development, China still lags behind other middle- and high-income economies in terms of social aspects of development. As Sen (1998) acknowledges some socioeconomic variables have a crucial impact on mortality, and we often pay attention to those socioeconomic variables at the time when economic growth was at its peak and figure out their influence on mortality change through the years. This may help readers to see China's efforts to improve health conditions and mortality and could be an example to other developing countries.

China demonstrated an economic miracle by being the fastest growing country in the world for many years. By sustaining average 10% growth rate of GDP for a sufficiently long period, the country relieved 800 million people from poverty (World Bank, 2017). In this study, we conducted an analysis to assess how economic growth benefitted social sectors and how these sectors directly or indirectly affected mortality in China over the years. The paper addresses the following research questions:

1. *To what extend does economic growth explain mortality and life expectancy trends over time? How are trends in socioeconomic development indicators related to mortality and life expectancy in China?*

2. *Are the regional differences in mortality and economic growth? If so, what are the reasons for such differences?*

In order to answer these questions both health related literature and development literature were reviewed thoroughly. A framework based on Dahlgren and Whitehead's Rainbow Model (1991), was developed in order to identify the social factors, layers that each social factor belongs, and how the factors interact with mortality (Figure 3.1). This framework assists us to explore the influence of each social determinant and their interaction with each other. The 'Rainbow Model' that illustrated the social determinants of health in concentric half-circles that represents the layers of the determinants such as individual lifestyle factors, social and community networks, and general socioeconomic cultural and environmental conditions. These three layers interacts with each other from individual level to surrounding community and social levels.

The model facilitated many researchers to explore the effect of the social determinants on health in different contexts. Based on this framework, we took an upstream approach and selected our socioeconomic determinants for the study. Individual traits are placed at the centre layer and surrounding layers at macro level socioeconomic, cultural and environmental factors that can be modified to change health conditions of the individual. The second layer is general socioeconomic conditions that provide support (i.e. increasing life standards, receiving health services), but in the case of no support or less support there can be negative influence (i.e. receiving no health care services). The third layer is cultural and environmental conditions. This layer is beyond receiving socioeconomic advantage from government, it includes urbanisation, inequality and regionality that has come thorough by the years). It is important to stress that although we are using a framework motivated by Dahlgren and Whitehead, we do not have individual level data available. The focus here is therefore on the impact of macro socioeconomic development on the environment (i.e. with increased economic conditions in eastern regions there is more urbanisation there and there is an income inequality between east and west) and their association with mortality.

Our study was inspired by Banister and Zhang's (2005) article on China's mortality trend and how the socioeconomic development influenced the mortality outcomes. The authors used several socioeconomic indicators that are commonly used in development literature such as per capita consumption, adult illiteracy rate (Xue & Tianjian, 2001), number of doctors (Anand, et al., 2008), government's share of expenditure on health and education (Kanbur & Zhang, 2003), urban-rural inequality (Sicular, Ximing, Gustafsson, & Shi, 2007), and regional status of the province (Kanbur & Zhang, 1999). In this study, we used similar indicators but for the economic indicator we preferred GDP per capita instead. In addition, we added urbanisation rate to the list of indicators because of increasing urbanisation rate in recent years.

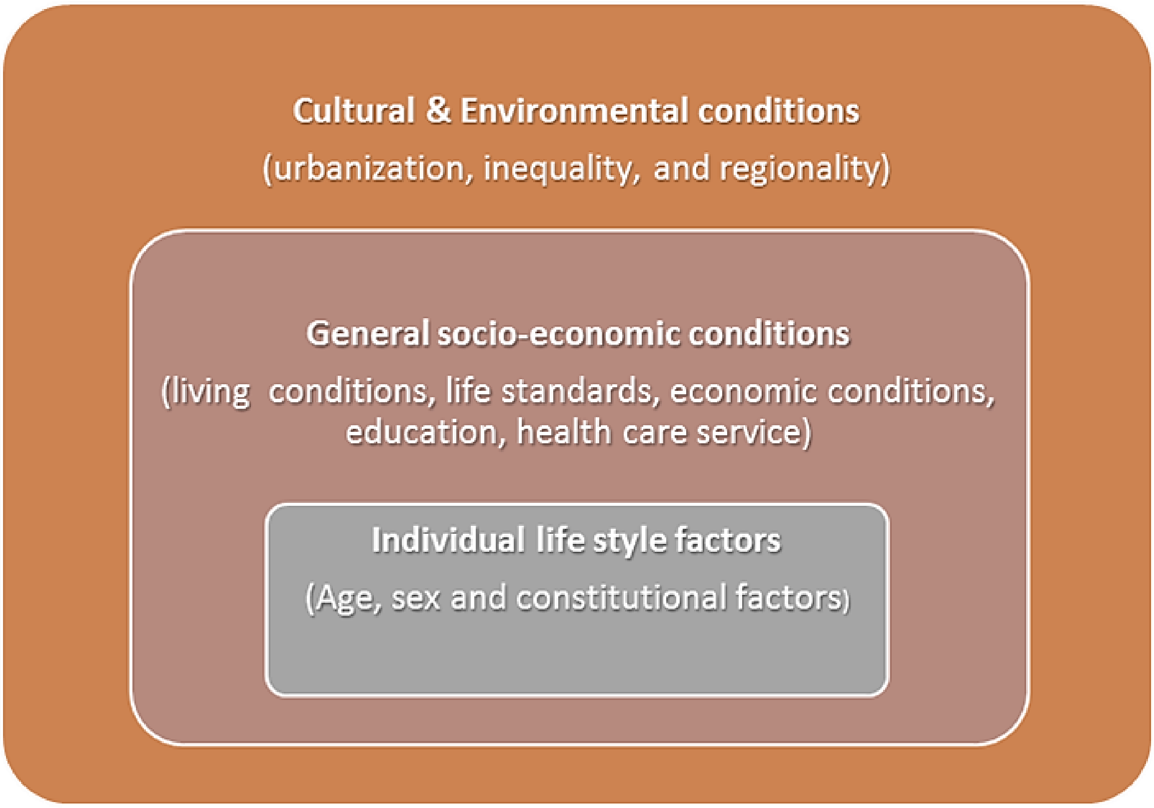


Figure 3.1 Social Determinants of Health Framework adapted to China

Source: Author's own work adapted from (Dahlgren & Whitehead, 1991)

3.2. Literature Review

Social Determinants of Health (SDH) are defined as life conditions that are determined by the "distribution of money, power and resources at global, national and local levels" (WHO, 2017). In the early 20th century, SDHs were not emphasized because there was a common understanding that being healthy meant absence of diseases so instead of preventive measures, elimination of disease was practiced. However, with McKeown thesis (1955; 1962; 1972) and (1975), there was a holistic shift in the approach towards understanding health and mortality. Causes of death and factors underlying health risks began to be emphasized more prominently in public health.

With changes in the complexity of factors that influence disease and health outcomes, McKeown's thesis has somewhat lost its credit in academia, however, it continues to stay relevant. McKeown (1962) introduced the idea of examining the causes of deaths instead of just focusing on the elimination of diseases. Moreover, it showed that the non-medical influence on health was bigger than what had been previously thought. Thus, it paved the way for studies on the social determinants of health that is now a fundamental element to public health. One of the first examples of SDH studies is Lalonde Report (1974). Lalonde, the Canadian health minister at the time, released a report that stressed the importance of human biology and socioeconomic conditions of society such as life style, environment and health services on the public health even before the SDH concept had established in the literature. The report became the first governmentally published document to advocate the importance of external factors to health (McKay, 2000). After that, many other SDH theories and models were created as a means of conceptual framework to explain relation between SDH indicators and health outcomes (Evans & Stoddart, 1990; Dahlgren & Whitehead, 1991; Commision on the Social Determinants of Health, 2008).

Majority of SDH literature is from the western world, particularly Canada, United States and United Kingdom (Lucyk & McLaren, 2017). Although not comparable in terms of quantity, there are some notable cases from developing countries like Iran (Bahadori, et al., 2015), and various Latin American countries (de Andrade, et al., 2015). However, there is a lack of literature regarding China that have utilized the "social determinants of health" as a framework , Lei et al. (2010), Liang et al. (2012) and Zhang et al. (2016) are one of the few studies available. Lei et al. (2010) analysed the epidemiological transition of hypertension in China and its relation to SDHs such as income, education and access to health care. They found that hypertension prevalence was not significantly affected by health care access, education and income but the diagnosis and treatment in urban regions were strongly affected by education levels. Liang et al. (2012) conducted a cross sectional survey in order to assess the impact of SDH on depression. They included socioeconomic status, social cohesion and negative life events in their SDH model and found that change in depression levels were affected by the change in SDHs. Zhang et al. (2016) examined the social determinants of school children's health behaviours in Beijing. They included demographic, educational and familial factors as well as health knowledge in their SDH model.

Analysing SDH is very important and fundamental to health studies. Most of existing SDH studies regarding China focus on health equity (Tang, et al., 2008; Liu & Griffiths, 2011; Gonzales, Liu, Roberto, & Kowal, 2016; Chen & Hao, 2016). There are some studies that have focused on specific type of health condition or mortality outcomes such as child mortality (Feng, et al., 2012), adult mortality (Banister & Zhang, 2005), and life expectancy (Song, Chen, & Zheng, 2010; Banister & Zhang, 2005). Banister is one of the most acknowledged researchers in the field of mortality in China. She examined the effect of China's socioeconomic (1981; 1998; 2005) and demographic (1984a; 1984b; 1987) transformation on mortality. In her recent work, Banister (2005) presented how certain socioeconomic factors influence mortality in China by conducting time series analysis. The SDH data consisted of GDP per capita, education, health services and income inequality from the year 1981 until 1995. The results showed that economic development and education, particularly adult illiteracy, played an important role in mortality reduction in China.

3.3. Mortality in China

China has shown a tremendous decline in mortality since the establishment of the new communist regime in 1950. With the help of rigorous medical interventions during the early years, mortality declined very fast. However right after the Communist Party of China (CPC) launched the great leap forward campaign in 1958, mortality decline took an opposite turn (Hesketh & Zhu, 1997).

The campaign was aimed to transform the country from agricultural society to industrialized socialist country. With the help of assertive policies to change the society into an industrialized one, some extreme measures had been taken. Rural population was prohibited private farming and forced into mandatory agricultural collectivization (Peng, 1987). In addition, many people were drawn into forced labour. The focus of this campaign was to outperform other countries in steel production, which was a crucial indicator in industrialization at the time being. Therefore, almost all the villages were transformed into working communes where people would live and work together and produce steel (Li & Yang, 2005). However, this led to poor life conditions and unsatisfactory results that was not foreseen on the planning stage. Agricultural production failed to keep up with the demand and due to the government's poor planning of redistribution of food and resources, it led to severe starvation and famine.

At the end of the year 1962, there was more than 15 million deaths occurred according to the national statistics but according to other sources the number of deaths were between 16.5 to 30 million (Li & Yang, 2005). After 1962, CPC loosened their strict regulations. They allowed farmers to sell their production surplus and abandoned the communes of steel workers. This led to decline in mortality rates again (Figure 3.2).

Since then mortality rates kept decreasing in a steady pace, as well as the birth rates. Even before the implementation of one-child policy in 1979, the birth rate gradually decreased over the years (Whyte, Feng, & Cai, 2015; Qin, Falkingham, & Padmadas, 2018). From the year 1949 to 1979 (the year that one-child policy implemented), the birth rate had already dropped from 36 per thousand to 17.8 per thousand. Moreover, birth rates increased during 1980s (Figure 3.2). Whyte et al (2015) claims that the further decline in fertility is due to the rapid economic growth rather than the implementation of birth limits.

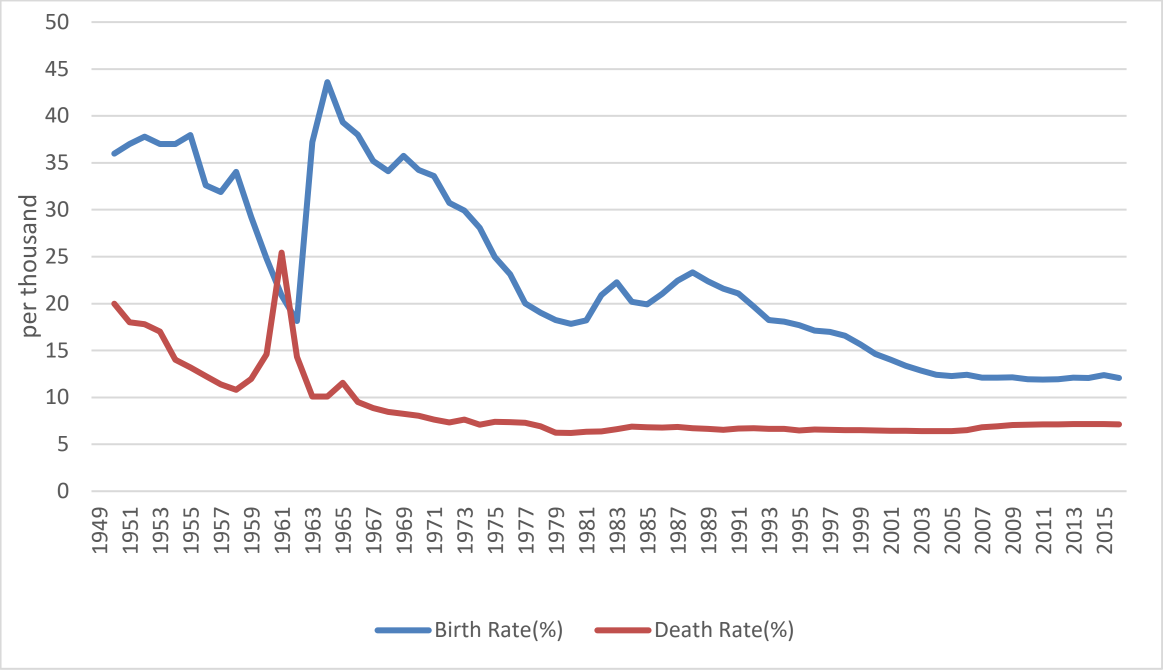


Figure 3.2 Crude birth and death rates of China after the establishment of PRC

Source: (National Bureau of Statistics of China, 2016)

China experienced a rapid mortality decline after the change of regime in 1950s until 1970s. This translates into an increase in life expectancy. Over the period between 1960 and 1970, life expectancy at birth had increased by 15 years (Figure 3.3); this period witnessed the most rapid increase of life expectancy throughout the history of People's Republic of China. Although the rate of increase slowed down after 1970s, the trend is always on the increasing side. By the end of the year 2015, life expectancy reached 75.98 years (World Bank, 2017).

In 1960, life expectancy in China was below the World's and regional average (

Table 3.1). However, it reached up to the similar levels by only in a decade in 1970. The increase in life expectancy was 15 years, whilst the increase of global life expectancy was only 6 years (World Bank, 2017). Despite the tremendous pace of the earlier decades, the rate of change slows down in 1980s. According to World bank data, the increase in life expectancy of China from 1980 to 1990 was 2.5 years while Japan had 4.28 of years increase at the time where they have similar life expectancy levels (i.e. Japan in 1960 has similar level of life expectancy to China in 1980). After the year 1990, the rate of change started increasing again but it was still slower than Japan. The rate of change in life expectancy shows a slowdown from 2010 to 2015.

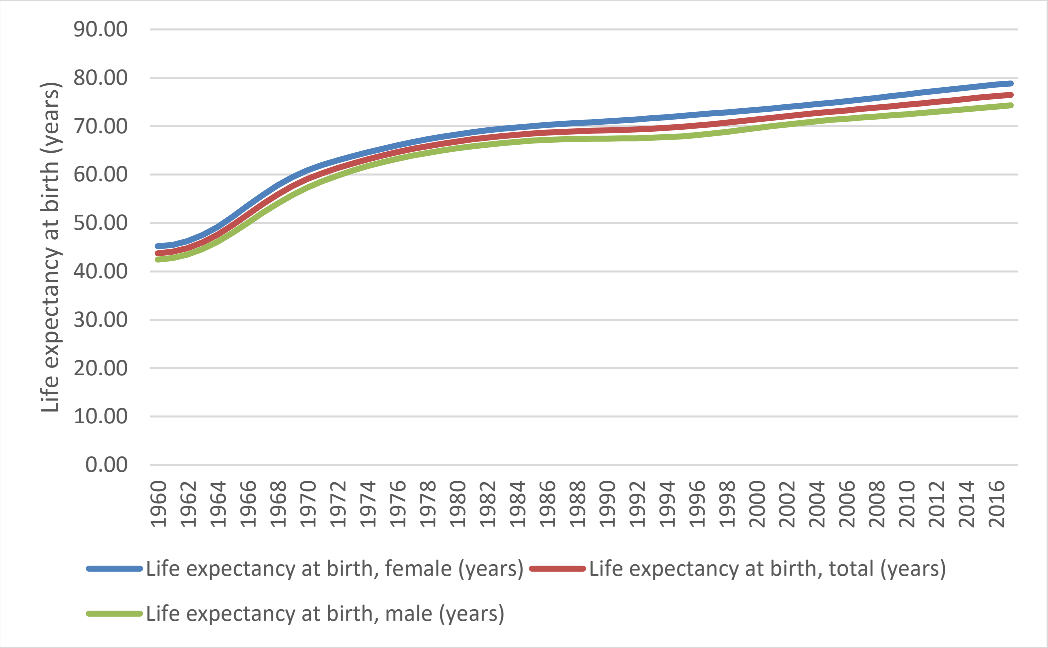


Figure 3.3 Life expectancy at birth China (1960 -2017)

Source: Created by the author with data from the World Bank (2017)

Table 3.1 Life expectancy at birth for selected regions

Country/sex	**1960**	**1970**	**1980**	**1990**	**2000**	**2010**	**2015**
China	43.35	58.68	66.52	69.03	71.73	75.01	75.99
Female	45.19	60.89	68.30	71.00	73.69	76.84	77.67
Male	42.43	57.33	65.43	67.72	70.38	73.77	74.64
East Asia & Pacific	48.23	59.64	66.08	68.93	71.39	74.19	75.10
Female	50.32	62.00	68.16	71.24	73.79	76.56	77.40
Male	46.75	57.91	64.53	67.15	69.52	72.36	73.24
Japan	67.67	71.95	76.09	78.84	81.08	82.84	83.84
Female	70.14	74.67	78.75	81.91	84.60	86.30	86.99
Male	65.31	69.36	73.56	75.91	77.72	79.55	80.75
Upper middle income	49.49	59.81	65.39	68.31	70.60	73.53	74.65
Female	52.07	62.63	68.17	71.18	73.49	76.39	77.53
Male	47.83	57.91	63.42	66.23	68.53	71.70	72.92
World	52.48	58.55	62.80	65.38	67.61	70.48	71.68
Female	54.58	60.82	65.12	67.73	69.93	72.88	74.09
Male	50.74	56.65	60.79	63.31	65.60	68.64	69.77

Source: The World Bank (2017)

China National Bureau of Statistics (NBS) published life expectancy data through population censuses, starting from the year 1981 (Table 3.2). Earlier life expectancy data was not published by NBS, but it is estimated to be 40.3 and 61.4 by Banister (1987) in the years of 1953 and 1970 respectively. Table 3.2 shows that the female life expectancy is estimated to be higher than the males. According to NBS data, female life expectancy increased by ten years from 1981 to 2015, while male expectancy increased by seven years. According to World Bank though, the life expectancy of both females and males increased by nine years. Similarly, average global life expectancy for females and males also increased by nine years from 1980 to 2015. The difference between the life expectancies of females and males is mostly constant over the years. For China, the difference is approximately three years while globally it ranges around four to five years. Japan display increasing trend in female-male life expectancy difference. Earlier in 1960, the difference was around five years, but it becomes almost seven years in 2015. The increase in female life expectancy exceeds the pace of increase in male life expectancy.

Table 3.2 Life expectancy at birth in China

	1981	**1990**	**2000**	**2005**	**2010**	**2015**
Life Expectancy (age)	67.77	68.55	71.4	72.95	74.83	76.34
Male Life Expectancy (age)	66.28	66.84	69.63	70.83	72.38	73.64
Female Life Expectancy (age)	69.27	70.47	73.33	75.25	77.37	79.43

Source: (National Bureau of Statistics of China, 2016)

In order to examine the development of a nation, one must look at the mortality indicators such as infant mortality and under-five mortality because these indicators are very sensitive to socioeconomic variations. Chinese government put immense effort to improve children and the maternal health by providing health care services and by establishing well-performing policies. After the World Summit for Children in 1990, China set new policies, programmes and targets in order to improve the health of children and reduce the child mortality (WHO, 2015). Figure 3.4 demonstrates newborn, infant, under-five and maternal mortality from 1991 to 2015. All mortality types show a trend of decline from 1991 to 2015. According to the NBS, newborn mortality was the lowest compared to other age groups, among other mortality rates, which declined from 33.1 to 5.4 per thousand from 1991 to 2015. Infant mortality was initially higher than newborn mortality at 50.2 per thousand in 1991 but displayed a greater reduction and declined to 8.1 per thousand by the year of 2015.

Under-five mortality is another important indicator to reflect on China's socioeconomic development. As well as other mortality indicators, it also showed a declining trend from 1991. For example, under-five mortality was 60 per thousand in 1991 and with a reduction by 82.6%; it declined to 10.7 per thousand at the end of 2015. Maternal mortality had the highest occurrence amongst the other mortality rates. In 1991, it was 80 deaths per thousand and with a decline by 74.88%; it reduced to 20.1 deaths per thousand at the end of year 2015. Compared to 1991, newborn mortality, infant mortality and under-five mortality displayed 83.68%, 83.86%, and 82.6% reduction until the year 2015, respectively. This means China has already achieved the target of Millennium Development Goal (MDG 4). Moreover, with the improvement in maternal health, China also reached the target of MDG 5 that is to reduce three quarters of maternal mortality rate from 1990 to 2015 (Ministry of Foreign Affairs People's Republic of China, United Nations System in China, 2015). Figure 3.4 shows that maternal mortality had reduced by 75% from 1990 to 2015.

Adult mortality between ages 15 to 60 indicates the probability of dying between the working ages of adults. China successfully reduced adult mortality over the years. The sharpest decline of mortality occurred between 1960 and 1972, approximately 53% from the mortality levels from the year 1960 for both females and males. In 1960, male adult mortality rate was 516.97 per thousand. This is around 20% higher than the female adult mortality rate, which was 412.5 per thousand. The difference in mortalities may be attributed to harsh living and working conditions during Great Leap Forward since mostly males were labourers in the strenuous steel industry. Although the male adult mortality continued to be higher than the females, the gap between narrowed a lot through the years. Only in seven years from 1960, the gap between male and female mortality reduced by 62% from 104.4 to 39.4 deaths per thousand adults. In 2015, both female and male adult mortality rates reached below 100 deaths per thousand, which is lower than world average but higher than high-income countries (World Bank, 2015; 2015)

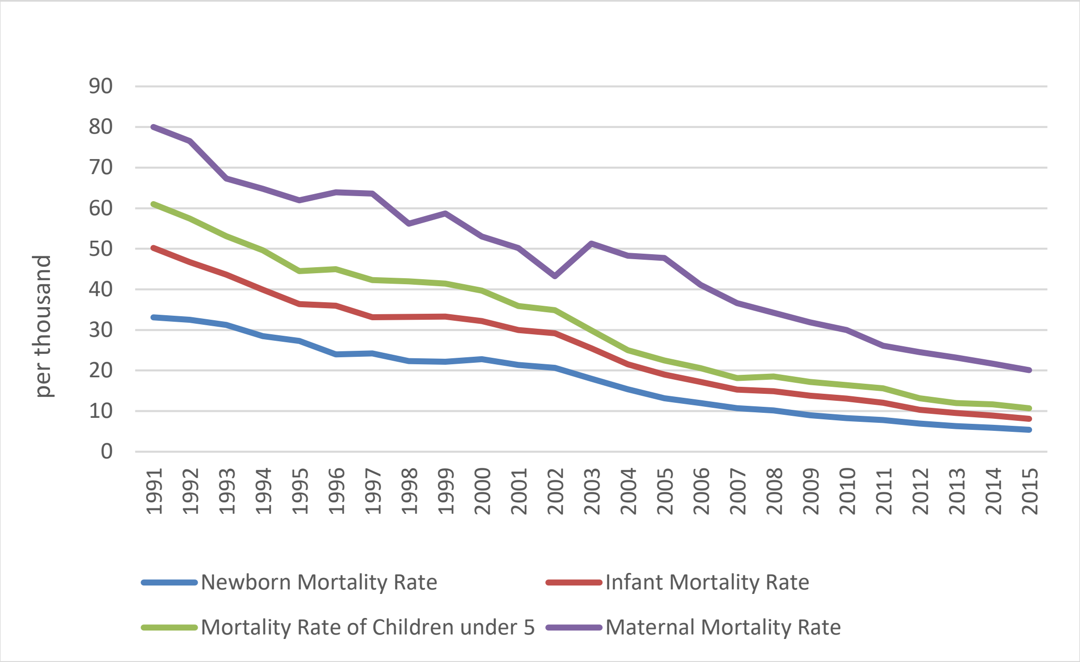


Figure 3.4 **Newborn, infant, under-five and maternal mortality rates in China (1991 - 2015)**

Source: Created by author with the data retrieved from (National Bureau of Statistics of China, 2016)

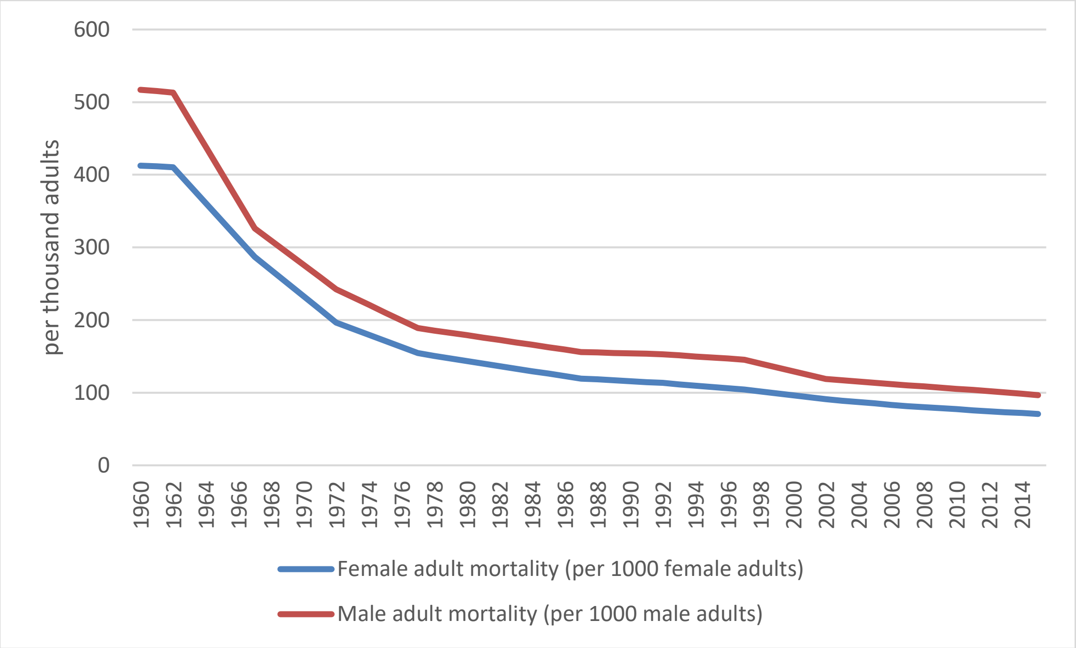


Figure 3.5 **Adult mortality between ages 15 and 60 in China (1960 - 2014)**

Source: Created by the author with data retrieved from (National Bureau of Statistics of China, 2016)

3.4. Regional Disparities in Mortality

Mortality rates show disparities between regions. All types of mortality display lower levels in urban areas than in rural areas, which is not surprising considering the fact that urban people would most likely have a better access to health services. Figure 3.6 demonstrates the trend of newborn, infant, under-five and maternal mortality in urban and rural areas from 1991 to 2015. All of them have declining trend over time. Newborn mortality was 67% higher in rural areas than in urban areas with the gap of 25.4 deaths per thousand in 1991, but since the rural mortality rates improved tremendously in two decades the gap reduced to only 3.1 deaths per thousand in 2015.

Despite being higher than the initial newborn mortality rates in 1991, infant mortality rates displayed a bigger reduction from 1991 to 2015. In 1991, rural and urban infant mortality rates were 58 and 17.3 deaths per thousand respectively, but they dropped to 9.6 and 4.7 deaths per thousand in 2015. Similarly, under-five mortality rate also was initially at high levels and rural under-five mortality was greater than the urban under-five mortality. In 1991, the rural under-five mortality rate was 71.1 per thousand whereas the urban under-five mortality rate was 20.9 per thousand. Although urban mortality followed a slower pace than the rural mortality, they reached much lower levels such as 12.9 and 5.8 per thousand respectively. Maternal mortality surpassed other types of mortality. In 1991, maternal mortality in rural areas was 100 per thousand and it was 46.3 per thousand in urban areas. In 2015, rural and urban area maternal mortality declined to average 20 people per thousand. The decline in mortality in rural part is impressive, and it is attributed to the government's effective interventions.

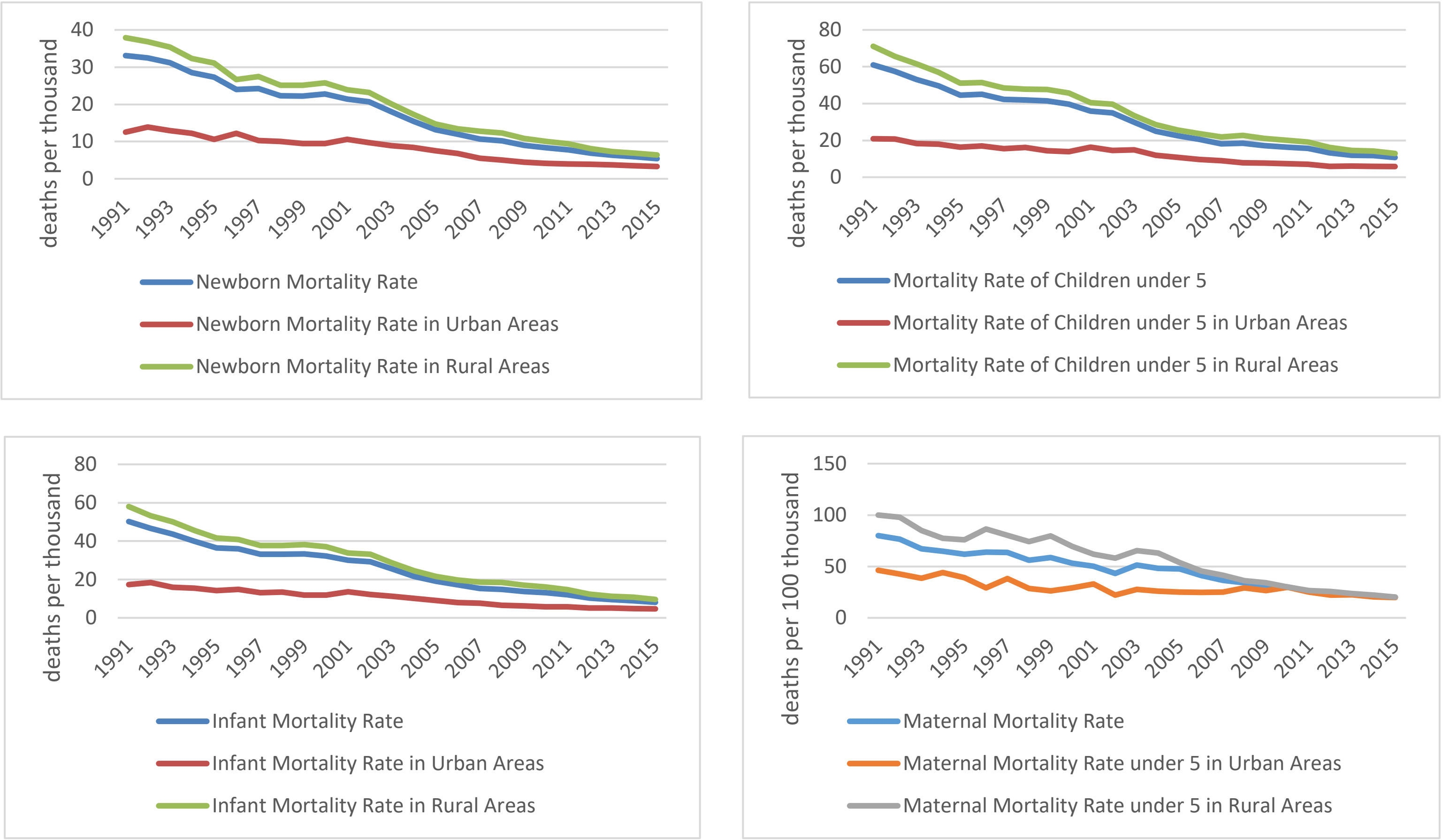


Figure 3.6 Newborn, infant, under-five and maternal mortality in urban & rural China (1991 - 2015)

Source: Created by the author with the data retrieved from (National Bureau of Statistics of China, 2016)

The government launched the new rural medical system after the collapse of the earlier rural cooperative medical system, in 2003. In addition, an urban medical insurance system too launched four years after that (Dong K. , 2009; World Bank, 2010). With the help of these two medical insurance services, children and mothers are incorporated to these systems. For example, rural cooperative medical service included children leukaemia and congenital heart disease and provided policy support. Many important diseases such as neurogenic, blood and hematopoietic organ diseases as well as congenital malformation and chromosome abnormalities are covered by the insurance system and thus percentage of the individual spending for those diseases to all covered major diseases has fallen to average of 48% (Ministry of Foreign Affairs People's Republic of China, United Nations System in China, 2015).

Moreover, the government cooperates with international organisations such as WHO, World Bank and UNFPA. Programmes like “Strengthening maternal and child health and family planning services at the Chinese communities”, “Prevention and treatment of children’s acute respiratory infection”, “Strengthening basic health services in China’s poor rural areas”, “HIVAIDS/venereal disease prevention and control and maternal and child health”, and “Mothers’ safety” are some of the successful programmes that the government got international support.

There are also disparities in terms of mortality between provinces. Based on the mortality data that is published by NBS; life expectancy, under-five mortality and adult mortality for each province were calculated for the years between 1981 and 2010. Table 3.3 shows the regional disparities of mortalities in 1981 and 2010. Coastal area has higher life expectancy and lower mortality rates in both 1981 and 2010. Despite the overall improvements in mortality and life expectancy, coastal areas show better results than the inland China. This might be due to the historical development of China. Throughout the history of the country, coastal areas took the benefit of location by the sea and became a trade centre therefore; most of the investments had been done in coastal areas where inland areas mostly remained agricultural. Because of the similar reasons, eastern China (which is mostly coastal region of the country) has the highest life expectancy amongst three regions (eastern, central and western). In 1981; Shanghai with 73 years, had the highest life expectancy and Xinjiang with 61.3 years had the lowest life expectancy in the country. They are located in eastern and western regions of the country, respectively. These two provinces were the richest and the poorest provinces in 1981. However, with the increased effort from the government and new policies focused on central and western regions, both economic and mortality levels improved over the years. In 2010, Shanghai still remained as the richest province and had the highest level of life expectancy; Xinjiang outperformed many other provinces and became the 17th province out of thirty that had the highest life expectancy. Although the gap between the regions lessened over the years, still coastal and eastern regions outperform the other regions.

Table 3.3 Regional mortality outcomes in 1981 and 2010

		1981			**2010**		
		Total	*Male*	*Female*	*Total*	*Male*	*Female*
Life Expectancy	Inland	65.72	64.75	66.73	77.23	74.92	79.83
	Coastal	70.62	68.92	72.34	80.02	77.63	82.65
	Eastern	70.69	68.98	72.43	80.12	77.83	82.60
	Central	67.80	66.53	69.10	78.80	76.37	81.51
	Western	64.48	63.68	65.32	76.25	73.91	78.91
Under-five Mortality	Inland	0.068	0.069	0.067	0.011	0.011	0.010
	Coastal	0.031	0.032	0.030	0.005	0.005	0.004
	Eastern	0.030	0.030	0.029	0.005	0.005	0.004
	Central	0.044	0.045	0.044	0.005	0.005	0.005
	Western	0.085	0.087	0.083	0.014	0.015	0.014
Adult Mortality	Inland	0.180	0.189	0.169	0.101	0.128	0.072
	Coastal	0.143	0.163	0.121	0.073	0.097	0.046
	Eastern	0.143	0.162	0.121	0.070	0.093	0.045
	Central	0.175	0.190	0.158	0.085	0.111	0.058
	Western	0.181	0.187	0.173	0.112	0.141	0.081

Source: Calculated by the author with census data retrieved from China NBS (1990) IPUMS (2017)

3.5. Methodology

Data preparation:

The present study uses the mortality data retrieved from open and published sources. For the mortality data, we used China National Bureau of Statistics (NBS). NBS collected death records through population censuses for the years 1982, 1990, 2000 and finally 2010; moreover, they conducted 1% population surveys in 1987, 1995, 2005 respectively, and collected death records in those years as well. According to Banister and Hill (2004), the quality of death data from 1982 and 1990 censuses were high, however the quality of data decreased for the later censuses from 1995 to 2005 due to underreporting of infant and under-five mortality. For the latest population census in 2010, Zhao et.al (2016) claim that there is a problem of under-reporting of infant deaths and old-age deaths. Keeping this in mind, we used the data from the sources that publish death records collected by NBS. In this study, we collected the unadjusted mortality data (from 1990 to 2010) from population censuses that are conducted by NBS. The population census in 1982 could not be reached through the NBS website so we retrieved it through IPUMS. In addition, we used Chinese resources to compile missing data.

This study uses the mortality data that are retrieved from open and published sources (see Box 3). China National Bureau of Statistics (NBS) published province level mortality data in the population censuses for the years 1981, 1990, 2000 and 2010 respectively.

Box 3: Data Sources

Mortality Data
(Death Records)

- World Bank (country level)
- China NBS (province level)
    - Population censuses: 1990, 2000, 2010
    - 1% population sample survey: 1995 and 2005
- IPUMS (2017) - population censuses
- Journal articles in Chinese:
    - Qi et al. (1999)
    - (Population Research Institute, Renmin University of China, 1987)

Socioeconomic Indicators
GDP per capita
GDP deflator
Urban and rural disposable income
Number of doctors per thousand persons
Government's expenditure on health and education
Illiterate and Semi-Literate Population aged above 15 (%)
Urban Population

- World Bank
- IPUMS
- NBS, Statistical Yearbooks (various issues)

In addition, 1% sample population censuses at 1995 and 2005 were used as well for the mortality data. Results from the descriptive analysis are presented in the Appendix. In order to calculate under-five mortality, adult mortality rate and life expectancies of each province and gender; abridged life tables for each province are constructed based on Chiang (1984). Sample life tables are also presented in the Appendix; life tables for each provinces and years are available (on request, not provided separately on the thesis). First, the probability of death ${}_nq_x$ in an age interval$(x, x+n)$ is calculated as following:

$$ {}_{n}q_{x} = \frac{(n)_{n}M_{x}}{1+[(a)(n)_{n}M_{x}]} \qquad \textit{(eq.1)} $$

“a” is the fraction of age interval lived by those died in the interval and “n” is the age interval. “a” is generally assumed as 0.5 for all age groups except the age that is younger than one years old, in that case it is 0.1. ${}_{n}M_{x}$ is defined as age specific death rates and calculated via dividing number of dead people of specific age by the number of people are alive at that specific age as below;

$$ {}_{n}M_{x} = \frac{{}_{n}D_{x}}{{}_{n}P_{x}} \qquad \textit{(eq.2)} $$

Number of alive people during the age interval $(x, x+n)$ are measured as subtracting the number of dying people at the age interval ${}_{n}d_{x}$, from the number of alive people at the beginning of the age interval l_{x}. When x equals to 0, l_{x} is assumed to be 100000.

$$ l_{x+n} = l_{x} - {}_{n}d_{x} \qquad \textit{(eq.3)} $$

The number of dying people at the age interval $(x, x+n)$ equals to the multiplication of probability of dying and the number of alive people at the age interval of $(x, x+n)$

$$ {}_{n}d_{x} = {}_{n}q_{x}(l_{x}) \qquad \textit{(eq.4)} $$

Number of years lived in the age interval calculated as following;

$$ {}_{n}L_{x} = n\,[l_{x} - (a)({}_{n}d_{x})] \qquad \textit{(eq.5)} $$

The number of years lived in the current and previous age intervals;

$$ T_{x} = T_{x+n} + {}_{n}L_{x} \qquad \textit{(eq.6)} $$

Finally, the life expectancy e_{0} is equal to number of years lived in all age intervals divided by number of years lived in the age interval x, where x is 0.

$$ e_{x} = T_{x}/l_{x} \qquad \textit{(eq.7)} $$

In this way, we were able to calculate not only life expectancy (e_0) but also under five mortality rates ($_5q_0$) and adult mortality rates between the age 15 and 60, ($_{45}q_{15}$) as it is shown in Table 3.4 below.

Table 3.4 Average life expectancy, under-five mortality and adult mortality in China between 1981 and 2010

	1981	**1990**	**1995**	**2000**	**2005**	**2010**
Average life expectancy (e0)	67.65	68.83	70.39	73.21	76.23	78.36
male	66.39	67.37	68.64	71.38	73.83	76.01
female	68.94	70.46	72.29	75.20	78.73	80.98
Average under-five mortality (5q0)	0.054	0.049	0.043	0.029	0.018	0.008
male	0.054	0.045	0.041	0.026	0.017	0.008
female	0.053	0.047	0.045	0.032	0.019	0.008
Average adult mortality (45q15)	0.165	0.143	0.142	0.123	0.107	0.090
male	0.179	0.175	0.167	0.148	0.137	0.116
female	0.150	0.132	0.114	0.095	0.076	0.062

Source: Calculated by the author with census data retrieved from China NBS (National Bureau of Statistics of China , 1990; 1995; 2000; 2005; National Bureau of Statistics of China, 2010), 1981 Census (Minnesota Population Center, 2015) and (Qi, Ma, Gao, Gao, & Ren, 1999) used for 1995 mortality data at province level.

For assessing the economic development of the region, GDP per capita is selected. NBS has published annual GDP and GDP per capita through the yearbooks. The data retrieved for this study are from multiple statistical yearbooks for the studied time periods. However, the published values are at current prices, so they are converted to constant values by taking 2010 as base year since it is the year that China took as base for their calculations too. GDP is one of the most common used indicators that used for economic development representation as a result it has been often considered while making policy decisions. Especially Chinese policy makers utilized this indicator as a performance evaluator for the regions. Therefore, central government encouraged local authorities to focus on increasing the regional GDP. Despite its common use as an economic development indicator, sometimes it is mistakenly used as an indicator for overall human development. Although it is a strong factor, which affects wellbeing directly and indirectly, measuring only economic progress neglects too many important aspects of human wellbeing. Therefore, in this study we utilize GDP only as an economic development indicator while we include other socioeconomic indicators for a relatively better analysis.

Education is another concept that has been commonly addressed in development literature. Education has been proved to have a strong link with mortality. In addition, Millennium Development Goals (MDG2) addresses the need to eliminate illiteracy for adults older than 15 years old. Although China has nine years of compulsory education and demonstrates high literacy rates (i.e. 96.4% of total population; (CIA, 2016)), illiteracy among adults still plays an important role in mortality in the provinces of China. This could be due to funding inequalities in some provinces therefore we included it as an indicator to shed light on the government's redistributive power on health care and education. In an attempt to obtain the impact of government's investment policy on health and education, the share of government expenditure on education and health care is used. Both national and regional information is available at annual yearbooks by NBS. In addition to that, the number of doctors per thousand people is used as another health proxy in order to assess the strength of province level health care systems. The information is gathered through annual statistical yearbooks.

Since this study examines mortality and socioeconomic status of the provinces, there is a need to examine whether there is any disparity between the provinces. Therefore, this study also measures the regional disparities between the provinces as well as within the province. In order to measure the regional income inequality within the provinces, Theil T index is calculated based on (Akita, 2003) using population weighted per capita rural and urban income.

Theil index is derived from generalized entropy GE (α);

$$GE(\alpha) = \begin{cases} \dfrac{1}{\alpha(\alpha-1)}\left[\dfrac{1}{N}\sum_{i}^{N}\left(\dfrac{y_i}{\overline{y}}\right)^{\alpha}-1\right] & \alpha \neq 1,0 \qquad (eq.8) \\ \dfrac{1}{N}\sum_{i}^{N}\ln\left(\dfrac{\overline{y}}{y_i}\right) & \alpha = 0 \qquad (eq.9) \\ \dfrac{1}{N}\sum_{i}^{N}\dfrac{y_i}{\overline{y}}\,ln\left(\dfrac{y_i}{\overline{y}}\right) & \alpha = 1 \qquad (eq.10) \end{cases}$$

The above equations show the generalized entropy. When α equals to zero, it is called Theil L or mean logarithmic deviation and when it is equal to one, it is called Theil T index. Both indexes cannot be determined if there are any zero incomes. In order to avoid that, zero incomes could be replaced with very small incomes. However, in this case, $GE(0)$ would not have upper bound while $GE(1)$ approaches the maximum value of $ln(n)$. Therefore, in this study we only considered Theil T index as income inequality indicator.

$$GE(1) = Theil\ index = \sum_{i}^{N}\frac{y_i}{N\overline{y}}\,ln\left(\frac{y_iN}{\overline{y}N}\right) \qquad (eq.11)$$

Theil index has the advantage over inequality indicators like Gini coefficient because it can be decomposed into “within group” and “between group” components. In order to decompose the index, the equation is written as in (eq.12). Y is the total income of all N people in the sample and $\overline{y} = Y/N$ is the mean income of the population. When $\overline{y}$ is replaced by Y/N, we obtain equation (eq.12);

$$Theil\ index = \sum_{i}^{N}\frac{y_i}{Y}\,ln\left(\frac{y_iN}{Y}\right) \qquad (eq.12)$$

In order to decompose the above into subgroups, we introduced Y_j as the total income of a subgroup j with population of N_j. T_j is the Theil index of the subgroup j. Equation 13 displays the decomposed inequality components; first part denotes the within group inequality whereas the second part is between group inequality.

$$\sum_j \left(\frac{Y_j}{Y}\right) T_j + \sum_j \left(\frac{Y_j}{Y}\right) ln\left(\frac{Y_j/Y}{N_j/N}\right) \qquad (eq. 13)$$

China has been going under a massive transformation of urbanisation; as a result, urbanisation is also included in the study as a socioeconomic indicator and examined whether it has any impact on mortality in China. According to CIA fact book (2016) urban population is 55.6% of the total population in 2015 and the urbanisation rate is estimated to be 3.05% annual rate of change.

Figure 3.7 displays the urbanisation level of provinces at the year of 2013. The most urbanized region is the coastal China because coastal regions are wealthier than rest of the country and it has more opportunities for immigrants. In addition, government creates new jobs in urban areas and shift agricultural workers to non-agricultural jobs in order to create labour force and sustain the economic cycle. Since China measures urbanisation as the percentage of urban population to total population; we also use the same method and include it in our analysis.

Figure 3.7 Urbanisation at province level in 2013

Source: Retrieved from Children in China: An atlas of social indicators (National Working Committee on Children and Women (NWCCW), National Bureau of Statistics, and UNICEF, 2014)

After gathering data from various sources for years from 1981 to 2010, we constructed time series data with 30 provinces and 180 observations. Chongqing was excluded since it was part of Sichuan and became a province in 1997 and thus it does not have data available before that year. Due to the missing mortality data of Tibet and Hainan for the year 1981, the number of observations is supposed to be 180 but it is 178.

As mentioned before, this study is inspired by the study of (Banister & Zhang, 2005) therefore; we use a similar approach and notations. Dependent and independent variables are listed respectively below (see Box 4):

Box 4: Dependent and independent variables for the regression models

Dependent variables, $y_{i,\ t}$

$le_{i,\ t}$: Life expectancy at birth, e0.

$U5MR_{i,\ t}$: Under-five mortality rates, probability of dying between birth and fifth birthday, 5q0.

$AMR_{i,\ t}$: Adult mortality rates, mortality between ages 15 and 60, 45q15.

Independent variables

$GDP\_pc_{i,\ t}$: GDP per capita constant at 2010 (yuan/person)

$Edu_{i,t}$: Percentage of Illiterate and Semi-Literate Adult Population to Population Aged 15 and Over (%)

$Docs_{i,\ t}$: Number of doctors per thousand persons

$h\&e_{i,\ t}$: Percentage of government’s expenditure on education and healthcare to its total expenditure (%)

$Ineq_{i,\ t}$: Urban and rural income disparity within the province i.

$Urban_{i,\ t}$: percentage of urban population to total population at province i

Inland: Regional dummy variable that sets coastal areas as 0 and inland as 1

D: year dummy when $\{\ \mathrm{d} = \mathrm{t}, \mathrm{d} = 1 \text{ or else } \mathrm{d} = 0\}$

i: 1, 2, 3…30 provinces in China

t= years; 1981, 1990, 1995, 2000, 2005, 2010

Using variables listed in Box 4, we created log-log OLS regression models for each dependent variable (y) as a function of:

$$y = f\left(GDP_{pc}, Edu, Docs, h\&e, Ineq, urban, inland, D\right) \qquad (eq. 14)$$

Since our data consists of repeated data as per province and year, adding regional and year dummies helps us to control and to see if there is any systematic change over the years and regions. Taking equation 14 as our base model 1, we constructed seven different regression models. In model 1, we included all the independent variables into the model. Then we tested the model without adding the time dummies in model 2. The remaining five models focus on pairwise analysis of two consecutive years from 1981 to 2010. The next section displays the results of regression models for each mortality outcomes. Then the conclusion will be presented.

3.6. Results

According to the results of OLS regression, adult illiteracy rate and income inequality between rural and urban areas within the province are observed to be significant in all three types of mortality outcomes. The results are presented in Table 3.4 through Table 3.13. It is notable that the effect of adult illiteracy rate is particularly significant for the under-five mortality rate. Income inequality between rural and urban areas are also a significant determinant for all three mortality outcomes in both model 1 and model 2 (only when the time controlled for the life expectancy, model 1). Income inequality is relatively more significant on under-five mortality in comparison to life expectancy and adult mortality.

For the life expectancy outcome, the dummy variables for the years 1995 and so on display statistical significance, which means there is a systematic change in life expectancy starting from the year 1995; especially in 2005 the impact is greater. The location of the province also has an influence on life expectancy. According to the results, odds of having high life expectancy is lower in inland provinces by 2.9% in comparison to coastal region (Table 3.5).

However, the location of the provinces does not show any significance in terms of under-five and adult mortalities when the gender is not considered specifically (Table 3.6 and Table 3.7). Urbanisation does not display any significance on any mortality outcome when the time controlled (Model 1) but only shows significance in model 2 for all three mortality outcomes. Although urbanisation is not statistically associated with mortality outcomes when the time is controlled, it indirectly affects inequality between urban and rural regions. Income inequality plays a significant role on mortality in each province. As the inequality decreases between rural and urban by 1%, the life expectancy increases by 0.01%, under-five mortality and adult mortality rate decrease by 0.173% and 0.06% respectively. However, life expectancy is not influence significantly by the income inequality when the time is not controlled. Another factor that affects life expectancy, when the time is controlled, is the number of doctors per thousand people. One percent increase in the number of doctors would yield a 0.007% increase in life expectancy. Moreover, it also does have crucial impact on under-five mortality. For example, 1% increase in the number of doctors would decrease the under-five mortality by 0.117%. In contrast, it does not have any statistical effect on adult mortality. Despite the significance of number of doctors in explaining the mortality outcomes, another health indicator such as government’s share on health and education expenditure does not hold any statistical importance on any mortality outcomes neither in model 1 nor in model 2.

In explaining under-five mortality, adult illiteracy rate, income inequality between rural and urban areas, number of doctors per thousand (only when the time controlled) and GDP per capita are statistically significant determinants (Table 3.6). GDP per capita has the most effect in comparison to other determinants on under-five mortality. To illustrate, a 1% increase in GDP per capita would reduce the under-five mortality by 0.53% (model 1). Illiteracy rate is the second most influential factor in explaining the under-five mortality with the coefficient of 0.4 so 1% decrease in adult illiteracy would lead 0.4% decrease in under-five mortality. Finally, there is not any systematic change over time since the year dummies do not show any significance as well as the location of the province whether it is in coastal or inland region when controlling for the other variables.

Adult mortality only has three significant factors such as GDP per capita, adult literacy and income inequality between rural and urban areas (Table 3.7). Similar to under-five mortality, GDP per capita is the most statistically significant determinant in explaining the mortality. To illustrate, a 1% increase in GDP per capita would lead a reduction of 0.231% in adult mortality at the age between 15 and 60. In contrast to under-five mortality, number of doctors does not have any statistical effect on adult mortality. However, adult illiteracy between ages of 15 and 60 and income inequality between urban and rural areas have crucial impact on adult mortality. One percent increase in adult illiteracy and income inequality result in 0.14% and 0.06% increase in adult mortality respectively. Urbanisation is observed to be only significant in explaining adult mortality when the time is not controlled (model 2). Finally, we did not observe any statistically significant effect of region or year on the regression results for adult mortality.

When we run the models for gender specific mortality outcomes, we see interesting results. Both female and male life expectancy are observed to be affected crucially by adult illiteracy rate, number of doctors, income inequality and regional location of the province as it was observed by the previous regressions (Table 3.8 and Table 3.9). GDP per capita is not significant to life expectancy even when the gender is specified as well as urbanisation, but if the time was not controlled both are statistically significant to female and male life expectancy (model 2). There is a systematic change over time for both female and male life expectancy since the year dummies show statistical significance, but the female life expectancy displays this effect starting from the year 1990 whereas male life expectancy shows the impact of time from the year 2000.

In the case of under-five mortality and adult mortality, regression results show differences. GDP per capita is significantly associated with both female and male under-five mortality, and adult mortality (only in model 2 for female adult mortality) – as well as adult illiteracy and income equality. Number of doctors only shows significance in under-five mortality for males but for females it is only significant in model 2. According to regression results, regional location of the province is important in explaining male under-five mortality when the time is controlled whereas it does not have any effect on female under-five mortality. Male under-five mortality is higher at inland regions than the coastal regions. In addition, there is a year effect on male under-five mortality as well. Starting from 2005, it shows systematic change over time (Table 3.11). Urbanisation is only significant when the time is not controlled (model 2) for gender specific under-five mortalities, female life expectancy and female adult mortality except for male life expectancy and adult male mortality.

Table 3.5 Determinants of life expectancy in China (1981 – 2010)

Covariates	Model1 (81, 90, 95, 00, 05, 10)	Model2 (81, 90, 95, 00, 05, 10)	Model3 (81, 90)	Model4 (90, 95)	Model5 (95, 00)	Model6 (00, 05)	Model7 (05, 10)
GDP per capita	0.012 (0.01)	0.052**(0.006)	0.027 (0.019)	0.022 (0.013)	0.036**(0.012)	0.043**(0.013)	0.0 (0.011)
Illiteracy rate	-0.021**(0.006)	-0.028**(0.005)	-0.022 (0.019)	-0.03*(0.013)	-0.04**(0.008)	-0.021*(0.01)	-0.021**(0.006)
No of Doctors	0.007*(0.003)	0.006 (0.003)	0.021**(0.007)	0.012*(0.006)	-0.001 (0.005)	0.005 (0.005)	0.004 (0.004)
Gov't share of education and healthcare expenditure	0.014 (0.011)	0.006 (0.011)	0.035 (0.023)	0.026 (0.015)	0.003 (0.014)	-0.012 (0.018)	0.019 (0.016)
Rural-urban inequality	-0.013**(0.005)	0.00 (0.003)	-0.003 (0.006)	0.001 (0.005)	0.002 (0.007)	0.006 (0.01)	-0.026*(0.011)
Urbanisation	0.005 (0.009)	-0.018*(0.008)	-0.001 (0.02)	-0.001 (0.014)	-0.004 (0.012)	0.021 (0.025)	0.019 (0.026)
Inland Region	-0.029**(0.006)	-0.015**(0.005)	-0.044**(0.011)	-0.041**(0.009)	-0.017*(0.008)	-0.001 (0.009)	-0.002 (0.007)
Dummy 1990	0.013 (0.009)						
Dummy 1995	0.031*(0.013)						
Dummy: 2000	0.056**(0.016)						
Dummy: 2005	0.095**(0.02)						
Dummy: 2010	0.097**(0.024)						
N	178	178	58	58	60	60	60
Adjusted R^2	0.867	0.836	0.710	0.752	0.815	0.713	0.739

[a] All the variables are in logarithmic form except dummy variables

[b] The figures in parenthesis are standard errors.

[**] Significant at the 1% level

[*] Significant at the 5% level

Table 3.6 Determinants of under-five mortality in China (1981-2010)

Covariates	Model1 (81, 90, 95, 00, 05, 10)	Model2 (81, 90, 95, 00, 05, 10)	Model3 (81, 90)	Model4 (90, 95)	Model5 (95, 00)	Model6 (00, 05)	Model7 (05, 10)
GDP per capita	-0.527**(0.149)	-0.756**(0.086)	-0.008 (0.226)	-0.241 (0.17)	-0.464*(0.191)	-0.925**(0.211)	-0.502*(0.232)
Illiteracy rate	0.4**(0.094)	0.498**(0.078)	0.037 (0.221)	0.092 (0.173)	0.181 (0.13)	0.427**(0.159)	0.524**(0.124)
No of Doctors	-0.117*(0.048)	-0.072 (0.048)	-0.205*(0.082)	-0.17*(0.073)	-0.073 (0.072)	-0.049 (0.081)	-0.177*(0.077)
Gov't share of education and healthcare expenditure	-0.013 (0.16)	0.071 (0.164)	-0.333 (0.271)	-0.018 (0.201)	0.29 (0.215)	0.212 (0.28)	-0.096 (0.34)
Rural-urban inequality	0.173*(0.069)	0.202**(0.046)	0.126 (0.072)	0.032 (0.065)	0.168 (0.106)	0.1 (0.157)	0.473*(0.233)
Urbanisation	0.074 (0.141)	0.366**(0.118)	-0.309 (0.233)	-0.324 (0.177)	-0.296 (0.192)	-0.178 (0.387)	0.335 (0.53)
Inland Region	0.122 (0.086)	0.022 (0.078)	0.469**(0.133)	0.392**(0.121)	0.139 (0.125)	-0.169 (0.141	-0.116 (0.145)
Dummy 1990	0.177 (0.139)						
Dummy 1995	0.231 (0.2)						
Dummy: 2000	0.21 (0.244)						
Dummy: 2005	-0.205 (0.299)						
Dummy: 2010	-0.302 (0.366)						
N	178	178	58	60	60	60	60
Adjusted R^2	0.849	0.828	0.630	0.683	0.784	0.800	0.779

All the variables are in logarithmic form except dummy variables

[b] The figures in parenthesis are standard errors.

[**] Significant at the 1% level

[*] Significant at the 5% level

Table 3.7 Determinants of adult mortality between ages 15 and 60 in China (1981-2010)

Covariates	Model1 (81, 90, 95, 00, 05, 10)	Model2 (81, 90, 95, 00, 05, 10)	Model3 (81, 90)	Model4 (90, 95)	Model5 (95, 00)	Model6 (00, 05)	Model7 (05, 10)
GDP per capita	-0.231**(0.054)	-0.26**(0.029)	-0.374**(0.078)	-0.125 (0.082)	-0.178*(0.076)	-0.223**(0.067)	-0.055 (0.065)
Illiteracy rate	0.139**(0.034)	0.12**(0.026)	0.098 (0.077)	0.119 (0.083)	0.128*(0.052)	0.066 (0.05)	0.07 (0.035)
No of Doctors	0.026 (0.017)	0.02 (0.016)	0.093**(0.029)	0.057 (0.035)	-0.003 (0.029)	-0.01 (0.026)	-0.012 (0.022)
Gov't share of education and healthcare expenditure	-0.107 (0.058)	-0.076 (0.056)	-0.062 (0.094)	-0.155 (0.096)	-0.101 (0.085)	-0.016 (0.089)	-0.215*(0.096)
Rural-urban inequality	0.06*(0.025)	0.056**(0.016)	0.007 (0.025)	0.02 (0.031)	0.041 (0.042)	0.151**(0.05)	0.25**(0.063)
Urbanisation	0.081 (0.051)	0.082*(0.04)	0.227**(0.081)	0.012 (0.085)	-0.045 (0.076)	-0.018 (0.123)	-0.199 (0.149)
Inland Region	0.054 (0.031)	0.045 (0.026)	0.089 (0.046)	0.114 (0.058)	0.018 (0.50)	-0.022 (0.045)	-0.003 (0.041)
Dummy 1990	-0.054 (0.05)						
Dummy 1995	-0.007 (0.072)						
Dummy: 2000	-0.022 (0.088)						
Dummy: 2005	-0.097 (0.108)						
Dummy: 2010	-0.055 (0.132)						
N	178	178	58	60	60	60	60
Adjusted R^2	0.810	0.808	0.641	0.466	0.712	0.785	0.837

All the variables are in logarithmic form except dummy variables

[b] The figures in parenthesis are standard errors.

** Significant at the 1% level

* Significant at the 5% level

Table 3.8 Determinants of female life expectancy in China (1981-2010)

Covariates	Model1 (81, 90, 95, 00, 05, 10)	Model2 (81, 90, 95, 00, 05, 10)	Model3 (81, 90)	Model4 (90, 95)	Model5 (95, 00)	Model6 (00, 05)	Model7 (05, 10)
GDP per capita	0.01 (0.011)	0.059**(0.006)	0.043*(0.02)	0.035*(0.014)	0.037**(0.014)	0.044**(0.016)	-0.007 (0.013)
Illiteracy rate	-0.019**(0.007)	-0.027**(0.006)	-0.018 (0.02)	-0.026 (0.014)	-0.04**(0.009)	-0.021 (0.012)	-0.025**(0.007)
No of Doctors	0.008* (0.003)	0.007 (0.004)	0.02**(0.007)	0.011 (0.006)	-0.002 (0.005)	0.008 (0.006)	0.005 (0.004)
Gov't share of education and healthcare expenditure	0.015 (0.012)	0.006 (0.012)	0.041 (0.025)	0.023 (0.017)	-0.003 (0.015)	-0.012 (0.021)	0.022 (0.019)
Rural-urban inequality	-0.014**(0.005)	0.003 (0.003)	-0.003 (0.007)	0.0 (0.005)	-0.002 (0.008)	0.015 (0.012)	-0.023 (0.012)
Urbanisation	0.001 (0.01)	-0.025**(0.009)	-0.012 (0.021)	-0.015 (0.015)	-0.014 (0.014)	0.029 (0.029)	0.014 (0.029)
Inland Region	-0.036**(0.006)	-0.019**(0.006)	-0.047**(0.012)	-0.044**(0.01)	-0.024**(0.009)	-0.006 (0.01)	-0.007 (0.008)
Dummy 1990	0.021* (0.01)						
Dummy 1995	0.045**(0.015)						
Dummy: 2000	0.073**(0.018)						
Dummy: 2005	0.119**(0.022)						
Dummy: 2010	0.124**(0.026)						
N	178	178	58	60	60	60	60
Adjusted R^2	0.861	0.826	0.711	0.730	0.790	0.655	0.665

All the variables are in logarithmic form except dummy variables

[b] The figures in parenthesis are standard errors.

** Significant at the 1% level

* Significant at the 5% level

Table 3.9 Determinants of male life expectancy in China (1981-2010)

Covariates	Model1 (81, 90, 95, 00, 05, 10)	Model2 (81, 90, 95, 00, 05, 10)	Model3 (81, 90)	Model4 (90, 95)	Model5 (95, 00)	Model6 (00, 05)	Model7 (05, 10)
GDP per capita	0.014 (0.01)	0.044**(0.006)	0.012 (0.018)	0.009 (0.013)	0.034**(0.012)	0.041**(0.012)	0.006 (0.011)
Illiteracy rate	-0.024**(0.006)	-0.03**(0.005)	-0.022 (0.018)	-0.032*(0.013)	-0.04**(0.008)	-0.023*(0.009)	-0.019**(0.006)
No of Doctors	0.006* (0.003)	0.005 (0.003)	0.02**(0.007)	0.013*(0.005)	-0.001 (0.005)	0.003 (0.005)	0.003 (0.004)
Gov't share of education and healthcare expenditure	0.015 (0.01)	0.007 (0.011)	0.027 (0.022)	0.028 (0.015)	0.012 (0.014)	-0.008 (0.017)	0.018 (0.016)
Rural-urban inequality	-0.011*(0.004)	-0.002 (0.003)	-0.003 (0.006)	0.002 (0.005)	0.005 (0.007)	-0.002 (0.009)	-0.026*(0.011)
Urbanisation	0.009 (0.009)	-0.009 (0.008)	0.011 (0.019)	0.015 (0.013)	0.007 (0.012)	0.018 (0.023)	0.028 (0.016)
Inland Region	-0.021**(0.006)	-0.011*(0.005)	-0.041**(0.011)	-0.036**(0.009)	-0.01 (0.008)	0.005 (0.008)	0.004 (0.007)
Dummy 1990	0.006 (0.009)						
Dummy 1995	0.017 (0.013)						
Dummy: 2000	0.039* (0.016)						
Dummy: 2005	0.07**(0.019)						
Dummy: 2010	0.069** (0.024)						
N	178	178	58	60	60	60	60
Adjusted R^2	0.858	0.835	0.689	0.746	0.806	0.746	0.766

All the variables are in logarithmic form except dummy variables

[b] The figures in parenthesis are standard errors.

** Significant at the 1% level

* Significant at the 5% level

Table 3.10 Determinants of female under-five mortality in China (1981-2010)

Covariates	Model1 (81, 90, 95, 00, 05, 10)	Model2 (81, 90, 95, 00, 05, 10)	Model3 (81, 90)	Model4 (90, 95)	Model5 (95, 00)	Model6 (00, 05)	Model7 (05, 10)
GDP per capita	-0.67**(0.163)	-0.81**(0.094)	-0.084 (0.24)	-0.242 (0.193)	-0.553*(0.21)	-1.045**(0.232)	-0.605*(0.25)
Illiteracy rate	0.401**(0.102)	0.467**(0.085)	0.042 (0.235)	-0.013 (0.197)	0.066 (0.143)	0.371*(0.175)	0.523**(0.133)
No of Doctors	-0.112*(0.052)	-0.072 (0.052)	-0.234**(0.087)	-0.209*(0.83)	-0.087 (0.079)	-0.047 (0.089)	-0.18*(0.083)
Gov't share of education and healthcare expenditure	0.091 (0.174)	0.186 (0.18)	-0.423 (0.289)	0.038 (0.228)	0.356 (0.236)	0.481 (0.309)	0.163 (0.366)
Rural-urban inequality	0.205**(0.075)	0.296**(0.051)	0.137 (0.077)	0.102 (0.074)	0.208 (0.117)	0.196 (0.173)	0.547*(0.24)
Urbanisation	0.094 (0.153)	0.355**(0.13)	-0.358 (0.248)	-0.432*(0.202)	-0.359 (0.211)	-0.241 (0.427)	0.27 (0.571)
Inland Region	0.014 (0.093)	-0.063 (0.085)	0.404**(0.141)	0.353*(0.137)	0.058 (0.138)	-0.357*(0.155)	-0.273 (0.156)
Dummy 1990	0.2 (0.151)						
Dummy 1995	0.394 (0.219)						
Dummy: 2000	0.487 (0.266)						
Dummy: 2005	0.063 (0.327)						
Dummy: 2010	-0.027 (0.399)						
N	178	178	58	60	60	60	60
Adjusted R^2	0.834	0.808	0.646	0.656	0.763	0.795	0.782

All the variables are in logarithmic form except dummy variables

[b] The figures in parenthesis are standard errors.

** Significant at the 1% level

* Significant at the 5% level

Table 3.11 Determinants of male under-five mortality in China (1981-2010)

Covariates	Model1 (81, 90, 95, 00, 05, 10)	Model2 (81, 90, 95, 00, 05, 10)	Model3 (81, 90)	Model4 (90, 95)	Model5 (95, 00)	Model6 (00, 05)	Model7 (05, 10)
GDP per capita	-0.332*(0.143)	-0.669**(0.082)	-0.071 (0.227)	-0.024 (0.172)	-0.365 (0.188)	-0.737**(0.201)	-0.386 (0.221)
Illiteracy rate	0.374**(0.089)	0.459**(0.074)	0.019 (0.222)	0.097 (0.175)	0.304*(0.128)	0.394*(0.152)	0.503**(0.118)
No of Doctors	-0.152**(0.045)	-0.123**(0.045)	-0.307**(0.083)	-0.266**(0.074)	-0.052 (0.071)	-0.097 (0.077)	-0.203**(0.073)
Gov't share of education and healthcare expenditure	-0.103 (0.153)	0.023 (0.157)	-0.475 (0.273)	-0.134 (0.202)	0.22 (0.211)	0.133 (0.267)	-0.163 (0.323)
Rural-urban inequality	0.162*(0.066)	0.134**(0.044)	0.056 (0.073)	0.05 (0.066)	0.14 (0.105)	0.035 (0.15)	0.39 (0.212)
Urbanisation	0.00 (0.134)	0.286*(0.113)	-0.319 (0.234)	-0.372*(0.179)	-0.229 (0.188)	-0.218 (0.37)	0.349 (0.504)
Inland Region	0.242**(0.082)	0.104 (0.074)	0.475**(0.133)	0.526**(0.122)	0.215 (0.123)	-0.001 (0.134)	0.003 (0.137)
Dummy 1990	-0.058 (0.132)						
Dummy 1995	0.022 (0.192)						
Dummy: 2000	-0.129 (0.233)						
Dummy: 2005	-0.566*(0.286)						
Dummy: 2010	-0.704*(0.350)						
N	178	178	58	60	60	60	60
Adjusted R^2	0.849	0.827	0.666	0.688	0.780	0.782	0.765

All the variables are in logarithmic form except dummy variables

[b] The figures in parenthesis are standard errors.

** Significant at the 1% level

* Significant at the 5% level

Table 3.12 Determinants of female adult mortality between ages 15 and 60 in China (1981-2010)

Covariates	Model1 (81, 90, 95, 00, 05, 10)	Model2 (81, 90, 95, 00, 05, 10)	Model3 (81, 90)	Model4 (90, 95)	Model5 (95, 00)	Model6 (00, 05)	Model7 (05, 10)
GDP per capita	-0.15**(0.058)	-0.36**(0.033)	-0.36**(0.83)	-0.188*(0.079)	-0.146 (0.087)	-0.248**(0.091)	0.032 (0.081)
Illiteracy rate	0.139**(0.036)	0.157**(0.03)	0.042 (0.081)	0.114 (0.081)	0.21**(0.059)	0.072 (0.069)	0.11*(0.043)
No of Doctors	-0.018 (0.018)	-0.018 (0.018)	-0.044 (0.03)	-0.03 (0.034)	0.01 (0.033)	-0.038 (0.035)	-0.024 (0.027)
Gov't share of education and healthcare expenditure	-0.187**(0.062)	-0.147*(0.064)	-0.111 (0.1)	-0.234*(0.094)	-0.142 (0.098)	-0.107 (0.121)	-0.401**(0.118)
Rural-urban inequality	0.078**(0.027)	0.008 (0.018)	0.01 (0.027)	-0.005 (0.03)	0.035 (0.049)	0.054 (0.068)	0.224**(0.077)
Urbanisation	0.057 (0.054)	0.157**(0.046)	0.205*(0.086)	0.072 (0.083)	0.003 (0.088)	-0.131 (0.168)	-0.316 (0.184)
Inland Region	0.164**(0.033)	0.093** (0.03)	0.173**(0.049)	0.176**(0.056)	0.119*(0.057)	0.05 (0.061)	0.078 (0.05)
Dummy 1990	-0.125*(0.053)						
Dummy 1995	-0.205**(0.078)						
Dummy: 2000	-0.305**(0.095)						
Dummy: 2005	-0.514**(0.116)						
Dummy: 2010	-0.531**(0.142)						
N	178	178	58	60	60	60	60
Adjusted R^2	0.874	0.856	0.727	0.633	0.720	0.718	0.810

All the variables are in logarithmic form except dummy variables

[b] The figures in parenthesis are standard errors.

** Significant at the 1% level

* Significant at the 5% level

Table 3.13 Determinants of male adult mortality between ages 15 and 60 in China (1981-2010)

Covariates	Model1 (81, 90, 95, 00, 05, 10)	Model2 (81, 90, 95, 00, 05, 10)	Model3 (81, 90)	Model4 (90, 95)	Model5 (95, 00)	Model6 (00, 05)	Model7 (05, 10)
GDP per capita	-0.23**(0.051)	-0.192**(0.027)	-0.12 (0.071)	-0.157*(0.073)	-0.202*(0.08)	-0.197**(0.062)	-0.103 (0.066)
Illiteracy rate	0.113**(0.032)	0.115**(0.025)	0.08 (0.069)	0.05 (0.074)	0.088 (0.055)	0.069 (0.047)	0.058 (0.035)
No of Doctors	0.007 (0.016)	0.011 (0.015)	0.009 (0.026)	-0.027 (0.031)	-0.007 (0.03)	0.009 (0.024)	0.002 (0.022)
Gov't share of education and healthcare expenditure	-0.043 (0.054)	-0.04 (0.052)	-0.004 (0.085)	-0.122 (0.086)	-0.093 (0.09)	0.02 (0.083)	-0.132 (0.097)
Rural-urban inequality	0.06*(0.023)	0.083**(0.015)	0.037 (0.023)	0.013 (0.028)	0.033 (0.045)	0.204**(0.046)	0.255**(0.064)
Urbanisation	0.036 (0.048)	0.038 (0.037)	0.027 (0.073)	-0.063 (0.076)	-0.063 (0.08)	0.048 (0.115)	-0.126 (0.152)
Inland Region	-0.002 (0.029)	0.01 (0.025)	0.083 (0.042)	0.031 (0.052)	-0.039 (0.053)	-0.05 (0.042)	-0.037 (0.041)
Dummy 1990	0.077 (0.047)						
Dummy 1995	0.103 (0.068)						
Dummy: 2000	0.121 (0.083)						
Dummy: 2005	0.117 (0.102)						
Dummy: 2010	0.152 (0.125)						
N	178	178	58	60	60	60	60
Adjusted R^2	0.768	0.770	0.536	0.519	0.641	0.780	0.816

All the variables are in logarithmic form except dummy variables

[b] The figures in parenthesis are standard errors.

** Significant at the 1% level

* Significant at the 5% level

Gender specific under-five mortality rates show similarities with the general results. GDP per capita, adult illiteracy rate and income inequality are one of the most significant determinants for both female and male under-five mortality in both model 1 and model 2.

Adult illiteracy rate displays the magnitude of impact on both female and male under-five mortality with coefficient ranging from 0.37 to 0.4, so in the case of 1% decrease in adult illiteracy rate would yield a decrease in of 0.37% to 0.4% in under-five mortality for both females and males. On the other hand, GDP per capita has doubled effect on female under-five mortality over male under-five mortality. For example, 1% increase in GDP per capita would result in 0.67% decrease in female under-five mortality whereas it would result in 0.33% decrease in male counterparts. Number of doctors per thousand people is statistically significant for under-five mortality for both females and males, as well as life expectancy. An increase of 1% in number of doctors would lead to approximately 0.1% decrease in under-five mortality for females and 0.15% decrease in under-five mortality of males separately. However, in the case of model 2, number of doctors does not display any significance on female under-five mortality (Table 3.10) as well as on any gender specific life expectancy but has significance over male under-five mortality with a coefficient of 0.123. In contrast, the share of government's expenditure on health and education over total expenditure of government does not have any statistical importance in explaining under-five mortality neither for females nor for males.

Income inequality between rural and urban areas within the province is another statistically significant determinant in explaining female and male under-five mortality in both models (1 and 2). To illustrate, 1% decrease in income inequality between rural and urban areas would lead to 0.2% decrease in female under-five mortality and 0.16% decrease in male under-five mortality. However, urbanisation does not have any significance on neither female nor male under-five mortality. Surprisingly this result does not translate into the relationship between under-five mortality and urbanisation. According to the regression results, urbanisation has no statistical significance to any gender specific under-five mortality rate unless the time effect is not controlled. In model 2, for females the coefficient is 0.355 while for the males it is 0.286 (Table 3.10 and Table 3.11). On the other hand, the location of the province does not hold any significance on explaining the under-five mortality of females but for males, it has a crucial impact. Being located in an inland province increase the chance of dying at the age of 5 and under by 0.24 compared to coastal provinces when the time is controlled. In addition, male under-five mortality is affected by the time change since 2005. Dummies for year 2005 and 2010 have very high coefficients and it indicates that there is a strong change going on in male under-five mortality after the year 2005 but female counterpart does not show any change over time.

The regression results for adult mortality at the age between 15 and 60 years old people show that GDP per capita and adult illiteracy rate are one of the most statistically significant determinants in explaining adult mortality for both sexes (Table 3.12 and Table 3.13). To illustrate; 1% increase in GDP per capita leads to 0.15% and 0.23% decrease respectively in adult females and males. In addition, 1% decrease in adult illiteracy rate results in 0.139% and 0.113% decrease in adult mortality respectively for adult females and males.

Unlike under-five mortality, number of doctors is not statistically significant for adult mortality neither for females nor for males. However, government’s share of expenditure on health and education is statistically significant but only on female adult mortality. One percent increase of the share of expenditure would decrease the female adult mortality by 0.187% when the time controlled otherwise decrease by 0.147% (model 2).

Income inequality between rural and urban areas within the province is another statistically significant determinant to females (only in model 2) and males. One percent decrease in income inequality would lead to 0.078% and 0.06% decrease in female adult mortality and male adult mortality, respectively. Urbanisation, on the other hand, is not significant unless the time is not controlled (for adult females only). Being located to inland or coastal regions do not make any crucial impact on male adult mortality but displays significance to female adult mortality. That is; if the province of residence is located inland, there is 0.164 more chance of dying for female adults but not for male adults.

Male adult mortality has only three factors that are statistically significant: GDP per capita, adult illiteracy rate and income inequality between rural and urban areas within the province. There is no systematic change over time for male adult mortality, but female adult mortality shows a systematic change over time since 1990, especially the impact of the time increases gradually during the last decade.

3.7. Conclusion

This study explored the impact of socioeconomic factors on mortality outcomes in China from 1981 until 2010. The 80s were the decade that when China started its rapid economic growth, after the market reforms in 1978. Therefore, we intended to capture the impact of this rapid growth in this study. After performing regression analysis, we found out that the economic level of a province is strongly associated with mortality reduction but not with the trends of life expectancy when the time is controlled. China has already reached a life expectancy levels as high as many developed countries, so it is only normal to have diminishing impact by the years. The rate of change slowed down in recent years, and this shows that improving economic conditions does not make such difference on life expectancy. On the other hand, economic growth has negative impact on under-five and adult mortality, especially there is a prominent impact after 1995 for under-five mortality. It does show that with right policies, there is still room for mortality reduction in China.

With poverty alleviation, China rescued more than 800 million lives by 2015 (World Bank, 2017). Western China, and relatively central China, still lag behind of economic development of the eastern regions. Although there is some correlation between economic status of the province and the under-five mortality levels, education showed up as a key determinant over the years. Eliminating adult illiteracy, especially among females, is strongly associated with mortality reductions in general. In 1995 and 2001, China implemented “the National Program for the Development of Women (1995-2000)” and “the National Program for the Development of Women (2001-2010)” that covered many areas like political, economic, education, health and social fields. In addition, these programmes were integrated to the 10th five-year plan (FYP) for national economic and social development. (UN Women, 2010). Female life expectancy, female adult mortality and under-five mortality for both genders demonstrated a meaningful influence by reduction of adult illiteracy rate after 1995. With help of such programmes, women have been empowered physically, socially and intellectually, as a result, not only women are positively influenced but children are as well.

Similar to Banister and Zhang (2005), we found out that adult illiteracy impacts all the three mortality outcomes we examined in this study. Except female under-five mortality rates, it influences life expectancy and adult mortality for both genders. China displays immense care on reducing adult illiteracy rate; the country achieved great results in reducing it. The latest population census showed that illiterate population was 54,190,000 in 2010, decreased by 30,880,000 in last 10 years. In other words, the illiteracy rate was decreased from 6.72% in 2000 to 4.08% in 2010. Among these illiterate population, 40,010,000 of them were women in 2010, reduced by 23,190,000 over the last decade (UNESCO & China Ministery of Education, 2013). As mentioned before, eradicating adult illiteracy is a strong factor in improving life expectancy and reducing mortality rates in the country. There are still millions of adults, particularly women are waiting to be educated; therefore, China has to put even greater emphasis on adult education in future years.

Number of doctors per thousand persons, does have a strong impact on mortality reduction and increase in life expectancy in China. However, it does not show any statistically significant impact on adult mortality reduction. We found out that adult mortality is influenced more by econometric factors than the rest. On the other hand, under-five mortality is deeply impacted by the social indicators like health services. While the influence of this determinant on life expectancy tailed off around 1995, yet it continued to be influential on under-five mortality until 2010. However China should reinforce a system to employ more doctors or health practitioners because, according to OECD (2017), China ranks one of the lowest with 2 doctors per capita, as it sits on the 27th place out of 28 OECD countries.

The results of our analysis showed that there is a regional disparity in mortality between regions and the provinces. The underlying reason behind that might be the historical development of the coastal region. Moreover, the coastal-privileged policies and government investments made the gap even bigger. Particularly, this situation affected life expectancy more than the other mortality outcomes. People who located in inland regions, observed to have less life expectancy than the people did in coastal areas. However, the influence wore off in 2000s, while rural-urban income inequality grew stronger influence. The income disparity between rural and urban areas began affecting all three mortality outcomes in late 2000s until recently. Even though the disparity decreases between urban and rural, it still causes problem.

Despite reduction in income inequality over the years, the inequalities still exist between rural and urban, even more severe in poorer regions of China (i.e. inland provinces). Both income inequality and being located in inland provinces influence life expectancy. Similarly, both of these determinants influence male under-five mortality and female adult mortality. Affordability of health services and accessing to education services are associated with such inequalities because the government share of expenditure on health and education in the poor provinces is not higher than the richer provinces, in fact there is no systematic distribution or increase in budget for health and education services. Observing this determinant as significant over the female adult mortality in our study proves this notion. In order to improve the mortality conditions in such poorer areas (i.e. inland and rural); the government should focus on regulating their distribution of expenditure on health and education, and they should provide a better health insurance coverage since the most medical expenses are paid by out of pocket money by people who are already in economically disadvantaged state. In addition, they should stop their coastal-privileged policies. Moreover, they might as well emphasize the importance of investment in those regions in order to alleviate those populations' economic level and thus reduce the income gap between rural and urban. Starting from the 10th FYP, government showed determination to decrease the disparities between regions. In the 11th FYP, they set targets to increase the coverage of the new rural cooperative medical care system from 23.5% in 2005 to over 80% in 2010, and they achieved 97% coverage of rural population by 2011. In addition, they launched urban resident basic medical insurance in 2007 and urban employee basic medical insurance in 1998, both have covered average 92% of urban people (Yu, 2015). With the help of such successful insurance schemes, government did relieve some financial burden on people, but these schemes are mainly for basic health care and government should provide a wide range of coverage of the health care system.

China shows an unprecedented pace of urbanisation especially in recent years therefore we intend to find out whether it has an impact on mortality in China. According to our results, there is only meaningful influence during 80s in adult mortality, particularly on female adult mortality. We could speculate that the impact of recent trend of urbanisation in 80s, people began to migrate to big cities where they faced harsh conditions and their life conditions worsened, whereas male workers were more prone to such harsh conditions already and it did not affect them. However, the effect of urbanisation did not remain long. The government encourages urbanisation, especially with recent records it reached more than 50% of the total population, but rather the urbanisation, inequality that comes along with urbanisation influences mortality outcomes more.

In this study, we showed that China achieved great reductions in mortality and increase in life expectancy over the years but for the studied time-period (i.e. 1981-2010); the rapid growth is not the only socioeconomic factor that the success could be attributed to. Although rapid economic growth has an impact on mortality outcomes but since China has already reached to certain level of economic development, it does not significantly translate into the performance of life expectancy improvements over time when the time is controlled. However, other socioeconomic indicators like adult illiteracy rate, number of doctors, rural-urban income equality are the factors that government should pay attention to, in order to further decrease mortality and increase life expectancy.

Chapter 4 AIR POLLUTION AND ENVIRONMENTAL INEQUALITY IN CHINA

Abstract

Background: Air pollution in China is major concern for both China and the world. According to WHO, China is the second most polluted country in the world. However, there is little attention on environmental inequality in the case of China.

Objective: This study examines the environmental inequality in terms of discrepancies of ambient air pollution across Chinese cities and further analyses the effect of economic growth and industrial activities on pollution levels in cities across China.

Methods: We tested three hypotheses: (i) the level of industrial activity in a city has no association with the city's air quality; (ii) pollution legislation in recent period in China has a positive impact in reducing air pollution levels and (iii) Air quality is better in cities with low levels of district variation in terms economic inequality, compared to cities with high levels of district variation. PM2.5 is chosen as dependent variable, which indicates the air quality level. As for independent variables; industrial activity, GDP per capita, Theil Index as a measure of income inequality and population density are used.

Results: Findings show that economic factors such as GDP per capita and income inequality are not statistically significant in explaining environmental inequality in China, in in contrary the level and the type of industrial activities are observed to be very significant.

Conclusion: Results indicates that the pollution legislation and thus implementation is not unified across China. Environmental policy implementation in western and central regions are not as strict as it is in eastern region. Differences in implementation of policies highly contributes to environmental inequality. State does not address the environmental inequality as it is supposed to be, there is a lack of awareness of environmental inequality in both administration and public level.

Contribution: The findings of this study contribute to knowledge and understanding of pollution trends and environmental inequality regarding China as Chinese literature is primitive and relatively new on this subject.

4.1. Introduction

Air Pollution is one of the critical public health problems that world has been dealing with since industrial revolution. Around 92% of world's population lives in the most polluted areas that cause crucial health risks (WHO, 2019). China is the second most polluted country in terms of ambient air pollution right after India (WHO, 2019). China has long been struggling with serious ambient air pollution.

The rapid economic growth and urbanisation since late 1970s triggered the establishment of industries especially in mega cities, along with an unprecedented increase in economic labour mobility and exponential growth of motor vehicles, which subsequently led to fuelling air pollution in the country. This study examines the environmental inequality in terms of ambient air pollution in China through a systematic examination of recent data on air pollution levels in Chinese cities and further analyses the effect of economic growth and industrial activities on pollution levels in cities across China.

Environmental inequality as a concept has not been systematically investigated in Chinese literature. International literature generally uses this term interchangeably with environmental justice, but environmental inequality is only an element in the broader concept of environmental justice. Downey (2005) presents five definitions of environmental inequality: discriminatory intent inequality, disparate exposure inequality, disparate social impacts inequality, disparate health impacts inequality, and relative distribution inequality. Discriminatory intent inequality usually refers to intentional racism towards certain group of people (e.g. African-American, Hispanics) with regards to environmental decisions. These could be determining the location of hazardous facilities and or environmental hazards in the areas where minorities are settled. Disparate exposure inequality refers to inequality where some group of people are more exposed to some certain pollutants than the case if they had been randomly distributed to the residential area. He states that these first two types of inequalities are relatively more discussed since they are easier to address and measure. Disparate social impacts inequality describes the inequality where a community is more likely to live in environmentally hazardous areas than it is normally expected, if the community members were randomly distributed across residential space. It is similar to disparate exposure inequality, but it covers not only exposure to certain pollutants but all type of environmental hazardous exposure as well as the economic and social aspect of settling to those environmentally hazardous neighbourhood. Disparate health impacts mean the adverse health effects due to residential proximity or exposure to environmental hazards that are distributed unequally among social groups.

Finally, the relative distribution equality describes the ideal situation where people who receive greater benefits than others from production-distribution cycle of economy ought to share greater burdens of this process. However, this is not generally the case. Low-income groups, certain ethnic, and lower social class groups are more vulnerable to environmental hazards and pollution. Research studies often address racial inequalities however, without considering the racial composition in the context. In this study, we focus on the disparate exposure inequality because it is relatively easier to capture given the difficulties in obtaining relevant data. Thus, we examine the disparate exposure inequality by analysing the effect of selected economic and industrial factors on air pollution levels in cities and their disparities between cities.

China started its battle against ambient air pollution from 1980s onward when the pollution began to increase to health threatening levels. In recent years, this battle has reached to a new phase with much stricter policy implementation than before, such as closing down hundreds of factories that do not meet the emission guidelines. However, China still is one of the world’s biggest manufacturer, import and export countries. According to World Bank (2017), manufacturing and total industry forms 30% and 40.5% of the country’s annual GDP respectively. Since industry has great importance in China’s economy and policies, it is worth studying its influence on air pollution levels. Moreover, it is equally important to study pollution control and prevention policies and their implementation since it has been a topic of intense public debate lately in China. These two factors are crucial in determining the environmental inequality in the region. Therefore, both industrial activities and the effectiveness of these policies are also analysed in this study. The research questions for the analysis are presented below:

i. *How does economic factors affect environmental inequality in China?*
ii. *What is the association between income inequality and environmental inequality? How does income inequality affect ambient air pollution in China?*
iii. *What is the role of state in addressing the environmental inequality?*

In order to answer these questions and to examine the effect of industrial activities and policy implementation, three hypotheses are developed:

***H₁**: The level of industrial activity in a city has no association with the city's air quality*

***H₂**: Pollution legislation in recent period has a positive impact in reducing air pollution levels in China*

Since we focus mainly on industrial and economic activities to understand the environmental disparities, economic inequality measures should also be included to develop comprehensive understanding of the air pollution and pollution exposure inequalities in China. This led to the formulation of the third hypothesis:

***H₃**: Air quality is better in cities with low levels of district variation in terms economic inequality, compared to cities with high levels of district variation.*

Environmental inequality is a relatively a new field that has not been explored much in both Chinese and international literature. This study will address the research gap by analysing whether environmental inequality in Chinese cities increases the pollution level. Moreover, by examining the latest ambient air pollution concentrations in cities, we intend to present a comprehensive and up to date information about the current state of air pollution in China.

The chapter is organised as follows. The literature review is included in the next section and the subsequent sections will address China's current air pollution conditions and changes in legislation, data and methodology, results and finally conclusion.

4.2. Literature Review

Air pollution has been an increasing threat to the environment and human beings. Protection and prevention actions assume that every individual and group of people are affected by the pollution equally, and hence environmental inequality has been neglected largely. Literature usually addresses environmental equality with environmental justice. Although the two concepts overlap, environmental equality is not the same as environmental justice. Environmental justice "is the fair treatment and meaningful involvement of all people regardless of race, colour, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (EPA, 2019). However, environmental equality is only an element of broader concept of environmental justice, which covers also environmental equity. Environmental inequality definition includes intentional racism and discriminatory outcomes of environmental actions (2005). Intentional racism highlights the significance of hazardous facilities locations while discriminatory environmental outcomes highlight inequality in health, exposure, and social impacts due environmental actions.

Laurent (2013) states that environmental inequality is closely related to social inequalities, in fact social inequalities are one of the major causes of environmental inequalities. Research show that there is a strong correlation between environmental conditions and income inequality (Dorling, 2010b; Holland, Peterson, & Gonzalez, 2009; 2003). Higher income disparity is found to increase environmental degradation such as pollution and waste generation. Moreover, Wilkinson and Pickett (2010) suggests that inequality increases consumerism due to stress and personal/societal fulfilment, therefore, it is difficult to attain environmental sustainability in unequal societies. Magnani (2000) presented in her comparative analysis of OECD countries that there is a "relative income effect" when making public spending on environmental causes, and greater income disparities are strongly correlated with less environmental expenditure. People with income lower than the average income are observed to be less willing to spend their money on pro-environmental acts.

Environmental inequality is a driver for social inequality as well. Environmental degradation does not have the same effect on everyone across the population. The initial studies showed that there is a systematic inequality of locating waste dumps in African American areas compared to other regions of other ethnicities; therefore, there is greater exposure of African Americans to pollution (Bullard, 1983). The link between pollution exposure and health is well proven in the literature. Disparities in exposure lead to disparities in health as well as quality of life for most vulnerable populations. Zhao et al. (2014) claims that environmental inequality is greater risk than income inequality to human health.

Environmental inequality is measured in many different ways. Some applied various composite inequality indices such as Gini coefficient, Atkinson index and Theil index (Boyce, Zwickl, & Ash, 2016); others incorporated environmental outcomes as an indicator. Biodiversity loss is one indicator that is often employed (Qian, et al., 2019). Socioeconomic inequalities such as education, employment and living conditions and especially income inequality, are frequently used indicators (Bell & Ebisu, 2012; Nazrul, 2015). Additionally, Boyce (1994; 1999) argued that power inequality is crucial indicator for environmental inequality studies as well. He described power in 5 categories: purchasing power, decision power, agenda power (i.e. decisions regarding to the issues that never make into public sphere), value power (i.e. ability of influencing other people's decisions), and event power (i.e. ability to set circumstances where people make choices). He claimed that inequalities in any form of power correlates with the social choices related to environmental protection as in favouring people with the power. With the cross-sectional analysis of power distribution, public health, and environment in 50 US states, he found that the higher power inequality gets, the weaker environmental policies become thus environmental degradation increase and eventually this led to health problems. However, the most common used environmental outcome indicator is population health disparities attributed, either directly or indirectly, to pollution. The correlation between health and pollution is studied thoroughly by many scholars (Brulle & Pellow, 2006; Finkelstein, Jerrett, & Sears, 2005), and widely acknowledged. Pollution is classified into various types including water, air, waste, plastic and so on. The present literature review focuses only ambient air pollution.

Most of the ambient air pollution literature are available in the western world with a focus on environmental racism (Mitchell & Dorling, 2003; Bell & Ebisu, 2012; Zwickl, Ash, & Boyce, 2014). However, this is not the case for China since the majority of population is Han (Ma, 2010). Chinese economy demonstrated rapid growth over the last few decades but the environmental issues along with the growth did not gain the same attention from the public as well as governments.

Data and research on environmental inequality and environmental justice subjects are limited in China. The Chinese literature classifies environmental inequality in three categories: regional differences between western and eastern China, rural and urban disparities, and social classification of occupational groups that work in environmentally hazardous industry, particularly migrant workers (Mah & Wang, 2017). Zhao et al. (2014) states that the shift of heavy industry from urban areas to rural areas is main cause of China's environmental inequality. Heavy industry used to be located mostly on the eastern region of China due the region's relatively more developed status. However, in recent years, the industry is largely shifted to western and more rural areas of the country, as an effort to reduce high pollution concentration in the eastern region. This suggest potential high exposure to pollution in rural areas and among economically deprived communities. Studies found that people living in less developed regions such as rural areas, living worse conditions such as migrant workers, and children and elderlies are most vulnerable to pollution related health risks (Schoolman & Ma, 2012; Zhao, Zhang, & Fan, 2014).

4.3. Air Pollution in China

Air pollution in China has been subject to serious debate for many decades. Due to rapid economic growth and urbanization, Chinese cities have been a victim to severe air pollution. Development-led urbanisation, increased energy consumption in which the main source was coal, and increased number of vehicles on traffic caused an important urban air pollution problem since 1980s. In 1990s, there were only “less than one percent of over 500 cities in China [that] reached Class I (the least serious of three levels) of the national air quality standards” (He, Huo, & Zhang, 2002). Since then the government put extra effort to reduce the air pollution in Chinese cities.

China initiated efforts to fight pollution with the introduction of Environmental Protection Law in 1979 on a trial basis. The law is officially endorsed in 1989 and later revised in 2014. In addition, China introduced a new law specifically targeting air pollution - Air Pollution Prevention and Control Law in 1987. Later on, the law is revised in 1995, 2000, and 2015 (Zhang, 2018). Moreover, the government introduced new policies through Five-Year Plans as well as set new air pollution standards (GB3095-1996 and GB3095-2012). Feng and Liao (2016) described China’s effort to prevent air pollution in three stages: the beginning, development and improvement stages.

The beginning stage (1979-1999) is more like a trial base for later policy implementations. Both Environmental Protection Law and Air Pollution Prevention and Control Law were introduced in this stage. In the development stage (2000-2013), many revisions made on the existing laws and new legislations added such as “Two Control Zones” which introduced zoning system for classifying regions based on Sulphur-dioxide (SO_2) concentration and acid rains, thus enforced collection of pollution fees from the polluters. In this stage, earlier selected and pilot regions were expanded, and the laws were implemented throughout the whole country. In addition, the Action Plan of Air Pollution and Control (2013) was accepted in this stage. This plan included certain targets for pollutant reduction (mostly PM10 and PM2.5) in key areas and the whole country by 2017. Moreover, the latest Air Quality Standards (GB3095-2012) were applied. In the improvement stage, the existing laws were revised to the new but stronger reinforcements. In 2015, the most stringent and inclusive Air Pollution Prevention and Control Law was introduced. This law included specific targets to increase air quality levels by controlling the pollution sources such as coal burning activities, vehicles, industrial activities and agricultural activities. With the introduction of this law, great measures were taken to prevent ambient air pollutants like particulate matter, sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and volatile organic compounds (VOC).

Recently, the government announced a “Three Year Action Plan” in 2018. This plan aims to improve the air quality from the 2015 levels by 2020. Reducing SO_2 emissions and NO_2 emissions by 15% from the 2015 levels by 2020 is one of the targets. For PM2.5 to reduce by 18% in comparison to 2015 levels is another. Increasing number of “good” air quality days at least by 80% while decreasing “severe pollution” days by at least 20% is targeted. In contrast to the Air Pollution Prevention and Control Law (2015), this plan pays special attention to controlling VOC and thus ozone. VOC is aimed to reduce by 10% by 2020. In addition, the plan includes more key areas to focus on. Beijing-Tianjin-Hebei key area is expanded, and Shanxi, Shandong, and Henan are included as a new key region called “Fen-Wei Plains”. (Xinhua, 2018).

4.3.1. Present Condition of Air Pollution in China

China published its first air pollution standard in 1982 (GB3095-1982). There are three revisions made in 1996, 2000 and finally in 2012. The latest version, GB3095-2012, is applied to all cities nationwide since January 2016 and still used as the air pollution guidelines for China (Table 4.1). Class I and Class II represent special areas like national parks and all other regions such as cities, respectively.

Table 4.1 China Ambient Air Quality Standards (GB3095-2012)

Pollutant	Average Time	Concentration Limit		WHO	
		Class I	*Class II*		*unit*
SO_2	Annual	20	60		µg/m^3
	Daily	50	150		
	1 Hour	150	500	20	
NO_2	Annual	40	40	40	
	Daily	80	80		
	1 Hour	200	200	200	
CO	Daily	4	4		mg/m^3
	1 Hour	10	10		
O_3	Daily (max 8-hour average)	100	160	100	µg/m^3
	1 Hour	160	200		
PM_{10}	Annual	40	70	20	
	Daily	50	150	50	
$PM_{2.5}$	Annual	15	35	10	
	Daily	35	75	25	

Source: (Ministry of Ecology and Environment, 2012); SO_2: Sulphur dioxide; NO_2: Nitrogen dioxide; CO: Carbon monoxide; O_3: Trioxygen or Ozone; PM: Particulate matter

According to Class II, cities must not exceed the limit in order to be considered environmentally safe and healthy. In 2015, out of 360 cities, 283 of them exceeded the PM2.5 limit, 63 of them exceeded the NO_2 limit and 11 of them exceeded SO_2 limit (Figure 4.1). By the year 2017, this number decreased to 240 for PM2.5, 61 for NO_2 and 3 for SO_2. NO_2 is high mostly in largely populated cities like Shanghai, Tianjin, Beijing, Guangzhou, and Shenyang. It is mostly due to transportation emission therefore, there is a direct correlation between such developed cities and the NO_2 level. SO_2 has been already very low nationwide since late 1990s (He, Huo, & Zhang, 2002). The preventive measures that the government such as imposing credit system on industrial firms, shutting down heavy industrial companies that don't meet the regulations, cutting out vehicle emissions by removing "Yellow-label Vehicles" that has high emission rates from the traffics took has been very effective. In 2017, only three cities remained beyond the guidelines, these are Jinzhong, Linfen and Luliang. All three of them are located in Shanxi province.

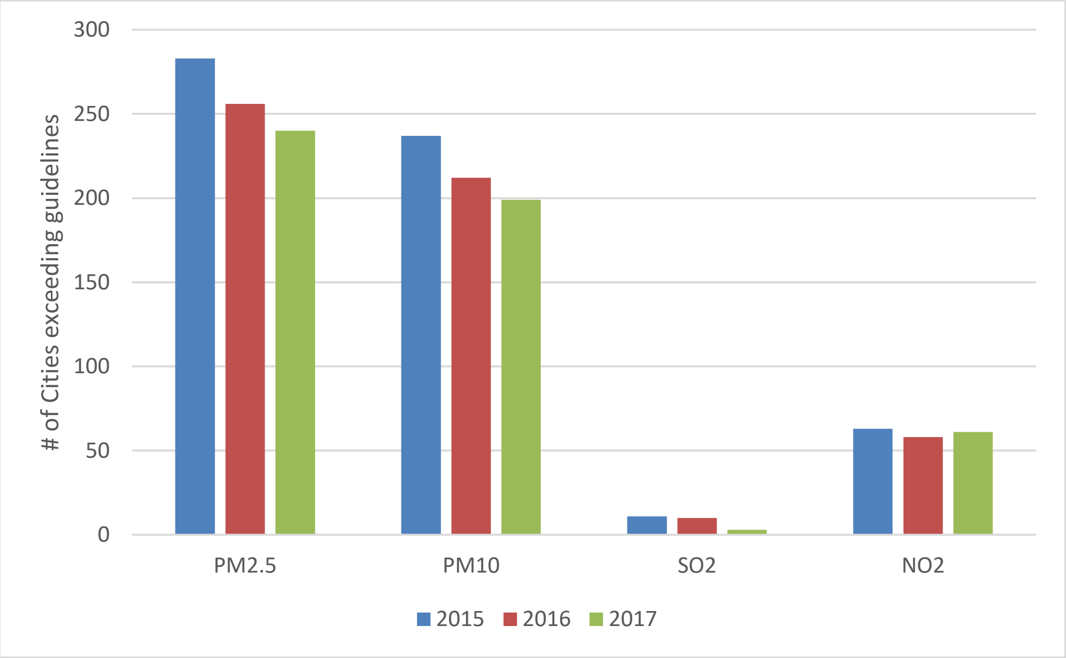


Figure 4.1 Number of cities that exceed the China air pollution standards

Source: Created by the author with the data retrieved from tianqihoubao.com

SO_2 is a crucial pollutant that has serious environmental and health effects. It is a significant factor, which initiates PM2.5 concentrations and acid rains. Main source of this gas is coal and sulphur containing crude oil. Therefore, it is emitted mostly during metal smelting and other industrial processes (EPA, 2017). Closer proximity to industrial facilities increases the chances of high SO_2 concentration of the region.

The three cities that are observed to exceed the guidelines in 2017 are all located in Shanxi. Due to large coal and other mineral resources available in the area, mining and heavy industry was well developed in Shanxi province. Linfen and Luliang were listed as one of the most polluted cities in China. Although the government took great measures to reduce air pollution in Shanxi by closing down the factories out of spec, SO_2 levels are still high in these mentioned cities. To illustrate, in 2017 local news reported a burst of SO_2 emission in 2017 in Linfen. According to Chinese news outlets (2017), SO_2 density in the air of Linfen, Shanxi was 1,303 $\mu g/m^3$ which was 21 times greater than the national standard of 60 $\mu g/m^3$ in 2017. The report claimed that reason was due to high dependency of coal in indoor heating in the city.

NO_2 is another crucial pollutant that affects environment and health. NO_2 is mainly emitted through fuel burning from vehicles, off-road equipment and power plants (EPA, 2018). Around 18% of cities exceeded the guidelines in 2015. This figure did not change much in the next two years. The average concentration of NO_2 is higher in mega cities. This observation is not surprising given the fact that these cities are highly populated and transportation activities are relatively much higher in comparison to small cities. Beijing, Shanghai, Chongqing, Tianjin, Chengdu, Handan, Baoding and Linyi are some examples of such mega cities that have high NO_2 concentration. These cities have always had high NO_2 concentration in each year and exceed the guidelines. However, the NO_2 concentration pattern is on the decreasing side due to government's strict control of the emission levels in these regions. These mega cities are all located in eastern China, contrarily western regions display increasing trend over time.

The shift of industrial activities from east to west has a crucial influence on increasing NO_2 concentrations. Xinjiang province is a good example of increased NO_2 concentrations due to this policy. Moreover, the neighbouring provinces of eastern provinces such as Shaanxi, Shanxi and Anhui are immensely affected by this move. These regions have the most number of cities that exceed the guidelines and have increasing concentration over time since they have become strong industrial zone in which power plants emits significant amount of NO_2 (Chen, Li, & Wu, 2010). In addition, the transportation sector grew so much that it became a hub, which connects China with other parts of Asia. Chen et al. (2010) estimates the final energy consumption of transportation sector to be increased by 20% by 2050. This means more NO_2 emission is expected in the future.

Moreover, the implementation of environmental policies relatively laxer in the west compared to the east. Especially on transportation sector, the leniency is apparent. For example, “Yellow-Label Vehicles” that are highly inefficient in meeting emission standards were banned from cities in eastern China while they were moved to western cities, since the restrictions on “Yellow-Label- Vehicles are not strict as they are in the east (Cui, et al., 2016).

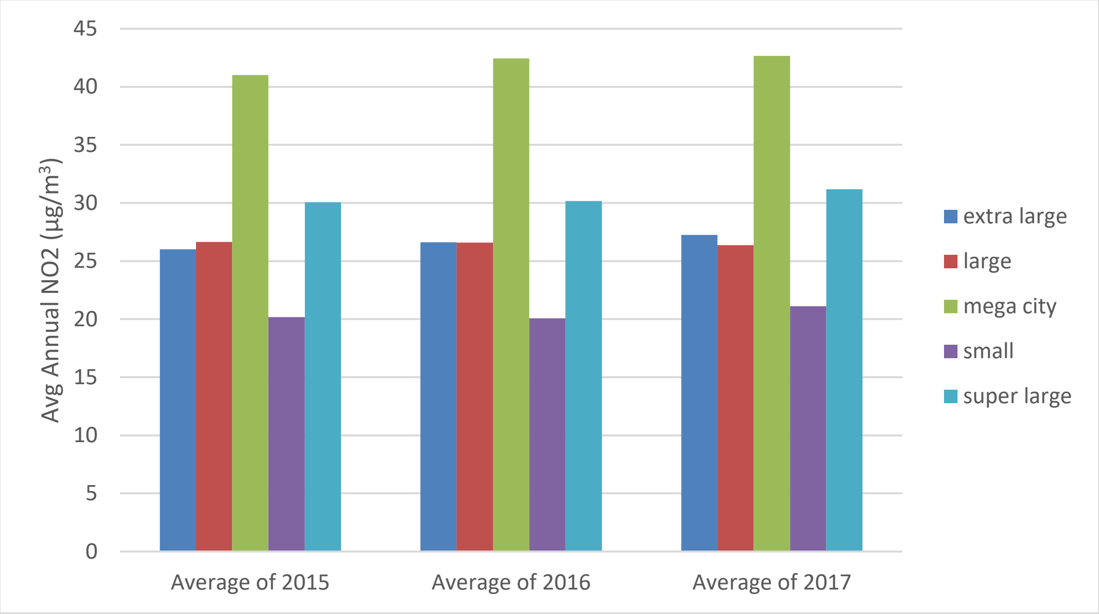


Figure 4.2 Average NO_2 concentration by city size (2015 - 2017)

Source: Created by the author with the data retrieved from tianqihoubao.com

Regardless of the material or the fuel, Carbon monoxide (CO) is a gas that end product of burning. The main source of CO in outdoor areas are combustion-based vehicles that burn fossil fuels. This gas could be harmful when breathed in large amounts. In this way, it prevents large amount of oxygen in the blood stream to be carried to the organs like heart and brain (EPA, Carbon Monoxide (CO) Pollution in Outdoor Air, 2016). Most vulnerable people to CO is exposed to the risk of heart diseases. Ninety-two cities exceeded the recommended CO limit in 2015, this number dropped to 63 cities in 2017. There is a general trend of reduction of CO concentration in the whole country. CO values of the cities range from zero to 2.8 mg/m3 in 2015 and zero to 2.07 mg/m3 in 2017.

Maximum CO concentration are seen at the cities in Shanxi province such as Luliang and Linfen. However, these values do not reflect the general trend in the country well. Taking 95th percentile as the base, the maximum CO concentration could be seen in Hotan, Xinjiang with 6.9 mg/m3 in 2015 and it is in Altay, Xinjiang with 5.7 mg/m3 in 2017. Baoding and Xingtai, well known regions for iron-casting and heavy industry were in top three in 2015 but in the next two years they dropped to 9th and 15th place in the ranking. This is due to the strict pollution control policies especially in such places that is known to the public as heavily polluted areas. On the other hand, some cities in Xinjiang show increasing trend in CO levels. Altay is a good example of it. In 2015, 95th percentile of CO was only 2.11 mg/m3 but it increased to 5.7 mg/m3 in 2017 and ranked first in the list of CO levels. This may be due to the residential heating and common usage of coal during long winter season in the northwestern regions (Zhao, Nielson, McElroy, Zhang, & Zhang, 2012). However, recent Greenpeace report (2016) states that shifting heavy industry from eastern region to western region where the environmental policy implementation is relatively less stringent caused great influence in worsening the air quality in western areas in general.

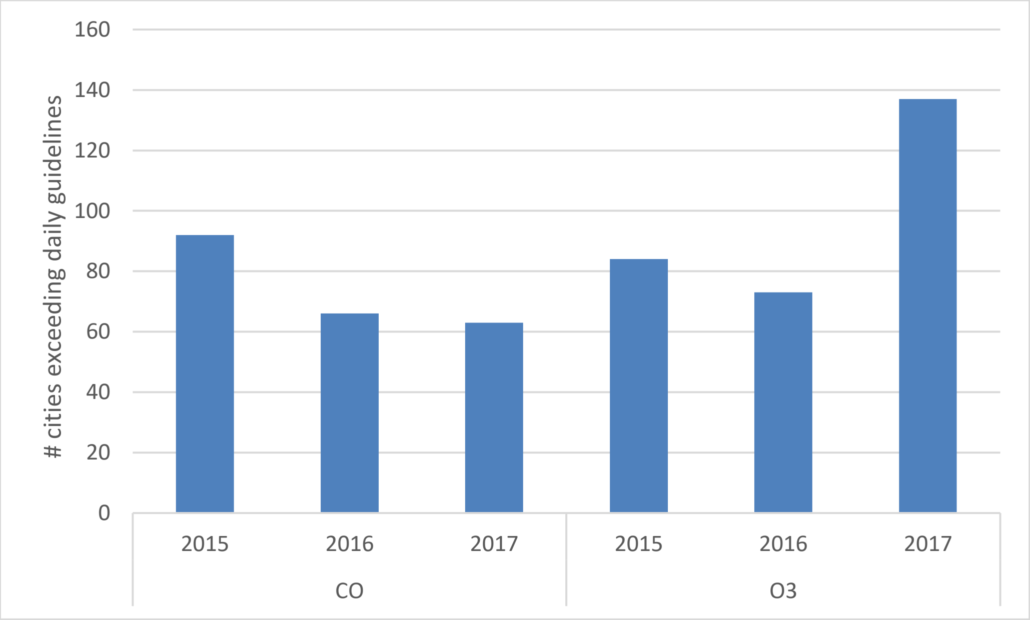


Figure 4.3 Number of cities exceeding daily limits of CO and O_3 (2015 - 2017)

Source: Created by the author with the data retrieved from tianqihoubao.com

Ground level ozone (O_3) is not directly released from a single source it is rather formed by the chemical reactions of other greenhouse gases like nitrogen (NOx) and volatile organic compounds (VOC) The main sources of this gas are mostly vehicles, powerplants, industrial boilers, chemical plants and refineries (EPA, 2018). Prerequisite of ozone formation is temperature being above 20 Celsius, wind speed lower than three m/s and strong sunlight.

Therefore, it is more commonly prevalent in coastal and southern areas. The number of cities, which did not meet the ozone targets, were 84 in 2015 but it increased to 137 cities in 2017. Beijing is far the most ozone-polluted city in whole China in comparison to other cities. The average O_3 concentration was 99 µg/m3 and the 95th percentile was 230 µg/m3 since 2015. Although it is decreasing, the city has the highest non-attainment days amongst the other cities.

Not only O_3, but also NOx is dramatically rising in Beijing. Vehicles are the main reason for high levels of O_3 in such urban areas like Beijing. Cars produce all required emissions for producing O_3, like NOx and VOC as well as CO. Number of private car ownership increased from 141 million in 2015 to 185 million in 2017 (National Bureau of Statistics of China, 2018). Just in two years, the number of cars increased around 31% in Beijing. In spite of this, China implemented series of policies such as driving restriction, car restriction, car license plate restriction and parking and congestion taxation in certain cities like Beijing and Shanghai. By the 2016, driving restriction policy had been implemented in 11 cities whereas car license plate restriction policy had been implemented in 8 cities (Zhang, Long, & Chen, 2019). Objective of these policies were to increase public transport, reduce traffic and thus emissions. Compliance to parking and congestion taxation is higher than the car purchasing restrictions (Geng, Long, Chen, & Li, 2018). This supports the increasing statistics of car purchasing that has been going on recently in China. As a result, there is an increasing trend of ground level ozone (O_3) urban cities like Beijing.

Ground level ozone has a serious impact on health. Inhaling ground level ozone leads to damage in lung tissue and lung functions; also, it worsens the respiratory diseases. According a research that studied Beijing ozone levels during the period between 2005 and 2013, it is found that O_3 has great influence on cause-specific, especially cardiovascular, mortality in Beijing during warm seasons (Li, Shang, Zheng, & Ma, 2018).

4.3.2. Particulate Matter (PM)

Particulate matter (PM) are “inhalable particles composed of sulphate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water” (WHO, 2018). These particles penetrate human body through respiration and spread to their blood circulation. It is considered a great risk to health and its contribution to diseases and eventually death is supported by various studies (Anderson, Thundiyil, & Stolbach, 2012; Kim, Kabir, & Kabir, 2015; Song, et al., 2016).

Sources of PM are combustions engines (i.e. automobiles); burning coal, heavy oil and biomass in both household and industry; also, construction sector and manufacturing sector of construction equipment (i.e. cement, ceramic, and bricks) as well as mining sector. There are two classifications of PM such as PM10 and PM2.5. PM10 is particles with diameters less than 10 microns and PM2.5 is particles with diameters less than 2.5 microns. China includes both in their air quality standards. In 2000, China substituted total suspended particles (TSP) with PM.

PM10 and PM2.5 both hold significant risk to health and environment but PM2.5 is a major pollutant amongst the others worldwide and has the greatest risk to human health. Since the particles are quite small, it is easily inhaled and could deeply infuse to lung and cause functional disorder in lungs (Xing, Xu, Shi, & Lian, 2016).

Moreover, PM2.5 is heavily present in the air, it has higher presence than the PM10 (Figure 4.4). Because of this reason, in this chapter, PM2.5 will be taken as the pollution indicator in the analysis. In this section we briefly discussed all the pollutants in the latter sections we will focus on PM2.5 trends in detail and will address the reasons of regional disparities in PM2.5 concentrations in China.

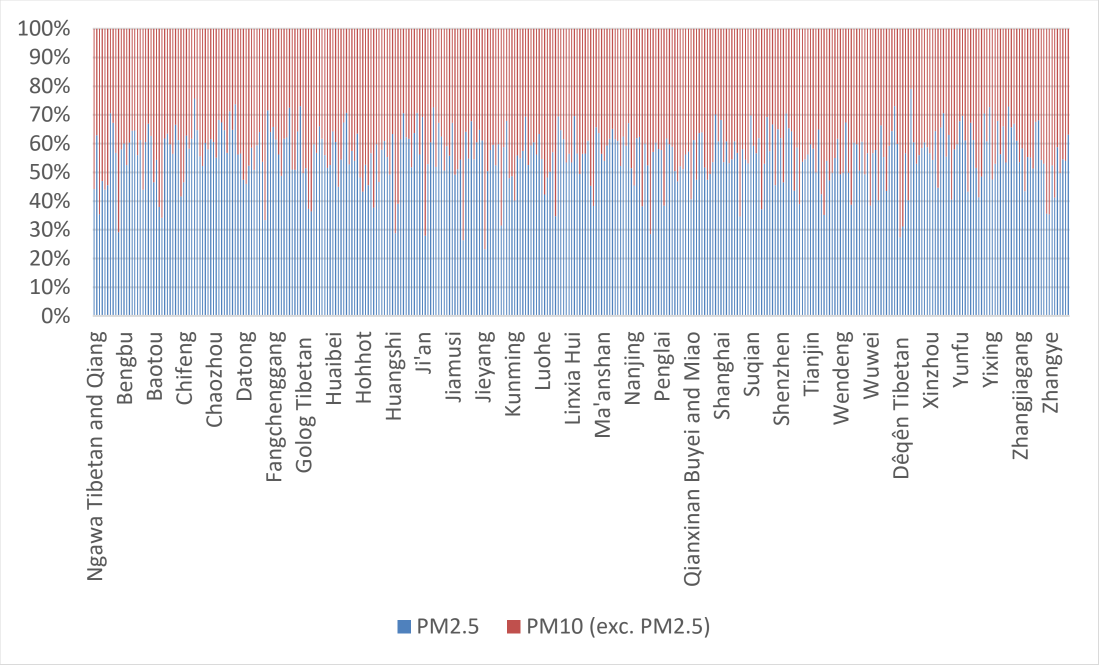


Figure 4.4 Particulate Matter, daily concentration percentage in the cities

Source: Created by the author with the data retrieved from tianqihoubao.com

China nationwide has been demonstrating a decreasing trend of PM2.5 concentration over the years (Figure 4.5). Because of the tighter implementation of air pollution policies and regulations over the last decade, the country managed to achieve a visible air pollution improvement. In 2015, the average PM2.5 concentration was 49.39 μg/m^3 and the 95th percentile was at 86 μg/m^3. These are still beyond the air pollution guidelines. In 2017, the average PM2.5 concentration dropped to 43.18 μg/m^3 whereas 95th percentile dropped to 70.4 μg/m^3. Although the values are still high, it is a good improvement made in only in two years.

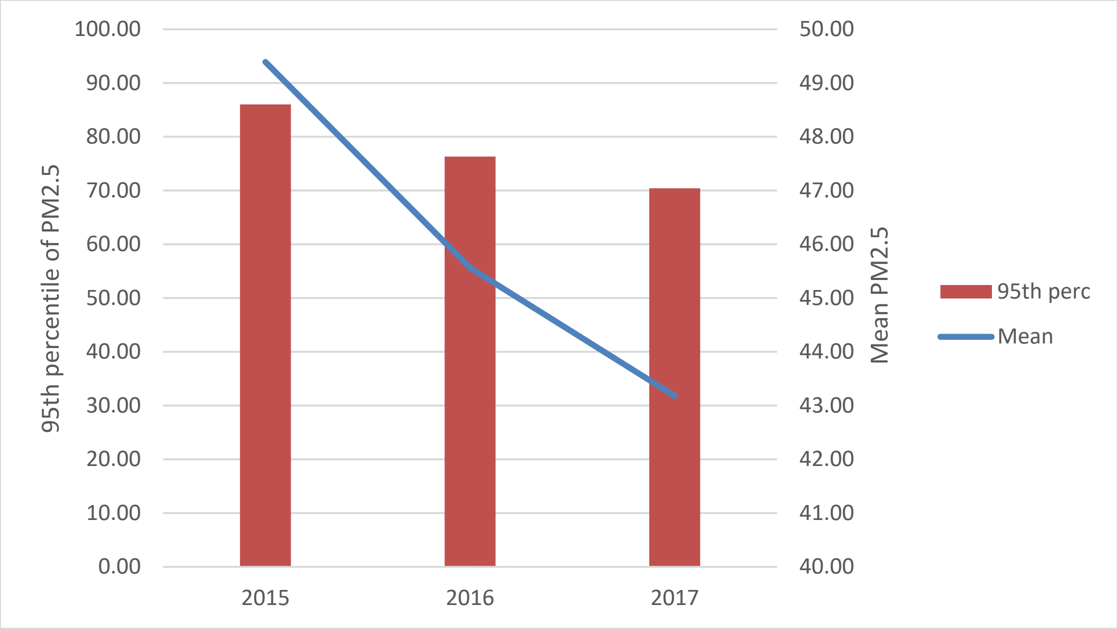


Figure 4.5 PM2.5 in China: Average & 95th percentile of annual concentrations (2015 - 2017)

Source: Created by the author with the data retrieved from tianqihoubao.com

According to the average PM2.5 concentration in 2017, ten provinces exceed 50 μg/m3. These provinces are Beijing, Anhui, Hebei, Henan, Hubei, Shaanxi, Shandong, Shanxi, Tianjin and Xinjiang. Except Xinjiang, the rest is located in the most developed eastern region and neighbouring central regions of the country. Traditionally those areas have been suffering from bad air quality in correlation with their relatively high development levels, urbanization and transportation activities in comparison to western regions.

Xinjiang, on the other hand, is located in far west of the country and does not inhabit highly dense population such as in those in the eastern region. However, it still shows one of the provinces with worst air quality in China. One reason might be seasonal effect. Xinjiang has longer winter and shorter summer sessions due to being located in the North, weather conditions are quite harsh. During spring, air pollution is observed to be high as well. This could be resulted from the frequent sandstorms from the deserts in spring (Zhan, et al., 2018). Compared to other northern regions like Inner Mongolia and Gansu, the air quality is quite different. The latter two regions do not display such bad air quality. Mamtimin and Meixner (2011) states that the reason Xinjiang has worse air quality is due to high dependency in coal usage in both heating and industry. Xinjiang is one of the major sources for coal, crude oil and natural gas. Moreover, with the western development plan Xinjiang become one of the electricity generation hubs for the country due to being close to resources and being connected to transportation network. In this way, Xinjiang has increased the pollution through power generation and transportation and expected to continue increasing in the future as well (Guo, Geng, Dong, & Liu, 2016).

China has shown a significant effort to improve air quality in cities. Pollution in cities mostly show decreasing trend since 2014. However, the levels of air pollution are still considered very high for health and environmental causes. One hundred sixty-six cities exceeded nation's average pollution levels in 2017.

Top 10 cities in terms of worst air pollution is shown in Table 4.2. Kashgar keeps its top position from 2015 until 2017, although its average pollution concentration dropped reasonably. Khotan, another Xinjiang city, risen up from 7th place to 2nd place. Cities from Hebei such as Baoding, Xintai and Hengshui dropped in higher ranks despite still suffers from significantly great pollution.

Shijiazhuang on the other hand was not in top 10 in 2015 but has 7th place in 2017 due to increasing pollution. Cities from Shandong such as Dezhou, Liaocheng, and Heze are dropped out of the top 10 list in 2017. Shandong displayed a decreasing air pollution in all the cities. In contrary, Shanxi, Shaanxi and Anhui (not in all but significant number of cities) demonstrated an increasing trend of air pollution.

Linfen and Xianyang are the cities that were not previously in top 10 but in 2017, they entered the list by increasing PM2.5 concentration by 42% and 34% respectively. Not only these two cities have shown increasing trend, but there are others as well. Suzhou, Fuyang, Huaibei, Huainan, Chizhou and Bozhou from Anhui; Yunchang and Jincheng from Shanxi, Wujiaqu, Turpan, and Ili Kazakh from Xinjiang; Xian and Weinan from Shaanxi are examples of such cities.

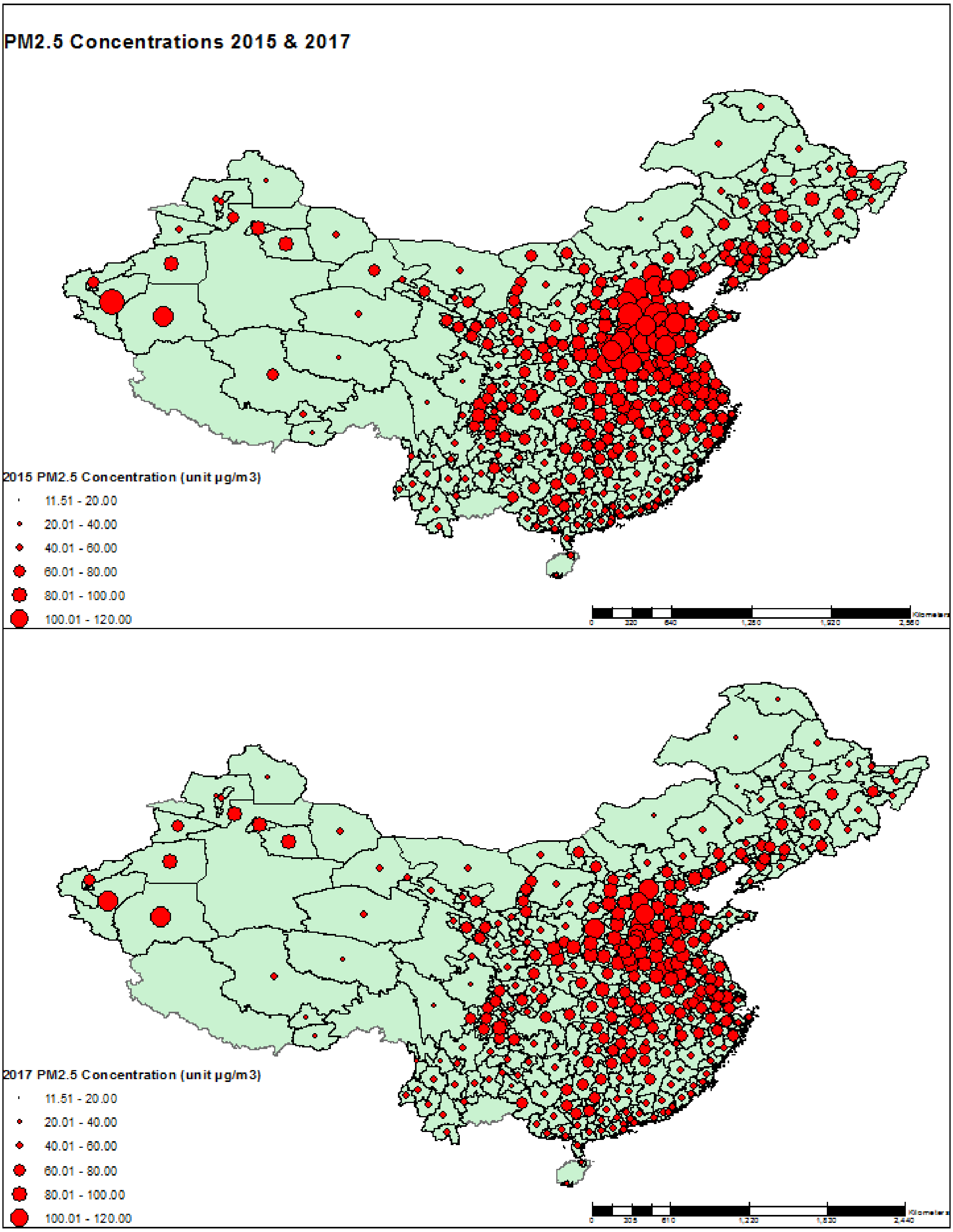


Figure 4.6 PM2.5 concentration map of China (2015 -2017)

Source: Created by the author with data from tianqihoubao.com using ArcGIS

Table 4.2 Top Ten Cities according to PM2.5 concentration (2015-2017)

Rank	City	Province	2015	Rank	City	Province	2017
1	Kashgar	Xinjiang	116.36	1	Kashgar	Xinjiang	98.77
2	Baoding	Hebei	105.70	2	Khotan	Xinjiang	90.75
3	Dezhou	Shandong	100.33	3	Handan	Hebei	85.12
4	Xingtai	Hebei	100.25	4	Baoding	Hebei	83.28
5	Hengshui	Hebei	98.32	5	Linfen	Shanxi	81.98
6	Liaocheng	Shandong	97.64	6	Anyang	Henan	81.37
7	Khotan	Xinjiang	97.29	7	Shijiazhuang	Hebei	81.18
8	Zhengzhou	Henan	94.59	8	Xingtai	Hebei	80.09
9	Heze	Shandong	93.59	9	Xianyang	Shaanxi	78.41
10	Xinxiang	Henan	92.69	10	Hengshui	Hebei	76.29

Source: Created by the author with the data retrieved from tianqihoubao.com

Despite, the air quality improvements in general (exceptions of the example cities above), the biggest challenge for China’s air pollution control effort is nonattainment days which means the number of days that were not able to attain pollution targets. Fen-Wei region (Shanxi-Shandong-Henan), as well as heavy industrial regions like Hebei display high non-attainment days in terms of PM2.5 targets. Xinjiang has 6 cities on the top 15 list. Kashgar has the worst attainment performance of all cities in each year. More than half of the year, PM2.5 concentrations do not meet the targets. Although number of non-attainment days decreased over the years, it still needs to decrease further. Some cities in the Table 4.3 shows increasing trend such as Linfen, Suzhou, Xianyang, Fuyang, Urumqi, Turfan and Wujiaqu. Xianyang and Fuyang needs to be highlighted due to the immense increase in the amount of non-attainment days since 2015. More than 80% increase could be observed in the two cities.

Table 4.3 Top 15 Cities according to non-attainment days of PM2.5 (2015-2017)

	Province	nonattainment days 2015	nonattainment days 2016	nonattainment days 2017	Change
Kashgar	Xinjiang	225	232	175	-22%
Handan	Hebei	188	126	154	-18%
Khotan	Xinjiang	174	190	154	-11%
Baoding	Hebei	199	173	139	-30%
Shijiazhuang	Hebei	171	160	130	-24%
Aksu	Xinjiang	135	178	128	-5%
Linfen	Shanxi	83	91	128	54%
Xingtai	Hebei	203	160	128	-37%
Liaocheng	Shandong	210	166	127	-40%
Hengshui	Hebei	195	171	126	-35%
Suzhou	Anhui	93	104	126	35%
Heze	Shandong	206	142	124	-40%
Xianyang	Shaanxi	68	135	124	82%
Anyang	Henan	168	138	122	-27%
Fuyang	Anhui	64	98	116	81%
Ürümqi	Xinjiang	100	118	116	16%
Binzhou	Shandong	165	138	115	-30%
Puyang	Henan	153	113	115	-25%
Turfan	Xinjiang	108	125	115	6%
Wujiaqu	Xinjiang	72	118	114	58%

Source: Created by the author with the data retrieved from tianqihoubao.com

4.3.3. Air Quality Index (AQI)

Air Quality Index (AQI) is introduced by EPA in order to serve as daily reporting of air quality and it indicates whether the day's air condition is healthy or unhealthy. AQI is calculated using five air pollutants such as particulate matter (2.5 micron and 10 micron), CO, SO_2, NO_2 and O_3. Based on the major pollutant of the day, daily AQI is monitored and published.

There are six levels of health concerns that corresponds to a certain level of AQI. They are shown in the table below (Table 4.4). Under the value of 100, the air quality considered healthy enough to perform activities outside.

Table 4.4 Air Quality Index Scale and the corresponding health concerns

AQI	Air Pollution Level	Health Implications	Cautionary Statement (for PM2.5)
0 - 50	Good	Air quality is considered satisfactory, and air pollution poses little or no risk	None
51 -100	Moderate	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
101-150	Unhealthy for Sensitive Groups	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Active children and adults, and people with respiratory disease, such as asthma, should limit prolonged outdoor exertion.
151-200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.	Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion.
201-300	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.	Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor exertion; everyone else, especially children, should limit outdoor exertion.
300+	Hazardous	Health alert: everyone may experience more serious health effects	Everyone should avoid all outdoor exertion

Source: Retrieved from US-EPA (2014)

China replaced its Air Pollution Index (API) system with AQI in 2013, and since then it is reporting daily AQIs for each city. Since 2015, Aksu, in Xinjiang, has maintained the first rank of highest AQI with maximum AQI at 500.

Most of the cities that lower AQI values are either located in southern regions such as Hainan, Fujian and Guangdong or located in high altitude like Tibetan Autonomous regions in Qinghai and Sichuan. The six category of air quality are excellent (AQI below 50), good (AQI between 50 and 100), mild pollution (AQI between 100 and 150), moderate pollution (AQI between 150 and 200), severe pollution (AQI between 200 and 300) and serious pollution (AQI above 300).

Cities that exhibit excellent air quality are generally clustered in the southern provinces such as Sichuan, Guizhou, Hainan, Yunnan and Guangdong. Ngawa Tibetan and Qiang, in which located in Sichuan, constantly shows great air quality over the years with having average 350 days of excellent air quality days in a year. Contrarily the worst conditions appear mostly in western and more developed eastern provinces.

Xingtai, Anyang and Shijiazhuang are observed as the most polluted cities that locate in eastern China. Xinjiang, a province that locates in the far west of the country has suffered from the heavy pollution. Hotan, Kashgar, Kizilsu Kirgiz, Aksu, Urumqi, Turpan, Shinezi and Wujiaqu are some of the most polluted cities that locate in Xinjiang province.

Hotan, with 99 days of experiencing serious pollution in 2015, had the worst air quality in comparison to other cities. Despite the decrease from 99 days to 81 days of serious pollution, Hotan remains to be most polluted city in China even in 2017 (Figure 4.7).

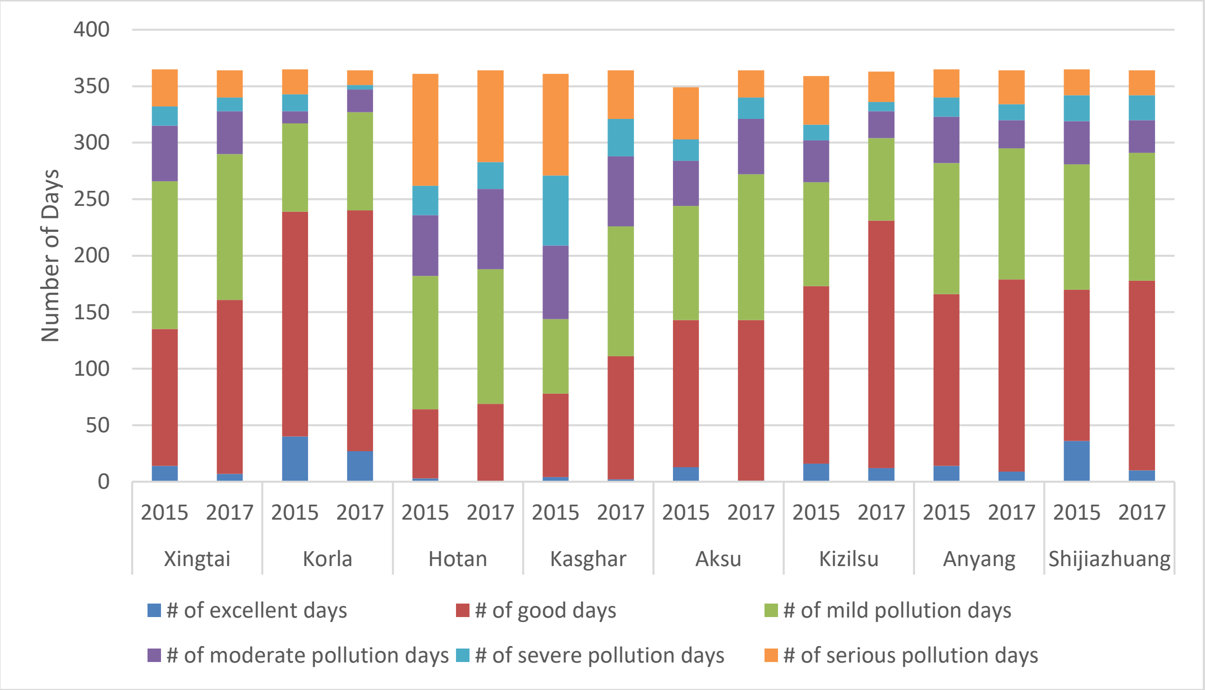


Figure 4.7 Cities with the worst air qualities (2015 - 2017)

Source: Created by author with the data retrieved from tianqihoubao.com

4.4. Methodology

Data preparations:

Air pollution measurements have become common in China since the launch of Clean Air Asia act. There are multiple air pollution monitoring centres in most cities. As a result, the real time air quality data collected by monitoring centres are generally available through China Ministry of Ecology and Environment and other various reliable online sources such as AQICN.org and PM25.in. For the purpose of analysis, the air quality data in this chapter is collected through http://www.tianqihoubao.com/ in which real-time air pollution from the monitoring centres are published. Compared to AQICN.org and PM25.in, this website also provides historical air quality and weather data. Chen et al. (2017) compared PM2.5 concentrations from the website to the concentrations that is published by US Embassy in China and observed a close linear relationship with slope 1.06 ($R^2 = 0.97$). As many studies (Sheng & Tang, 2016; Wang, Cao, Li, & Singh, 2015; Cai, Shao, & Wang, 2015) utilized this website as a reliable source, we also retrieved our air pollution from this source for the purpose of this study.

Air quality data that is provided on the website includes Air Quality Index (AQI), AQI ranking of the day, PM2.5, PM10, SO_2, NO_2, CO, O_3 and air quality levels such as excellent, good, mild pollution, severe pollution and serious pollution. There are total 376 cities from all the provinces, but 17 cities do not provide air quality data; as a result, 359 cities have the required data. The data from the year 2015 is available for all cities across the country however, 2014 is not available for all of them. In 2014, 188 cities were included, and 171 cities had no data. Regardless of this, all the available data are compiled from year 2014 until the end of 2017.

The data is compiled in daily format from 2014 until 2017. Some cities do not have 2014 air pollution data therefore, despite collecting data of 2014, we only used data from 2015 until 2017 for the analysis. Daily data is first aggregated into monthly data and then annual data. Then the data are categorized by province, township and city size, respectively.

Demographic data such as population, population density, GDP per capita and industrial activities are retrieved from China NBS annual statistical yearbooks. Industrial activities are defined as the proportion of local industries to total number of industries. For the local industrial data, China publishes “number of enterprises above designated size”. This is described as a classification that includes all state-owned enterprises and the not-state-owned enterprises with an annual revenue of and above 5 million yuan (National Bureau of Statistics of China, 2018). Thus, the industrial activities in a city is estimated as following:

Number of enterprises above designated size (city) / Total number of enterprises above designated size (National)

In order to assess economic inequality, Gini coefficient and Theil Index were calculated for each city. In order to assess the inequality within the city (i.e. prefecture or above), we compiled district level economic data, in our case GDP per capita. Therefore, our inequality index assesses not individual level inequality but inequality between districts within a city. In total we compiled data from 2062 districts. Then we calculated the inequality index for

281 cities. As Boyce et al. (2016) suggested Theil Index as a better indicator than Gini Index when measuring vertical inequality, we preferred Theil Index in our study. Due to lack of income data on district level, GDP per capita had to be used instead of income. Therefore, our inequality index mostly represents economic inequality and/or GDP per capita variation among cities.

Methodology:

Linear regression is used to check the hypotheses and assess the effect of certain elements on air quality levels in Chinese cities. Because it is the major pollutant in general throughout a year and also has a serious effect on health, PM2.5 is chosen as dependent variable, which indicates the air quality level. As for independent variables; industrial activity, GDP per capita, Theil Index and population density are used.

Since GDP per capita is major driving force for local governments, we included it in our analysis to see whether it reflects the regional economical differences. Theil Index is another indicator to support this decision. However though, the main indicators to measure the inequalities are the dummies that are created for regions and city size.

Regions are categorized into 4 groups: Eastern (Hebei, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan, Beijing, Tianjin, Shanghai and Shandong), North-Eastern (Liaoning, Jilin, and Heilongjiang), Central (Anhui, Jiangxi, Henan, Hunan, Shanxi and Hubei) and Western (Inner Mongolia, Guangxi, Sichuan, Guizhou, Yunnan, Gansu, Qinghai, Ningxia, Xinjiang, Chongqing, Shaanxi, and Tibet). There are 3 dummies in the models with reference to eastern region and each dummy that consists of binary numbers represents a certain region.

Another dummy to measure differences based on the city size is also included in the models. The cities are classified into three: Mega (i.e. population greater than 10 million people), Large (i.e. population between 500 thousand and 10 million people) and Small (i.e. population lower than 500 thousand people). This classification is derived from China's city size classification but is modified to maintain simplicity. We added 2 dummies regarding city sizes (large and small) with reference to mega cities. Lastly, one dummy variable called

"Policy Achievement" was added to capture pollution policy achievement of cities. Since general pollution prevention policies aim to reduce pollution levels, the increasing pollution levels shows a contrasting picture of the policy intentions. Therefore, any increase in pollution levels in a city means that the policies were not successful. In this context, we described this dummy variable. Zero value represents policy achievement while one represents no policy achievement.

There are 6 models created for regression analysis. Model 1 and 2 are done with 2015 data while Model 3 and Model 4 are done using 2016 data. In order to measure the average effect and the change effect, we considered two additional regression models. Thus, Model 5 and 6 are using average of 2015 and 2016, and the change from 2015 to 2016. Although we collected 2017 air pollution data, we could not incorporate it into the regression models due to lack of demographic data for the same year. Because of this, we only examined years 2015 and 2016 in our analysis.

4.5. Results

In this section, the results of regressions, which test the hypotheses, are presented. There are 6 regression models in total, first two models use data of 2015 the second two models use data of 2016 and the last two models are average of these years and the change between these years (Table 4.5). The first model measures the influence of industrial activity, GDP per capita, inequality that is measured by theil index and population density of a city on the city's air pollution concentration in the year 2015. The third model uses the same covariates and dependent variables for the 2016 data. Model 2 and Model 4 also include these same independent variables but also control for geographical regions and city size. In order to do so, 4 regions (i.e. eastern, northeastern, central, and western) and 3 city size (i.e. mega, large, and small) dummies are added to the previous model. Since inputting all dummies to the model at the same time creates multi-collinearity, we took eastern region and mega cities as a reference base for other dummies. Model 5 measures the same factors influence on the average pollution concentration of two years while Model 6 measures the same factors on the change in pollution concentration in a year from 2015.

Before running the regression, the assumptions of linear regressions were checked and verified. There is a linear relationship between dependent and independent variables. All the outcome variables are normally distributed and there is no multi-collinearity detected.

Table 4.5 Regression Results

Covariates	**M1(2015)**	**M2(2015)**	**M3(2016)**	**M4(2016)**	**M5(Average)**	**M6(Change)**
Industrial Activity	0.312***	0.202***	0.278***	0.153**	0.181**	-0.048
GDP per capita	-0.002	0.045	-0.059	0.005	0.026	-0.027
Theil Index	-0.071	-0.038	-0.040	-0.034	-0.036	-0.022
Population Density	0.189***	0.092*	0.192***	0.091	0.092*	-0.015
City Size(small)[a]		-0.227*** (-24.166)		-0.274*** (-26.422)	-0.254*** (-25.337)	-0.129** (-0.089)
City Size(large)[a]		-0.315*** (-23.423)		-0.299*** (-20.098)	-0.312*** (-21.718)	-0.016 (-0.008)
Region(central)[b]		0.244*** (9.844)		0.273*** (9.993)	0.263*** (9.959)	0.007 (0.002)
Region (northeastern)[b]		0.22 (1.194)		-0.072 (-3.566)	-0.022 (-1.110)	-0.223*** (-0.079)
Region(western)[b]		-0.149* (-5.483)		-0.094 (-3.135)	-0.123 (-4.253)	0.062 (0.015)
Policy Achievement					-0.005 (-0.215)	0.683*** (0.191)
N	281	281	281	281	281	281
Adjusted R2	0.13	0.275	0.098	0.258	0.263	0.59

Note: ***at 1% significance level
**at 5% significance level
* at 10% significance level
Values in parenthesis are unstandardized coefficients
[a] reference category for city size dummy variable is "mega cities"
[b] reference category for region dummy is "eastern region"

Results show that industrial activity at a city level has the most significance in explaining the air pollution in that city. In all models, except the last, the coefficients show high statistical significance in comparison to other independent variables. Therefore, we reject our first hypothesis which indicates the level of industrial activity in a city has no association with the city's air quality. There is an important relationship between air pollution levels and industrial activities in a city. In 2015, one unit increase in industrial activity would result in 0.3 $\mu g/m^3$ increase in PM2.5 concentration. In 2016, this value drops to 0.28 $\mu g/m^3$.

When controlling for region and city size, the effect relatively decreases but it is still significant at 1% significance level. Ranging from 0.15 to 0.3, the effect of industrial activity has a positive influence on pollution concentration. However, it does not show any significance in explaining the change of pollution concentration in a year according to the results. It is an expected result since the industrial activities do not change drastically over a year so there would not be any significant effect on the change of pollution concentration.

Population density is another strong variable that has high significance in explaining the variation in pollution concentration. The degree of influence ranges from 0.09 to 0.19 (Table 4.5). Both in 2015 and in 2016, it has crucial influence on air pollution after the industrial activity. One unit increase in population density leads approximately 0.19 µg/m3 in air pollution. When controlling for regions and city size though, statistical significance drops steadily. Only in model 2 and model 5, it has significance at 10% level. In this case, region and city size help explain the variations in air pollution better than the population density of the given city. In order to interpret the dummy variables reasonably and without any multi-collinearity effect, mega cities and eastern region categories were set as reference points for city size and regional dummy respectively. The reason is that, mega cities and eastern region are already known to have great pollution levels in China so comparing other cities and regions to those areas are easier to understand.

According to results, central region has almost 10 µg/m3 higher pollution levels than eastern region when controlling industrial activities of the given cities. Northeastern region has a slight difference so it does not show any statistical significance in any of the models except model 6. It has great significance in model 6, in which we analyse the change in pollution levels in a year. Western region is significant in 10% significance level in model 2 and has around 5.5 µg/m3 less than eastern region in 2015 but it does not show any statistical difference in 2016 as well as in the rest of the models. When it comes to city size, both small and large size cities display great statistical significance in almost all models, except for large cities (model 6).

Small cities have an average of 25 µg/m3 less air pollution compared to mega cities. In 2015, it was 24.2 µg/m3 whereas in 2016 it was 26.4 µg/m3 less than the mega cities. In model 6, small cities show 0.09 µg/m3 more decrease than in mega cities. Including large cities however do not show statistical significance in explaining the variation in pollution level change. The unstandardized coefficients show that large cities have less pollution level, ranging from 20.1 to 23.4 µg/m3 when compared to mega cities.

We hypothesised that the pollution legislation has a uniform impact on air pollution levels across China. However, the results show there is a regional difference as well as city size difference. For example, the western region does not show statistical significance in any model. Moreover, in some cities in western region, there is a rather increase in pollution concentration. Model 6 indicates that only north eastern and small cities show change in pollution levels, compared to eastern and mega cities where the policies are quite strict, to be statistically significant. As a result, we reject the null hypothesis that states the pollution legislation's impact is similar in everywhere.

In order to have a clear understanding of the policy legislation we added an independent dummy variable called policy achievement into model 5 and 6. The pollution improvement policies aims to reduce the air pollution concentration in the given city. In this analysis, we categorized the policy achievement into zero when the policy achieved (i.e. pollution levels dropped) and into one when the policy is not achieved (i.e. pollution levels increased). In the appendix B, we provide binary logistic regression results where policy achievement is analysed when city size and regions considered. According to the results, city size does not matter to policy achievement however, regions do. Central and western regions demonstrate statistical significance. Locating in central region leads to the odds of policy achievement being lower by 84% in comparison to eastern region. Similarly, for western region the odds are lower by 87% in comparison to eastern region. This furthermore approves the results found in regression models.

GDP per capita is widely used indicator and performance measure for Chinese local governments. It is also included in this analysis to see whether it has any effect on pollution concentration levels. Although it is a strong indicator of economic development, it does not explain the air pollution concentrations in China. It does not have significant effect in any of the models. In order to check whether industrial activities mask the effect of GDP per capita, we run the models excluding industrial activities (see appendix B). According to the results, GDP per capita only has significant effect in year 2015. In model one; it is statistically significant at 5% level while in model 2, it is only significant at 10% significance level.

The third hypothesis relates to whether economic inequality affects pollution levels in China. In order to measure economic inequality, theil index is considered. Theil index for each city is calculated in R with “dineq” package by using 2062 districts GDP per capita values. Theil index does not show any statistical significance whatsoever in the regression models. It has no effect at all in the pollution levels and explaining the variation in them. As a result, we reject the null hypothesis that claims the inequality in cities has an effect on air pollution. However, we have to note that this may be also because the index is calculated using GDP per capita values rather than income values as usual. GDP per capita as explained before does not have any significance in explaining the pollution levels so does the Theil index.

The variation in GDP per capita is not so high that it captures variation in pollution levels. In this case, an income inequality of rural and urban areas in a city would be a better indicator but due to the lack of data in district level, it is currently not possible.

4.6. Conclusion

This study analysed environmental inequality in the context of air pollution in Chinese cities. We focused on the latest air pollution levels in the cities across the country, further examined the effect of economic growth and industrial activities on air quality in the cities.

We tested three hypotheses to check whether industrial and economic activities affect air pollution and if so, whether their impacts are in accordance with the degree of activities across the cities. Results show that air pollution levels are significantly affected by industrial activities but not similarly affected by economic activities. GDP per capita is one of the most important indicators that local governments focus on but in this context the variation of GDP per capita among cities does not capture the air pollution variation. In other words, the economic status of a city does not explain the pollution levels. It could be argued that pollution concentrations are mostly due to the heavy industry rather than individual consumption. Along with economic status, economic inequality is also found to be not significant in explaining pollution levels in a city. Contrarily to some studies (Dorling, 2010b; Holland, Peterson, & Gonzalez, 2009; Boyce J. , 2003), we found that economic inequality does not affect environmental inequality however it should be noted that we had a limited data, so with available data in future it is better to re-check the relationship between these two inequalities.

According to the results, there is great geographical disparities in pollution. Eastern region has been the most developed yet most polluted region of the country for many decades, but central region observed to showed higher pollution levels than the east in 2015 and it continues to increase when we controlled the industrial activities in cities. This is a result of industry transfer from east to west. In order to reduce the pollution levels of traditionally most polluted coastal area, government implemented a policy to shift all the heavy industry outside those areas to the less urbanized western regions. Because of this, air pollution in neighbouring cities has been tremendously increasing. Government took preventive measures in the latest action plan and announced some of the cities in a new key area that will be given special attention. However, pollution policy’s implementation is observed to be not as strict in western region as it is in eastern region. This raises concern. No matter how strict the policies are, implementation of them is unbalanced according to the region. There has to be a nationwide framework of environmental inequality implementation and local governments should be encouraged to prioritise it as well as they do economic growth.

Compared to US and other western countries, environmental inequality studies are at primitive level in China. Mah and Wang (2017) states that most literature regarding China discusses environmental justice and its political and legal aspects. There are only few quantitative studies, which analyse the environmental inequality regarding China. Therefore, this study aims to contribute to the literature of environmental inequality as well as ecology literature since we also examine the current air pollution trends in Chinese cities.

Environmental issues are pressing concerns currently in China; as a result, it is getting more attention both nationally and internationally. However, there is still a lack of understanding of what environmental inequality means in both public and political level. Even the broader concept of environmental justice is not known well to the public. According to Mah and Wang (2017) only four newspaper articles titled “environmental justice” from 2000 until 2017. This clearly shows the lack of attention, thus a limitation to action to this inequality issue too. Government should take a clear stance in increasing the awareness. Additionally, growing academic coverage about this subject would also help increasing awareness and trigger actions on preventing environmental inequality and further impact of inequality on vulnerable populations.

Chapter 5 AIR POLLUTION IMPACT ON MORTALITY: CASE STUDY OF PROVINCES IN CHINA

Abstract

Background: Because of rapid economic growth, China has experienced high pollution concentration for many decades. China's ambient air pollution related deaths represents 20% of the global estimations (GBD 2016 Risk Factors Collaborators, 2017). Therefore, increasing risks of mortality due to high pollution concentration is a great concern in China.

Objective: This study examines the risk of mortality due to ambient air pollution (PM2.5) as well as the estimation of deaths that is associated with long term exposure to PM2.5 in Chinese provinces.

Methods: We estimated number of deaths that is associated with long-term exposure to PM2.5 for each province in 2010 and 2015 using log-linear exposure-concentration functions as suggested in the literature. Meta-analysis is done by extensive literature review in order to estimate coefficient β of the exposure-response function.

Results: Findings show that 2.8 million deaths (43% of total reported deaths) are associated with long-term exposure to ambient air pollution (PM2.5) in 2015. Forty-eight percent increase in exposure related deaths are observed from 2010 until 2015. Regional differences are evident as eastern provinces and nearby provinces of central region suffer relatively more from pollution related deaths compared to other regions of the country. Provinces such as Hebei, Henan, Beijing, Shandong, Tianjin and Hubei are observed to have the highest pollution related deaths.

Conclusion: Increasing air pollution and thus increasing pollution related deaths are posing great concern for China**.** If China implements the Three-Year Action Plan not only in selected regions but across all the provinces and meets the targets by 2020, 16% of pollution related deaths from the baseline deaths in 2015 would avoidable. Moreover, if WHO interim targets IT-1, IT-2, IT-3 and eventually Air Quality Guidelines (AQG) were to achieve, the reduction in pollution related deaths would be 39%, 58%, 79% and 91% from the baseline.

Contribution: This study intends to contribute to the literature which has limited studies that examine the long-term exposure effect of PM2.5 on mortality in Chinese provinces.

5.1. Introduction

This study aims to assess the effect of ambient air pollution in terms of PM2.5, on mortality in Chinese provinces. We examined this effect by estimating the deaths associated with long-term exposure to PM2.5 for each province in 2010 and 2015 using exposure-response functions as suggested in the literature.

Air pollution has great impact on health. The effect of long-term and short-term exposure to air pollution, particularly to PM2.5, on human health and mortality is well documented. Exposure to high pollution concentration increases the risk of people suffering from diseases like cardiovascular diseases, cardiopulmonary diseases, respiratory diseases and lung cancer (WHO, 2019). In addition to physical wellbeing, it could affect people's mental wellbeing as well (Evans, 2003; Guxensa & Sunyer, 2012). Studies show that excess pollution impacts neurocognitive functions, moreover has significant correlation with depression (Allen, et al., 2017; Lim, et al., 2012).

According to WHO estimates (2019), there are 4.2 million deaths per year that are associated with long-term exposure to air pollution. Because of rapid economic growth, China has experienced high pollution concentration for many decades. China's ambient air pollution related deaths represents 20% of the global estimations as it was estimated 852,000 people (GBD 2016 Risk Factors Collaborators, 2017). Therefore, increasing risks of mortality due high pollution concentration is a great concern in China.

To help pollution abatement policies aimed at fighting against mortality, there is a need of understanding the impact of air pollution on mortality. With this motivation, this study examines the pollution and mortality trends in Chinese provinces and further presents the risk of mortality due to ambient air pollution as well as the estimation of deaths that is associated with exposure to ambient air pollution.

This study intends to answer two questions:

> *How does long term exposure to ambient air pollution impact mortality in Chinese provinces? Are there any regional differences?*

How much does mortality decrease in case China achieve pollution abatement targets?

This study intends to contribute to the literature of epidemiology, mortality and air pollution that is related to China. Although there are studies available regarding China, most of them are either focused on the most polluted areas like eastern region or used PM10 as the pollutant and most importantly majority of them are about the impact of short-term exposure on the mortality. Because PM2.5 is the major pollutant in China, it has grabbed a great attention by Chinese authorities (Cao, Liang, & Niu, 2017).

In the present study, PM2.5 is used as the pollutant to examine all 31 provinces of China. Since there is a direct link to PM2.5 exposure and diseases such as cardiovascular diseases, respiratory diseases and particularly lung cancer; deaths due to these diseases are estimated and presented in this study. There are only few analyses that examines the long-term exposure to mortality in the literature. This study estimates the impact of long-term exposure to PM2.5 on mortality with using latest data available for all 31 provinces of China. Therefore, our study contributes to the literature by presenting the latest PM2.5 related death estimates for all 31 provinces of China. This makes this study as one of the most comprehensive and up to date study amongst the other studies regarding China.

5.2. Literature Review

Mortality is one of the most significant indicators of assessing health impacts. Studies commonly address the impact of air pollution on mortality in order to present a clear understanding of how air pollution affects human health. The impact of air pollution on health, especially mortality, is widely acknowledged. In 2015, outdoor PM2.5 concentration was the fifth leading risk of mortality; and it’s estimated cost was 4.2 million (95% CI 3.7 million– 4.8 million) deaths and 103.1 million (95% CI 90.8 million – 115.1 million) DALYs which denotes to 7.6% of total global deaths and 4.2% of total global DALYs (Cohen, et al., 2017). The number of deaths associated with PM2.5 exposure in 2015 are found to be 20% higher than the previous Global Burden of Disease study in 1990, and it increased even more by half a million from 2015 in 2017 (Health Effects Institute, 2019).

One of the earliest studies that focused on the relationship between air pollution and human health was the study where Pope (1989) examined the relationship between PM10 concentration and hospital admissions in Utah Valley, United States. This study simply applied regression models for monthly hospital admissions and PM10 concentration over three years from 1985. Results indicate strong correlation between PM10 and hospital admission for bronchitis, asthma, pneumonia and pleurisy. The effect on children were observed to be much higher than the adults. The same case study was used for later studies which presented strong evidence on respiratory (Pope, Dockery, Spengler, & Raizenne, 1991) and lung dysfunction (Pope & Dockery, 1992) as well as respiratory and cardiovascular deaths (Pope & Kalkstein, 1996).

Epidemiological studies regarding air pollution are classified into two in terms of exposure period to pollution: short-term and long-term exposure. Short term studies examine the acute health cases whereas long-term studies focus on chronic health problems. Earlier studies mostly focused on short-term exposure impact on health and short-term exposure impact is well covered in the literature (Brook, et al., 2004). These studies generally utilize daily air pollution and daily mortality (or hospital admission) data through time-series analysis (Lu, et al., 2015; Li, et al., 2017; Shang, et al., 2013). The estimated relative risks for death was reported ranging from 0.4% to 1.5% for 20 μg/m^3 increase in PM10, and from 0.6% to 1.2% for an increase of 10 μg/m^3 in PM2.5 (Stieb, Judek, & Burnett, 2002).

On the other hand, long term exposure studies are relatively few and they utilized larger data set like cohorts. One of the earliest and the most cited cohort study of long-term exposure was where Dockery et al. (1993) examined 6 cities in the United States for around 14 to 16 years. They calculated the estimated mortality caused by exposure to ambient air pollution via Cox proportional hazards regression modelling and the results indicates that the long term-exposure to air pollution, particularly fine particles, is significantly correlated with deaths due to lung cancer and cardiopulmonary disease. Pope et al. (1995; 2002) presented similar results in their cohort study on American Cancer Society which included around 1.2 million adults from the year 1979 until 2000. The relative risks of deaths in case of 10 μg/m^3 increase in PM2.5 reported to be 1.06 (95% CI 1.02-1.11), 1.09 (95% CI 1.03 – 1.16) and 1.14 (95%CI 1.04 – 1.23) for all cause, cardiopulmonary disease and lung cancer respectively (Pope, et al., 2002). The European Study of Cohorts for Air Pollution Effects (ESCAPE) is one of the latest cohort studies that provides great source of air pollution database and publications regarding Europe. The regarding studies show that the impact of PM2.5 on mortality is even relevant at the pollution levels lower than 15 µg/m^3 (Raaschou-Nielsen, et al., 2013).

Relative risks of death are usually calculated with an exposure-response function. Although depending on the distribution of data, short term studies mostly utilize linear exposure-response function while long term studies mostly utilize log-linear functions (Ostro, 2004). Pope et al. (1995) first applied linear function but in the follow up study in 2002, they re-estimated the data since linear functions do not fit high pollution concentration trends, however it works well within the range of 10 to 30 µg/m^3 (Pope, et al., 2002). Above that level, linear functions tend to overestimate the mortality. Recently, Burnett et al. (2014) presented a new adaptation of log-linear function which is named integrated exposure response function. The function integrates various sources of emissions such as ambient air pollution, household solid cooking fuel, active smoking and second-hand smoking. They assume the shape of relation between pollution and mortality is supra-linear. As a result of this the estimated number tends be lower than the log-linear functions.

Literature regarding the impact of air pollution on mortality is less documented in China compared to Western world. Though it has been steadily growing over the years, especially after when the collection of air pollution data become easier. However, there is a lack of China related study in the literature in terms of long-term studies as well as cohort studies regarding PM2.5 exposure in overall China. The available cohort studies related to China are Cao et al. (2011), Dong et al. (2012), Wong et al. (2015), and recently Yin et al.(2017).

Cao et al. (2011) research is China’s first cohort study that analysed the pollution exposure and its impact on mortality. The authors estimated the relative risks of deaths from 1991 to 2000 by utilizing “China National Hypertension Survey” that includes 70,947 adults in 31 cities. Since China was collecting TSP instead of PM10 or PM2.5, this study included TSP as the pollutant. Results suggested that with every 10 µg/m^3 increase in TSP would increase all-cause deaths, cardiovascular deaths, respiratory death and lung cancer deaths by 0.3%, 0.9%, 0.3% and 1.1%. Dong et al. (2012) conducted a cohort study with 9,941 adults reside in Shenyang for 12 years. Unlike Cao et al. (2011), PM10 was utilized as the pollutant instead of TSP. Results showed that each 10 µg/m^3 increase in PM10 would result in relative risks of 1.67 for respiratory diseases. Moreover, they claimed that the effect is more noticeable on women compared to men. Wong et al. (2015) used a cohort survey with 66,820 elderly participants in Hong Kong and examined the impact of exposure to PM2.5 for 10-13 years. The authors preferred using NASA satellite data rather than ground level data. The results showed that relative risks for all-cause deaths were 1.14, for cardiovascular diseases were 1.22, for IHD was 1.42, for cerebrovascular diseases were 1.24 and for respiratory diseases were 1.05.

Most of the studies that are available are either city specific studies (Dong, et al., 2012; Zheng, Pozzer, Cao, & Lelieveld, 2015) or they utilize PM10 as pollutant (Aunan & Pan, 2004; Wang, Yu, Ciren, & Jiang, 2015). There are few studies that show the impact of PM2.5 exposure on cardiovascular diseases (Sun, Zhou, Zhang, Cao, & W., 2017) and respiratory diseases (Xing, Xu, Shi, & Lian, 2016; Chen, Yin, & Meng, 2017), and particularly and most popularly on lung cancer (Chen & Cao, 2019; Li, et al., 2018). This is due to the lack of data, since accessing morbidity data and mortality data is quite difficult. In addition, PM10 had been more widely collected and published than PM2.5 until recently. Because of this, more inclusive studies use meta-analysis and estimate health risks with data from literature (Zhao, et al., 2017). Despite the relatively more numerous short-term studies (Shang, et al., 2013; Chen, Lin, Su, & Cheng, 2017), in terms of long-term study, there are handful of studies related to China.

One of the few long-term studies that focus on PM2.5 concentration is by Rohde and Muller (2015). They used integrated exposure-response function (a variation of log-linear function) and found that the deaths associated with PM2.5 exposure was 1.6 million (95% CI 0.7 million – 2.2 million) which denotes to 17% of all deaths in China. On the other hand, Maji et al. (2017) used log-linear function and analysed the mortality impact of PM2.5 of 190 cities from 2014 to 2015. They estimated the PM2.5 associated deaths as 722,370 persons (95% CI 322,716 – 987,519) and DALY as 7.2 years. Similarly Fang et al. (2016) analysed mortality risks of 74 cities of China in 2013 by using log-linear functions. In those

74 cities, 1.03 million deaths are estimated to be associated with long term PM2.5 exposure. This equals to 32% of observed deaths.

5.3. Air Pollution and mortality in China

This section summarises the existing literature regarding general trends in mortality and ambient air pollution and their association.

5.3.1. General Mortality Trends in Chinese Provinces

Since the establishment of People's Republic of China from 1958 until early 1980s, the crude death rate had been in rapid decrease. During that period, rapid increase in education level as well as rigorous health initiatives, infant and under-five mortality rates decreased around 50% to 70% so it contributed to overall mortality reduction a lot (Babiarz, Eggleston, Miller, & Zhang, 2015). In late 1980s, the pace of decrease slowed down but did not stop until mid-2000s because of the impact of earlier dramatic reduction in infant mortality started to diminish as the pace of reduction in infant mortality also started to slow down in 1980s. After 2005, crude mortality rate increased marginally and almost stabilized around 7.1 deaths per thousand (World Bank, 2019).

According to Banister (2009) mortality of young men aged between 15 to 39 reported to unexpectedly increased at 2005. We may argue its effect on the general trend of mortality. Because nationwide crude death rates do not tell much about the actual mortality trends in the country as well as the provinces, so age adjusted mortality rates are calculated based on China's age specific death rates. Table 5.1 shows the top five provinces that have the highest indirect age adjusted mortalities (IAR) in years 2010 and 2015. Tibet, Qinghai and Yunnan are at top three in both years, although the mortality rates decreased.

Mortality rates are not always on the decreasing trend over the years for some provinces. Three eastern provinces such as Tianjin, Hainan and Guangxi display increase in IAR respectively by 31%, 27% and 5% from 2010 levels. The reason for such change may be increase in Tianjin's under five mortality rates and Hainan and Guangxi's aging population.

However, these provinces are already on the lowest rank of mortality rates amongst the other provinces.

Table 5.1 Top 5 provinces with highest IAR (per 1000 population) in 2010 and 2015

Rank	Province	IAR_2010	Province	IAR_2015
1	Tibet	8.79	Yunnan	7.24
2	Qinghai	7.91	Tibet	6.56
3	Yunnan	7.52	Qinghai	5.88
4	Ningxia	7.19	Jiangxi	5.75
5	Guizhou	6.75	Shanxi	5.60

Source: Created by the author with the data retrieved from National Bureau of Statistics of China: Population Census (2010) & (2015)

When standardized mortality ratio (SMR) taken into account, there are more provinces that show increasing trend over time. SMRs for each province are calculated using China's national deaths by age as the standard. Table 5.2 shows that there are twelve provinces that have increased SMR since 2010; seven eastern, four central and one western province increased their SMR from 2010 to 2015. Eight of them had mortality rates below national level in 2010 but in 2015 they all increased beyond national mortality levels, except Guangdong and Shanghai.

In 2010, the highest mortality rate was in Tibet by 58% above national average while it was Yunnan by 50% more than national average in 2015. Top three provinces with highest mortality rates in both years were Tibet, Yunnan and Qinghai. Out of ten western provinces, nine of them were above the average mortality in 2010, except for Chongqing. The central provinces that were above the average were Jiangxi, Shanxi and Henan. The only eastern province that was above the average was Hebei. Shandong, as an eastern province, was above national level by 0.6% but not the average mortality of the provinces.

In 2015, there were five western, three central and six eastern provinces above the average mortality of all provinces and addition to that one more central province that was above national mortality levels. Although the top three provinces of highest mortality did not change and remained to be all western provinces, in general the mortality levels in western provinces dropped while eastern provinces increased from their previous levels. The highest decrease in mortality was in Ningxia by 26% from 2010 levels while the highest increase was in Tianjin by 52%. Air pollution may be a significant contributor to such change in mortality. Increase in PM2.5 levels from is one of the highest changes amongst other provinces for Tianjin, as it was increased by 59% from 2010 until 2015. It is worth noting that 9 out of 19 provinces that had a reduction in mortality were western provinces. The remaining 10 provinces were equally divided as central and eastern.

On the other hand, only Yunnan in the western region was the only province among 12 provinces that showed an increase in mortality. The rest included 4 central and 7 eastern provinces. In only 4 out of 12 provinces where the mortality increased, the rates were already higher than the national level in 2010. These provinces are Yunnan, Shanxi, Jiangxi and Henan. Although their mortality levels increased from 2010 levels, Shanghai and Guangdong remained to be below national levels in 2015. The remaining 6 provinces were lower than the national level in 2010 but increased above the national levels in 2015. While there is not any western province in this category, Hubei is the only central province. The rest of them are all from eastern region such as Guangxi, Fujian, Jiangsu, Hainan and Tianjin.

Table 5.2 Provinces with increased SMR between 2010 and 2015

Rank	Province	Region	SMR_2010	SMR_2015	% change
1	Tianjin	Eastern	74.14	112.36	52%
2	Hainan	Eastern	74.75	109.29	46%
3	Guangxi	Eastern	95.51	115.92	21%
4	Shanghai	Eastern	70.82	80.25	13%
5	Fujian	Eastern	95.47	107.22	12%
6	Yunnan	Western	135.04	149.92	11%
7	Jiangxi	Central	107.63	119.12	11%
8	Jiangsu	Eastern	92.81	102.22	10%
9	Henan	Central	102.81	111.49	8%
10	Hubei	Central	96.57	101.03	5%
11	Shanxi	Central	111.97	115.92	4%
12	Guangdong	Eastern	91.73	94.49	3%

Source: Created by the author with the data retrieved from National Bureau of Statistics of China: Population Census (2010) & (2015)

5.3.2. General PM2.5 trends in Chinese provinces

In 2010, the average PM2.5 concentration of China was 41.46 µg/m^3 which is higher than the Chinese standard (i.e. 35 µg/m^3), by 2015 the average PM2.5 concentration increased by 25% and reached to 51.72 µg/m^3. The highest pollution was in Gansu with 67.36 µg/m^3 and lowest was in Hainan with 18.36 µg/m^3 in 2010. However, in 2015, the highest pollution was in Hebei with 89.63 µg/m^3 and the lowest was in Guizhou with 15.64 µg/m^3. Initially, in 2010, there were five western provinces above the average PM2.5 such as Gansu, Xinjiang, Qinghai, Shaanxi and Ningxia but only Xinjiang and Shaanxi remained above the average and Sichuan was added later due to the 51% of increase from 2010 pollution levels. Also, Chongqing experienced increase in pollution by 32% and exceed the average level of pollution. However, Gansu, Guizhou, Qinghai and Yunnan decreased their PM2.5 concentrations by 31%, 59%, 16% and 23% respectively and dropped below the average by 2015. On the other hand, central region experienced the highest increase in PM2.5 levels by approximately 55%, each province almost doubled the 2010 PM2.5 levels in 2015.

There were four central provinces such as Henan, Anhui, Hubei and Hunan that were above the average pollution (i.e. 41.46 µg/m^3) in 2010. In 2015, 7 out of 9 central provinces exceeded the average pollution of 51.72 µg/m^3. Although, air pollution levels increased from 2010 to 2015 in all central provinces, Inner Mongolia and Jiangxi could not exceed the average PM2.5 level in 2015 and remained around 43 µg/m^3. Even though Henan had the highest PM2.5 pollution (i.e. 48.35 µg/m^3) in 2010 compared to other central provinces, it also had the highest increase in pollution levels by 72% from 2010 to 2015. Jilin, Shanxi, and Heilongjiang also experienced more than 50% increase from 2010 levels and exceeded the average pollution level in 2015. Except Fujian and Guangxi, all eastern provinces increase their PM2.5 concentrations from 2010 until 2015. In 2010, there were 6 provinces above the average such as Beijing, Tianjin, Jiangsu, Shandong, Liaoning, Zhejiang. Hebei experienced the highest increase in pollution by 123% from the level of 2010 and exceeded the average pollution in the country and became the top polluted province in 2015. Shanghai also increased and reached above the average pollution due to 47% increase of pollution from 2010. Despite the increase in pollution by 15%, Zhejiang dropped below the average pollution in 2015.

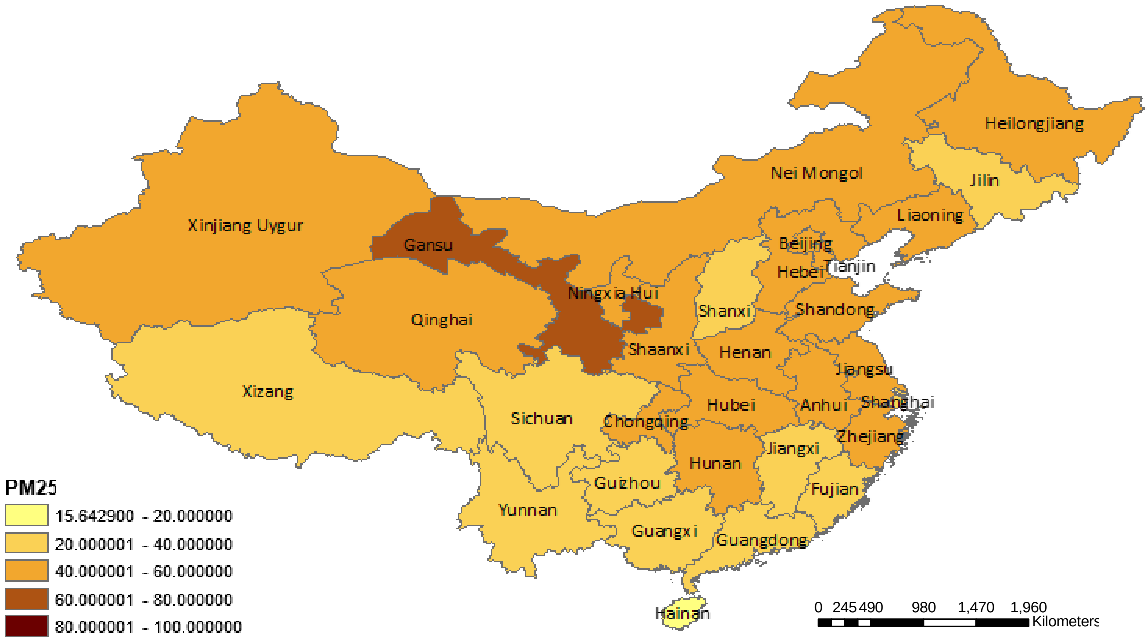


Figure 5.1 PM2.5 concentration in Chinese provinces (2010)

Source: Created by the author with the data retrieved from tianqihoubao.com

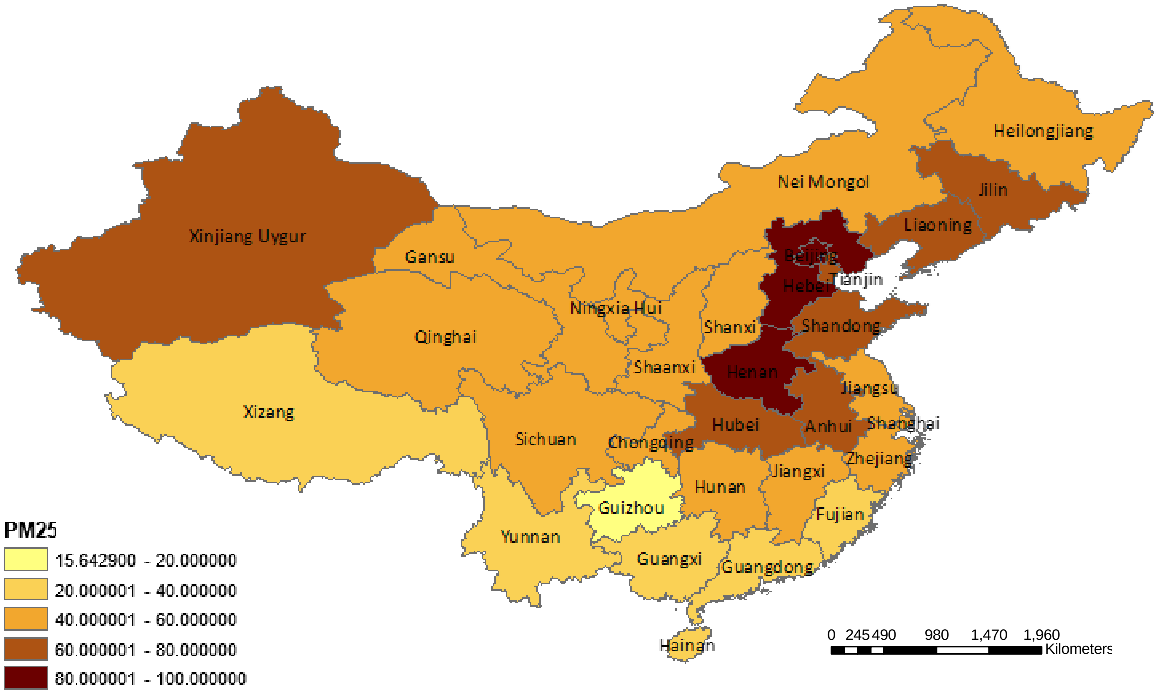


Figure 5.2 PM2.5 concentrations in Chinese provinces (2015)

Source: Created by the author with the data retrieved from tianqihoubao.com

5.3.3. Correlation between PM2.5 concentration and mortality

The top five provinces that had the highest mortality rate were all western provinces in 2010. Tibet had the highest mortality with 58% higher than the national level. In contrast, Tibet was the second lowest polluted province in the same year. There were seven provinces where the PM2.5 concentration and standardized mortality rates were higher than the national average. These provinces are as Gansu, Qinghai, Shaanxi, Xinjiang, Henan, Shandong and Ningxia (Figure 5.3). Amongst these provinces only Gansu and Qinghai displayed decrease in PM2.5 levels respectively by 31% and 16% from 2010 levels. Despite the increase in pollution levels, the remaining provinces except Henan demonstrated decrease in mortality rates from the year 2010. In 2015, we observed six provinces to be greater than national average of both mortality and air pollution. They are Shanxi, Tianjin, Hubei, Jiangsu, Hebei and Henan (Figure 5.4). Except Hebei, all these provinces experienced increase in air pollution and mortality rates in 2010. Hebei experienced the highest air pollution increase by 123% and became the most polluted province in the country but had 3% decrease in mortality rates, although it had the highest mortality rate above the national level.

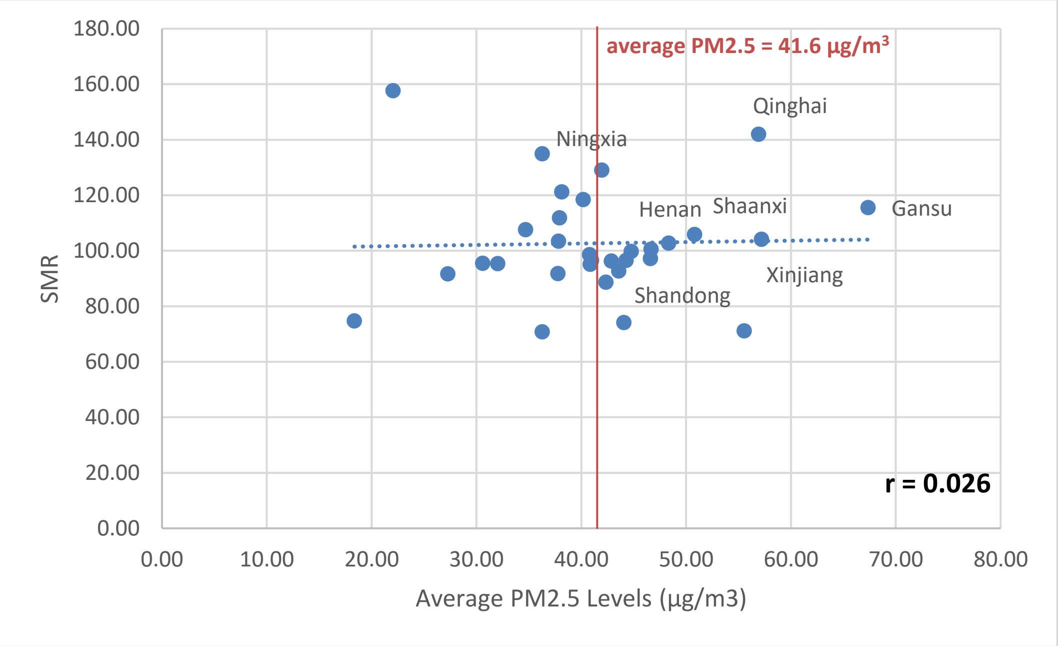


Figure 5.3 Average PM2.5 concentrations and SMR in Chinese provinces (2010)

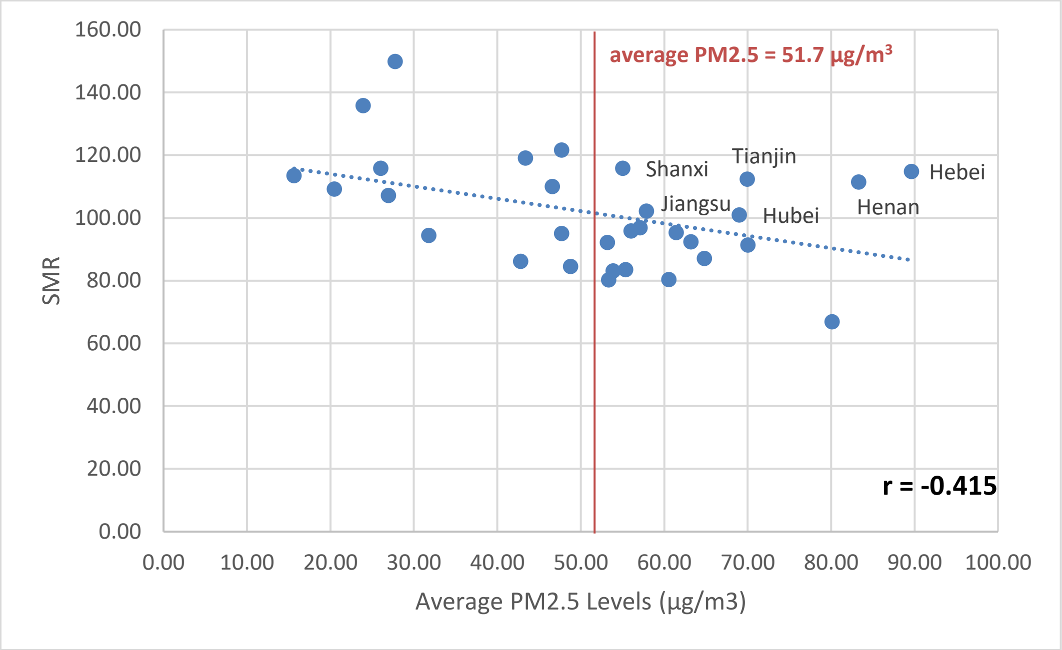


Figure 5.4 Average PM2.5 concentrations and SMR in Chinese provinces (2015)

Source: Created by the author with the data retrieved from tianqihoubao.com

As mentioned previously at the beginning of this chapter, our aim is to analyse the effect of ambient air pollution on the mortality of China. When examining the correlation between air pollution and standardized mortality rates (SMR), a positive correlation of 2.6% was observed for the year 2010. However, same cannot be observed for the year 2014 and 2015. In contrast to 2010, there was no significant association between air pollution and SMR at the province level when controlling for other variables. This finding suggests that by the time the impact of air pollution on SMR might be overshadowed by the other externalities that is not considered here. Therefore, we checked whether some socioeconomic indicators are masking PM2.5 impact on mortality (SMR) by regression. see Appendix C.1 for the regression results.

There are many studies that analyse the relationship between air pollution and mortality globally (Lim, Vos, Flaxman, Danaei, & Shibuya, 2012; Cohen, et al., 2017). Studies on air pollution have significantly increased in the last decade in China with better access to air pollution data. Earlier studies mostly focused on the eastern China where industrial activities and urban population was concentrated. Also lack of ambient air pollution monitoring coverage for whole country, made it very difficult for researchers to examine the other regions of China. However, after establishing ambient air pollution monitoring centres with the range that inclusive of all China in 2013, it became easier to study air pollution in other regions as well. With this motivation, we estimated the impact of PM2.5 pollution on deaths in Chinese provinces. Next section explains the methodology and then we presented results of our analysis and finally a detailed discussion in the conclusion section.

5.4. Methodology

<u>Data preparation:</u>

Daily air pollution data were collected for each province for the years 2014 and 2015 from website: http://www.tianqihoubao.com/. After the monitoring centres' coverage increase to whole country in 2013, data became more available through China Ministry of Ecology and Environment as well as other various reliable online sources like AQICN.org and PM25.in. However, these sources provide real time data, for the purpose this study we need historical data for previous years therefore we collected the data for 2014 and 2015 in August 2018, through http://www.tianqihoubao.com/ where the real time data from PM25.in is compiled and published. This website resource is used widely in many other studies (Wang, Cao, Li, & Singh, 2015; Chen, Lin, Su, & Cheng, 2017; Cai, Shao, & Wang, 2015). The website provides several pollutants and air quality index, but for this chapter we only use the PM2.5 concentrations. Before 2013, China only published air pollution data for selected cities that are the most urbanized and polluted, especially those located generally in the eastern region. As a result of the lack of data, we were unable to collect 2010 pollution data from Chinese sources. Therefore, the air pollution data for 2010 is collected from WHO, because they published the relevant data that is compiled through Clean Air Asia and literature regarding China.

We collected daily air pollution data of 329 cities for the year 2014 and 2015 however only 111 cities had air pollution data in 2010 available. Therefore, we only used 111 cities in our analysis. The air pollution data are compiled in daily format for each city. Daily data is aggregated into first monthly and then annual data. After that, the annual data for cities aggregated into province level by population weighting.

Deaths and population by age and sex for each province are collected through China’s population census in 2010 and 2015. Using this data, we calculated indirect age standardized mortality, adult mortality of people aged above 30 and elderly mortality of people aged above 60 years old for each province. National cause of death data is collected through WHO Global Health Estimation for all-cause, cardiovascular diseases, chronic respiratory diseases and lung cancer. Provincial annual statistical yearbooks are used for other socioeconomic data.

Methodology:

First, daily pollution data is aggregated into annual provincial level data. Then indirect age standardized death rates for each province are calculated taking China’s national level death distribution by age as the reference. In order to estimate the deaths due to long term exposure to air pollution, exposure-response function is used. Exposure-response functions are commonly applied in epidemiological studies (Hoek, et al., 2013; Burnett, et al., 2014; Pope, et al., 2002). This function utilizes current level of PM (either PM10 or PM2.5) and a threshold of a PM concentration which is considered the level that does not hold health risks. With the help of this function, attributable risks of exposure to air pollution and then pre-mature deaths could be estimated.

In this study, PM2.5 is used because studies showed that particulate matter size that is less than or equal to 2.5 µm are more harmful to human health than the particles sized above 10 µm (i.e. PM10) due to being relatively easier to breathe in through nose and mouth and accumulated in lungs and even bloodstream (EPA, Particulate Matter (PM) Basics, 2018).

Estimation of deaths due to exposure is significantly dependant on the shape of exposure-response function. In Europe, due to lower levels of pollution concentration which ranges between 5 to 30 µg/m^3, the shape of the function is mostly assumed as linear, but for a highly polluted areas such as China, the pollution level exceeds this range, and this suggests more concave shape rather than flat-linear relationship (Pope, Cropper, Coggins, & Cohen, 2015). WHO previously recommended log-linear functions for assessment of long-term exposure to PM2.5, but in recent reports WHO suggests Integrated Exposure-Response (IER) function (Lim, Vos, Flaxman, Danaei, & Shibuya, 2012). However, IER function requires input of different pollution sources, since we are not interested in the analysis of pollution sources, we used log-linear function as previously recommended by WHO. Moreover log-linear exposure-response functions provide good estimates for high relative risks which occurs in urbanized areas (Ostro, 2004).

The exposure-response function as following:

$$RR = \exp\big(\beta(X - X_0)\big) \qquad (eq. 15)$$

RR is the relative risk that is attributed to pollution concentration of the studied area. X is the annual ambient air pollution of the province while X_0 is the threshold concentration. The threshold concentration is defined either as background level that assumes concentration levels without man made pollution or minimum observed pollution concentration in the given area. It commonly assumed between 3- 10 µg/m^3, in this case we used 5.8 µg/m^3 as suggested by Apte et al. (2015). β is the coefficient of exposure-response function. It is common to derive this coefficient through literature in the absence of relevant data. In this study we conducted a meta-analysis to determine β. We searched literature that includes key words like “air pollution”, “PM2.5”, “mortality” and “cohort” in Web of Science. Out of 402 studies, we collected 47 studies that included cohort data, PM2.5 data and at least one of the causes of death. In case of data handling problems and further understanding of the meta-analysis, we referred to other meta-analysis studies (Lu, et al., 2015; Vodonos, Abu Awad, & Schwartz, 2018; Borenstein, Hedges, Higgins, & Rothstein, 2009; Fang, et al., 2016). For the meta-analysis we used DerSimonian Laird Random Effects in OpenMeta-Analyst software. We found that β for all-cause mortality 0.007 (95% CI 0.006 – 0.009), for cardiovascular disease mortality 0.011 (95% CI 0.008 – 0.013), for respiratory diseases mortality 0.008 (95% CI 0.003 – 0.012) and for lung cancer mortality 0.01 (95% CI 0.008 – 0.013). These are slightly higher than the other meta-analyses (Fang, et al., 2016). Our study included recent literature that was published after those studies. Therefore, including more studies in the meta-analysis might have increase the β coefficient. Detailed information is presented in Appendix C.

Population attributable fraction (PAF) that is exposed to pollution is calculated as following:

$$PAF = \sum P_i RR_i - 1 / \sum P_i RR_i \qquad (eq. 16)$$

P_i is the population fraction i that is exposed to pollution, whereas RR_i is the relative risk of exposure that this exposed population compared to the unexposed reference population. However, in the case of no fraction in the given population, that is whole population is exposed to same exposure, the equation is simplified as:

$$PAF = RR - 1/RR \qquad (eq. 17)$$

Then burden of disease is calculated as:

$$BoD = PAF \times B \times P \qquad (eq. 18)$$

BoD is the burden of disease which translates as estimated deaths due to exposure to ambient air pollution. B is death rates of given health effect (e.g. death rates due to lung cancer), and P is population exposed to air pollution (e.g. total population of the province).

5.5. Results

In this section, we present the results of analysis of deaths estimation due to long term exposure to PM2.5 in Chinese provinces in 2010 and 2015. First, we estimated deaths due to all cause of death, then cardiovascular diseases, respiratory diseases and lung cancer.

According China Population Census, total registered deaths were 7.4 million in 2010 and 6.64 million in 2015. According to WHO Global Health Estimates (GHE), cardiovascular diseases, respiratory diseases and lung cancer deaths are reported to denote 47%, 13% and

7% of total deaths in 2010 respectively. In 2015, they increased to 62%, 14% and 10% of the total deaths.

Based on the exposure-response function, the relative risks of deaths are calculated. Table 5.3 shows the relative risks of death for the causes that is examined for this analysis. An increase of 10 μg/m^3 in PM2.5 would increase the relative risk of death by 1.29, 1.49, 1.33 and 1.44 from all causes, cardiovascular diseases, respiratory diseases and lung cancer in 2010. However, in 2015, the relative risks are increased subsequently such as 1.39, 1.69, 1.46 and 1.61 for deaths due to all cause, cardiovascular diseases, respiratory diseases and lung cancer respectively.

Table 5.3 Relative risks (RR) of deaths attributable to 10 μg/m^3 change in PM2.5 concentration

	2010		**2015**	
Cause of death	**RR**	**95% CI**	**RR**	**95% CI**
All cause	1.29	(1.24 - 1.38)	1.39	(1.32 - 1.53)
Cardiovascular diseases	1.49	(1.33 - 1.60)	1.69	(1.46 - 1.87)
Respiratory diseases	1.33	(1.11 - 1.56)	1.46	(1.15 - 1.78)
Lung Cancer	1.44	(1.33 - 1.60)	1.61	(1.46 - 1.87)

Source: Created by the author

Table 5.4 shows the estimated deaths that is attributed to long term PM2.5 exposure in China in 2010 and 2015. Regardless of age and cause, the estimated deaths were approximately 1.9 million in 2010 which is 26% of the total reported deaths. Approximately 1.29 million exposure related deaths are estimated to be due to cardiovascular diseases, that corresponds to 15% of total reported deaths. Respiratory diseases and lung cancer mortality that are associated with PM2.5 exposure is estimated as 239,265 and 146,514 deaths respectively. As a result, they only correspond to 3% and 2% of total deaths respectively.

Because the annual PM2.5 concentration increased greatly from 2010, the estimated deaths are also increased in 2015. With 48% increase, the total deaths associated with PM2.5 exposure is estimated as 2.8 million in 2015, that is 43% of total reported deaths. 1.6 million of deaths are attributed to cardiovascular diseases while 299,875 and 243,425 deaths are attributed to respiratory diseases and lung cancer in 2015. This means that these deaths correspond to 25%, 5% and 4% of total reported deaths, respectively. The increases in deaths due to cardiovascular diseases, respiratory diseases and lung cancer are 49%, 25% and 66% from 2010 levels. Despite the relatively less deaths due to lung cancer, the increase of 66% from 2010 levels indicates a growing threat of lung cancer in China (Table 5.5).

Table 5.4 Estimated deaths due to long term exposure to PM2.5

Cause of Deaths	2010	2015
All cause	1,915,204.91	2,827,045.62
Cardiovascular diseases	1,129,129.96	1,679,503.69
Respiratory diseases	239,265.82	299,875.48
Lung Cancer	146,514.58	243,425.08

Source: Created by the author

Table 5.5 displays the percentage of deaths that attributed to long term PM2.5 exposure to total reported deaths. In addition, it demonstrates the factors that contribute to the change in pollution associated deaths. Based on Cohen et al. (2017), we calculated the total change of estimated deaths from 2010 until 2015. Moreover, we calculated the effect of change in mortality rates that is not associated with exposure to pollution and the effect of change in pollution exposure. As mentioned earlier, overall PM2.5 related mortality increased from 1.9 million to 2.8 million in only 5 years. Although the total change is 48% from the 2010 level, it cannot simply be attributed to pollution exposure change. Baseline rate change explains how much mortality rate change impacts the pollution related deaths. For all-cause deaths that is associated with PM2.5 exposure, it is -0.47%, this means the change in all-cause mortality rate that is unrelated to pollution exposure has decreasing effect on estimated deaths.

Our results support the fact that China's death rates have been on the declining trend. The effect of such decline is very small for all-cause and cardiovascular diseases mortality whereas it is much higher for respiratory diseases. On the other hand, it has a positive effect on pollution related lung cancer deaths. Lung cancer mortality rates that are unrelated to pollution exposure increased by 26% from 2010 but the effect of such increase on pollution related estimated deaths are 11%. Another factor we measured is the exposure change effect. The impact of change in PM2.5 exposure on pollution related deaths is assessed.

Until 2015, China's average PM2.5 concentration increased by approximately 25% from the 2010 levels. This increase in PM2.5 concentration contributed to 45% of increase in pollution related all-cause deaths. For pollution related deaths due to cardiovascular diseases, respiratory diseases and lung cancer, the effect of exposure is 47%, 39% and 52% respectively. Overall results indicate that lung cancer should be taken seriously since the mortality rates are increasing compared to other non-communicable diseases that is examined in this study, as well it shows higher risk due to PM2.5 exposure.

Gender based analysis suggests almost similar results for men and women (Table 5.6). Around 26% of reported deaths are associated with exposure to PM2.5 for females and males in 2010. Female all-cause deaths were estimated as 809,606.4 persons and cardiovascular disease deaths were 514,981.65, respiratory disease deaths were 103,951.67 and finally lung cancer deaths were 43,984.58 persons in 2010. In 2015, the all cause deaths of females increased to 1.2 million. Estimated deaths due to cardiovascular diseases were 775,158.70 persons, respiratory diseases were 130,493.01 and lung cancer were 74,804.00 persons.

Table 5.5 Percentage of estimated deaths to reported deaths & Change of estimated deaths from 2010 to 2015

	% of reported deaths		**Change from 2010 to 2015 (%)**		
Cause of Deaths	*2010*	*2015*	*Total Change (%)*	*Baseline Rate Change (%)*	*Exposure change effect (%)*
All cause	26%	43%	48%	-0.47%	45%
Cardiovascular diseases	15%	25%	49%	-2%	47%
Respiratory diseases	3%	5%	25%	-16%	39%
Lung Cancer	2%	4%	66%	11%	52%

Source: Created by the author

On the other hand, death amongst men are higher than women. In 2010, there were 1.1 million deaths associated with long-term PM2.5 exposure amongst men. Deaths due to cardiovascular diseases estimated as 613,700.62 persons while it was 135,155.10 and 102,192.76 persons due to respiratory diseases and lung cancer. In 2015, estimated deaths increased considerably from 2010 levels. Increased by 46%, all-cause pollution related deaths for males were 1,612,124.69 persons in 2015. Also, deaths due to cardiovascular diseases, respiratory diseases and lung cancer increased significantly to 903,654.13 persons, 169,136.15 persons and 167,952.59 persons respectively. Although men have higher rates of exposure related deaths than women (i.e. exposure associated mortality rate of men is almost 1.3 times more than women), the ratio of exposure related deaths to reported deaths for females are higher than males, especially in 2015 (Table 5.6) This is because reported deaths of men are much higher than women. Regardless, the results show that there is a significant effect of exposure on female and male deaths in China. More than 40% of reported deaths are attributed to PM2.5 exposure in 2015 for both men and women.

Mortality rates of cardiovascular diseases and respiratory diseases do not differ much between men and women, but lung cancer mortality difference is striking. The difference in lung cancer mortality rate should be highlighted. In 2015, female lung cancer mortality rates that is associated with exposure was 0.112 per capita while it was 0.24 for males which is more than two times higher than females. Men are known to have higher mortality rates than women. This could be due their social and behavioural conditions, but genetic factors also could be an effect. Despite high prevalence of lung cancer, survival rates are higher in women in comparison which suggests a genetic protecting factor (Carey, et al., 2007; LoMauro & Aliverti, 2018). Although lung cancer mortality rate is less than men's, women displayed a greater increase (i.e. 47%) than men from 2010 level. Guo et al. (2017; 2016) suggests that less prevalence of smoking would be the reason since non-smoking people are found to be more susceptible to the effects of air pollution than the people who has long experience of smoking. Therefore, women need to be paid special attention to prevent increasing lung cancer deaths in the future.

Table 5.6 Percentage of estimated deaths corresponds to observed deaths for females and males in China

	Female		**Male**	
	2010	*2015*	*2010*	*2015*
All Cause	26%	44%	26%	41%
Cardiovascular disease	16%	28%	14%	23%
Respiratory disease	3%	5%	3%	4%
Lung Cancer	1%	3%	2%	4%

Source: Created by the author

Deaths associated with PM2.5 exposure shows regional variation. Because of high pollution concentration, eastern and neighbouring central regions experience higher mortality compared to western regions in 2015. In terms of number of estimated deaths, Henan province is at top with 286,658.87 deaths in 2015 which corresponds to 59% of total reported deaths in the province. Henan also has the highest deaths due to cardiovascular disease, respiratory disease and lung disease in 2015 that denotes to 34%, 6% and 5% of total reported deaths respectively. Shandong and Hebei follow Henan with 257,137.78 and 237,913.21 deaths associated with long term exposure to PM2.5, respectively. However, we need to examine the death rates in order to make a better assessment of the relation.

Death rates due to exposure to air pollution are in accordance with the pollution concentration for the given province. In 2015, Hebei had the highest risk of death due to the exposure therefore has the highest estimation of death rates with 3.19 per capita compared to other provinces (Figure 5.6). Death rates of PM2.5 exposure related cardiovascular diseases, respiratory diseases and lung cancer were 1.81, 0.33, and 0.27 per capita respectively in Hebei in 2015 (Table 5.7). Highest pollution related mortality rates occur along the eastern cost and in some neighbouring central provinces such as Henan, Hubei, Anhui and Jilin in 2015. Xinjiang, on the other hand, is the only western province that is amongst the top ten provinces with highest mortality rates. In 2015, PM2.5 exposure related all-cause mortality rate was 2.38 per capita whereas mortality rates of exposure related cardiovascular diseases, respiratory diseases and lung cancer were 1.41, 0.25 and 0.2 per capita.

Table 5.7 Top 10 provinces with the highest exposure related mortality rates (per thousand) in 2010 and 2015

		2015				2010				
Rank	*Province*	*all cause*	*CVD*	*Respiratory*	*Lung Cancer*	*Province*	*all cause*	*CVD*	*Respiratory*	*Lung Cancer*
1	Hebei	3.19	1.81	0.33	0.27	Gansu	2.30	1.30	0.28	0.17
2	Henan	3.01	1.72	0.32	0.25	Xinjiang	1.98	1.14	0.25	0.15
3	Beijing	2.92	1.68	0.31	0.25	Qinghai	1.98	1.14	0.25	0.15
4	Shandong	2.60	1.52	0.28	0.22	Beijing	1.93	1.11	0.24	0.15
5	Tianjin	2.60	1.52	0.27	0.22	Shaanxi	1.77	1.03	0.22	0.13
6	Hubei	2.57	1.51	0.27	0.22	Henan	1.69	0.99	0.21	0.13
7	Liaoning	2.43	1.43	0.26	0.21	Shandong	1.63	0.96	0.20	0.12
8	Xinjiang	2.38	1.41	0.25	0.20	Anhui	1.63	0.95	0.20	0.12
9	Anhui	2.32	1.38	0.25	0.20	Liaoning	1.57	0.92	0.20	0.12
10	Jilin	2.29	1.36	0.24	0.20	Hubei	1.55	0.91	0.19	0.12

Source: Created by the author

In 2010, regional distribution of exposure related deaths was different than in 2015. Western China demonstrated higher exposure related mortality rates in 2010. Top 3 provinces with the highest pollution related mortality rates were Gansu, Xinjiang and Qinghai. In addition, another western province, Shaanxi, was in high ranks. Although, in terms of absolute number of deaths Henan remained at the top position (i.e. 159,023.21 deaths in 2010), Gansu with 2.3 per capita mortality rate ranked as first in the top 10 list in Table 5.7. Mortality rates of cardiovascular diseases, respiratory diseases and lung cancer were 1.3, 0.28 and 0.17 per capita in Gansu in 2010. Since the ambient PM2.5 concentration was the highest in Gansu, this outcome is expected. However, as the average PM2.5 concentration was less in 2010 in comparison to 2015 averages, the exposure related death rates are also less than the death rates in 2015. Increase in death rates are expected in 2015. However, provinces which had reduction in their annual PM2.5 levels such as Fujian, Gansu, Guangxi, Guizhou, Qinghai, and Yunnan experienced decrease in their pollution related death estimation.

Gansu, once at top of highest mortality rate list in 2010, experienced decrease in mortality rates from 2.3 per capita to 1.79 per capita in 2015. Change in exposure concentration contributed 50% of this change while the change in baseline mortality rates (unrelated to exposure) contributed 21%. Guizhou experienced the highest decreased in exposure related deaths (i.e. 63%) and decrease in pollution concentration contribution was 94%.

There are 14 provinces (mostly eastern or neighbouring central provinces) in which mortality rates unrelated to PM2.5 exposure declined in 2015, but this did not contribute much to exposure related deaths. The highest contribution of decline in baseline mortality rate from 2010 levels was by 23% in Hebei but it was not enough to decrease the overall deaths since the contribution of increase in PM2.5 exposure was the highest (i.e. 155%) compared to other provinces. So, the overall exposure related deaths increased the most in Hebei by 136% from 2010 levels. Then Tianjin, Henan, Jilin, Hubei, Shanghai, Sichuan, Beijing follow by 101%, 80%, 75%, 70%, 69%, 68%, and 67% increase respectively in exposure related deaths in 2015.

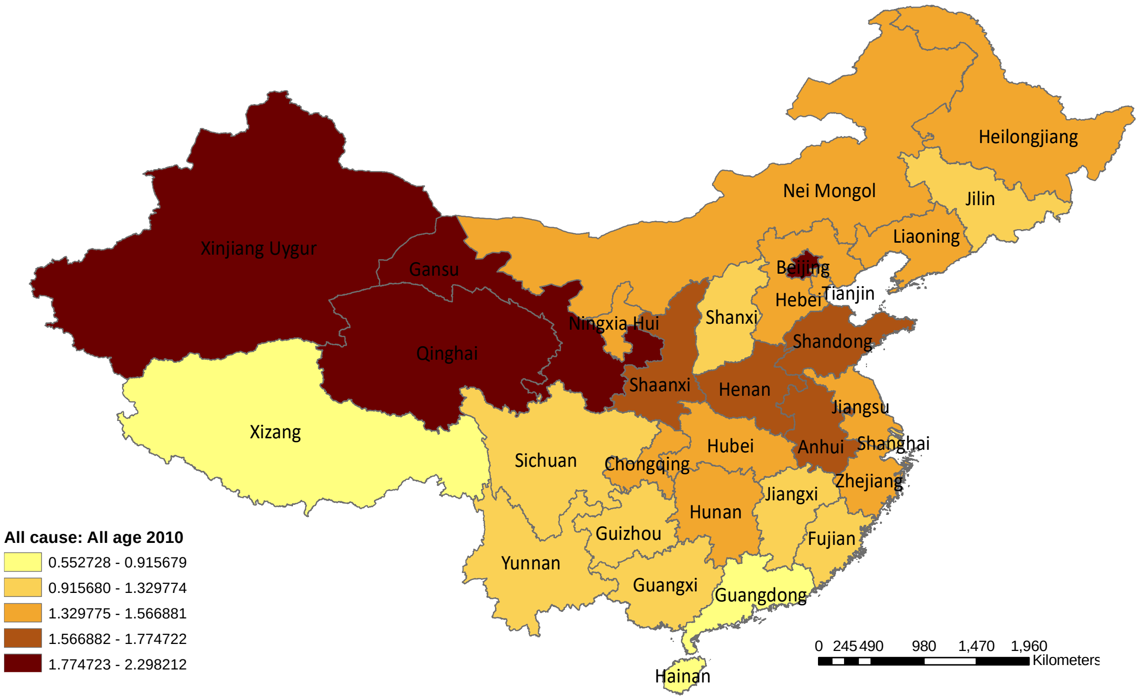


Figure 5.5 All-cause death rates that is attributable to long-term PM2.5 exposure (2010)

Source: Created by the author using ArcGIS

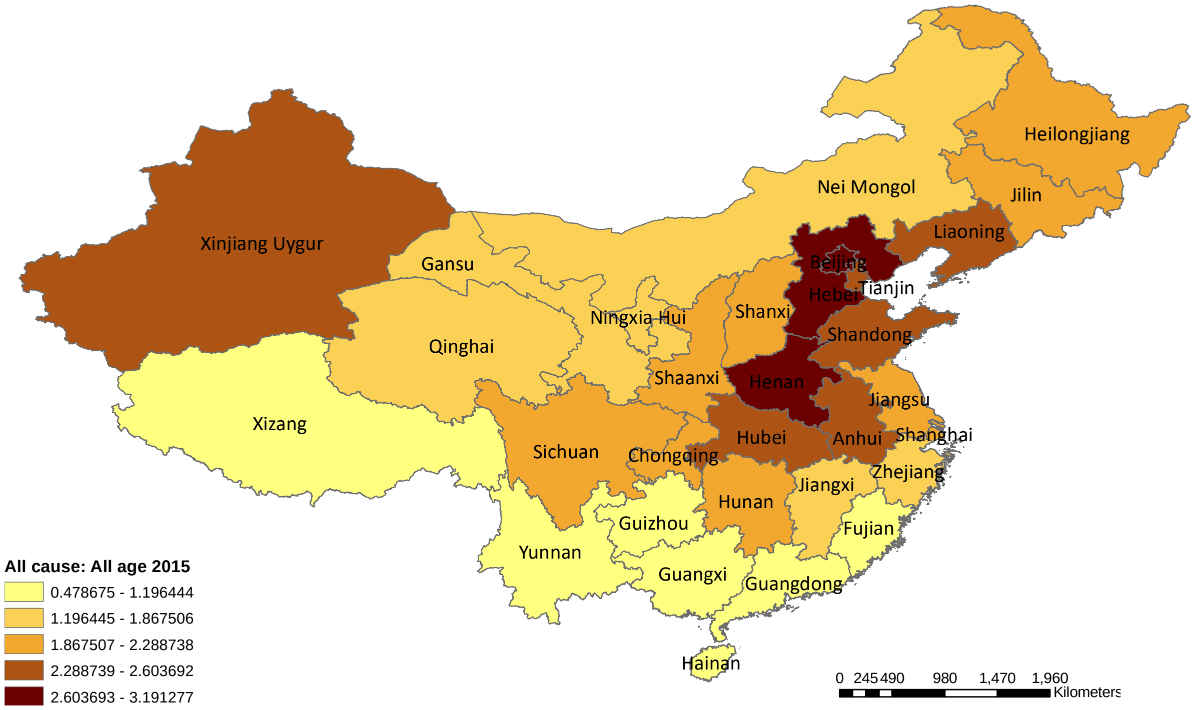


Figure 5.6 All-cause death rates that is attributable to long-term PM2.5 exposure (2015)

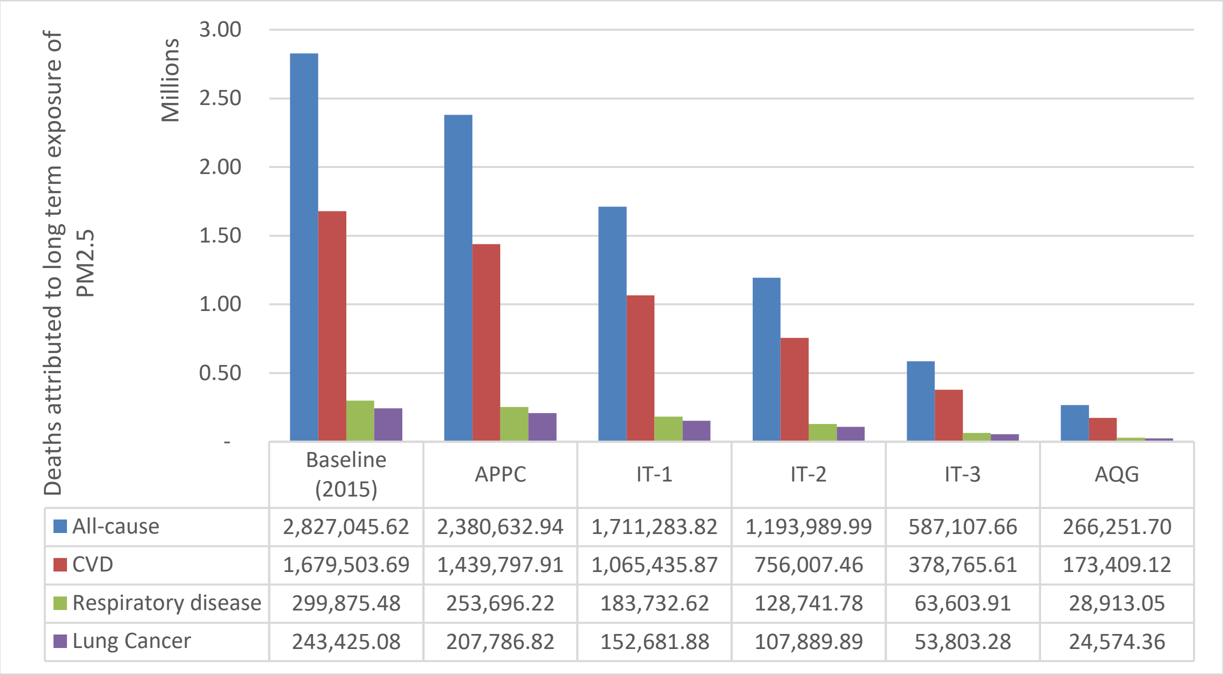
Source: Created by the author using ArcGIS

Previously China announced Air Pollution Action Plan in 2013, setting the target to reduce PM2.5 pollution in certain areas such as Yangtze River Delta, Pearl River Delta and Beijing-Tianjin-Hebei key region by 20%, 15% and 25% respectively until 2017 (State Council, 2013). Even with reasonable decrease in some areas, all Chinese cities are still above the WHO Air Quality Guidelines (AQG) of 10 µg/m^3 (Health Effects Institute, 2019). Therefore, China launched a follow up plan of the original action plan in 2013. This new action plan is called “Three-year Action Plan” (State Council, 2018). The target is set for PM2.5 to be reduced at least 18% for the mentioned key regions by 2020. On the other hand, WHO set three interim targets for the regions with high pollution where achieving Air Quality Guidelines of 10 µg/m^3 would be difficult to achieve. According to Health Effects Institute report (2019), these interim targets are as following:

$$IT-1\ \leq 35\,\mu g/m^3\ , IT-2\ \leq 25\,\mu g/m^3\ ,\ IT-3\ \leq 15\,\mu g/m^3$$

Since WHO targets are for all cities, we applied China Action Plan target reduction to all cities and calculated the population weighted pollution levels for each province to make comparison. Figure 5.7 demonstrates the deaths associated with PM2.5 when the reduction targets achieved. For the purpose of visual integrity, we didn’t include deaths by sex in the figure.

In case China attains the Three-Year Action Plan (APPC) targets by 2020, all-cause deaths would be reduced by approximately 16%. Lung cancer and respiratory disease deaths would be reduced by 15% while cardiovascular disease deaths would reduce by 14%. However, if WHO IT-1 targets achieved, the decrease from the baseline would be much higher. All-cause deaths would decrease by 39%. Cardiovascular diseases and lung cancer deaths would decrease by 37% while respiratory diseases deaths would reduce by 39%. In case of WHO IT-2 attainment, the reduction from baseline for all-cause deaths would be by 58%. Reduction in deaths due to cardiovascular diseases, lung cancer and respiratory diseases would be 55%, 56% and 57% respectively. If WHO IT-3 targets are attained, 79% of deaths from baseline would decrease in all cause. Reduction in deaths of cardiovascular diseases, lung cancer and respiratory diseases would be by 77%, 78% and 79% from the baseline estimated deaths of 2015. Finally, if China achieves WHO Air Quality Guidelines, there would be more than 90% decrease in all cause and other causes of deaths. In this scenario, pollution levels in Guizhou would drop below the minimum health risk threshold so there would be no deaths attributed to PM2.5.



	Baseline (2015)	APPC	IT-1	IT-2	IT-3	AQG
🟦 All-cause	2,827,045.62	2,380,632.94	1,711,283.82	1,193,989.99	587,107.66	266,251.70
🟥 CVD	1,679,503.69	1,439,797.91	1,065,435.87	756,007.46	378,765.61	173,409.12
🟩 Respiratory disease	299,875.48	253,696.22	183,732.62	128,741.78	63,603.91	28,913.05
🟪 Lung Cancer	243,425.08	207,786.82	152,681.88	107,889.89	53,803.28	24,574.36

Figure 5.7 Deaths attributed to long-term PM2.5 exposure if meeting pollution targets

Source: Created by the author

5.6. Conclusion

In this study we analysed the impact of long term PM2.5 exposure on the mortality in Chinese provinces. With the help of WHO recommended exposure-response functions, deaths associated with PM2.5 exposure is estimated as 1.9 million that is 26% of total reported deaths in 2010. By 48% increase from the 2010 levels, exposure related deaths estimated to be 2.8 million in 2015. This corresponds to 43% of total reported deaths in China. Cardiovascular disease caused deaths are significantly higher than deaths caused by respiratory diseases and lung cancer. However, lung cancer mortality increased greater than the other two diseases. Out of 66% of increase in pollution related lung cancer deaths from 2010 levels, 52% is contributed by the increase in China's average ambient air pollution. Particularly men have disadvantage over women in terms of lung cancer mortality. Lung cancer mortality rates are found to be more than two times higher in men in comparison to women. This could be due to social, environmental and behavioural factors but also genetic factors suggest that men has less chance of survival in lung cancer than women since they lack hormonal predictive factors that women have (Carey, et al., 2007; LoMauro & Aliverti, 2018).

However, the rate of increase in lung cancer is higher in women in men. Women had 47% increase in exposure related lung cancer deaths while men had 39% increase from 2010 until 2015. Since prevalence of smoking is very low among women, they are more susceptible to the increasing effect of PM2.5 exposure (Guo, et al., 2017; Guo, et al., 2016). According to Chinese health statistics (National Bureau of Statistics of China, 2016), cancer is the top cause of death compared to other diseases in both rural and urban China. Lung cancer is the leading cause of cancer deaths in 2015 (Chen, et al., 2016). Therefore, it requires special attention as it causes increasing concerns.

Regional differences are apparent. Mostly western provinces and some neighbouring central provinces experienced decline in exposure related mortality rates from 2010 levels until 2015. Despite the increasing mortality rates that are unrelated to exposure, decline in PM2.5 concentrations had greater impact on exposure related mortality estimates.

On the other hand, Eastern provinces and some neighbouring central provinces suffer more from the PM2.5 related deaths recently. Because of high pollution concentration, the risk of PM2.5 related mortality is high too. Hebei had the highest exposure related mortality rate as it was 3.19 deaths per capita in 2015. Neighbouring provinces like Henan, Beijing, Shandong, Tianjin, Hubei have above 2.5 deaths per capita. Despite located in western, Xinjiang also have 2.38 deaths per capita. This might be because Xinjiang has high PM2.5 concentration due to the increasing number of industrial facilities as well as being surrounded by the desert which frequents sandstorms that contributes PM2.5 concentrations.

Actual mortality rates are observed to be lower in eastern regions in comparison to western regions. Eastern regions benefitted from their relatively superior economic level and prioritized public health facilities over the years, which contributes a lot to their low mortality rates. In contrast to east, western provinces have higher under five mortality rates and this contributes to their mortality rates in general. So, there is still a room for improvement in these regions. According to our analysis, air pollution is not strong in explaining the mortality in aggregate level in Chinese provinces in comparison to number of doctors and percentage of elderly in the total population, but it does have serious influence in individual level as it increases relative risks of deaths. If China continues to have increasingly aging population as well as not being able to reduce its air pollution levels to the desired targets, PM2.5 related deaths will be a serious threat in the future. Currently PM2.5 associated non-communicable diseases such as cancer, cerebrovascular and heart diseases are top three causes of deaths (National Bureau of Statistics of China, 2016).

Therefore, meeting pollution reduction target is crucial. Three-year Action Plan by 2020 is relatively more feasible for a highly polluted country like China rather than WHO targets. If the Three-year Action Plan targets are met in all over the country, it would help China to reduce PM2.5 related deaths by 16%, as well as around 15% of cardiovascular diseases, respiratory diseases and lung cancer deaths respectively. On the other hand, in case of WHO first interim (IT-1) targets are attained, the avoidance of death would be around 39% and for cardiovascular diseases, respiratory diseases and lung cancer it would range between 37% to 39% of baseline deaths in 2015. The rest of interim targets (IT-2 and IT-3) as well as WHO Air Quality Guidelines would be harder to meet in the short time but in case they are met, 58%, 79% and 91% deaths from the levels of 2015 would be avoided.

One of the uncertainties come from the exposure-response functions. The threshold of PM2.5 for health risks that is used in the function adds uncertainty to every Burden of Disease analysis, including ours. Lim et al. (2012) and Pope et al. (2002) suggest using a threshold between range of 5.8 $\mu g/m^3$ and 8.8 $\mu g/m^3$. Because of it is most commonly recommended, we assumed the threshold as 5.8 $\mu g/m^3$ (Pope, et al., 2002; Lim, Vos, Flaxman, Danaei, & Shibuya, 2012; Apte, Marshall, Cohen, & Brauer, 2015; Fang, et al., 2016). Although we compiled the most recent studies in the meta-analysis, exposure-response coefficients might show difference from the other meta analyses. Recent studies show that the coefficients might have large regional variations (Fang, et al., 2016). Especially there is only few cohort studies regarding China, and we could only add four studies (including Hong Kong and Taiwan) compared to greater number of European and American studies included. Therefore, we should expect some differences.

There are limited number of studies available that focus on China’s PM2.5 related mortalities therefore it is difficult to make comparison. Our results are relatively higher compared to Fang et al. (2016) . This might be because they studied a smaller number of cities than our study. Another study that used log-linear exposure response function is by Maji et al. (2017). Their estimated deaths are lower than ours as well. That would be because they used short term exposure as the indicator. Moreover, we refrained from making comparison with the studies where they used IER functions to estimate deaths. We did not prefer using IER functions since it usually integrates other sources of emission into the model and we do not have such data available now.

Our findings offer a comprehensive understanding of the impact of PM2.5 pollution on mortality in Chinese provinces. Since we do not have mortality data on city level, we had to aggregate pollution data on province level and estimate the deaths for provinces. There are great variations within the provinces in some cases. This led us to have a rough estimation of the provinces. Therefore, when the mortality data is more available for city level in the future, this will be helpful to make more detailed and precise estimations.

Chapter 6 CONCLUSIONS AND DISCUSSION

This thesis investigated the aggregate trends and regional patterns of mortality and associated socioeconomic and environmental factors during the period of rapid economic growth in China over the past two decades. Detailed analysis of trends in mortality and causes of deaths, environmental and industrial effects on mortality are presented, with a particular focus on the relationship between exposure to ambient air pollution and mortality. Economic growth has frequently been presumed to be the main driver of mortality decline; however, we observed its effect to be implicit compared to other socioeconomic factors such as improved education. Moreover, the findings support the increasing concerns of environmental threat on mortality, underlining that not all growth is necessarily 'good' for mortality improvement.

6.1. Key contributions of the thesis

The key contributions of this thesis are as follows:

1. A systematic evaluation of aggregate trends and regional patterns of mortality and associated macro socioeconomic and environmental factors
2. A better assessment of environmental inequality in terms of industrial activities and exposure to ambient air pollution
3. Quantification of mortality impact attributed to exposure to ambient air pollution

In China, there remains a lack of literature about environmental inequality as well as the assessment of long-term air pollution impact on mortality related to China. This thesis therefore makes an original contribution towards to addressing this literature gap.

An additional product of the research process has been the compilation of extensive and up-to-date air pollution data and estimation of life tables by sex for each province during the period of peak in economic growth. Together these data comprise an original resource and contribution in their own right.

6.2. Summary of key findings

A summary of key findings with a reflection on main research questions is presented below.

To what extent does economic growth explain mortality and life expectancy trends over time? How are trends in socioeconomic development indicators related to mortality and life expectancy in China?
The findings demonstrate that economic growth has a direct effect on under-five mortality and adult mortality. However, life expectancy is influenced by the economic growth only when the time is not controlled. Socioeconomic and development indicators such as adult illiteracy, number of doctors per capita and rural-urban economic inequality are found to be the most significant factors amongst the other indicators in the regression models in determining mortality and life expectancy trends in China.
Are there regional differences in mortality and economic growth? If so, what are the underlying explanations?
The regional differences in the trends of mortality and economic growth are pronounced. Economically less developed western regions demonstrate higher mortality rates, particularly under-five mortality rates than overall mortality. The reason is that coastal (eastern) region has been historically more developed than any other region in China, thus the region has benefitted from preferential policies and investments as well as better economic and health care institutions when compared to other regions.

How does economic factors affect environmental inequality in China?
Our results show that economic factors are not statistically significant in determining environmental inequality in China, instead the level and type of industrial activities seem to have profound influence in determining differences in environmental risks and hazard.
What is the association between income inequality and environmental inequality? How does income inequality affect ambient air pollution in China?
The findings suggest that there is no association between income inequality and environmental inequality. In fact, economic factors such as GDP per capita and income inequality are not statistically significant in explaining environmental inequality.
What is the role of state in addressing the environmental inequality?
The results suggest that the impact of pollution legislation is not unified across China. Environmental policies in western and central regions seem to be less effective in comparison to eastern regions where the policy implementation is firmer. The regional differences in implementation of policies contributes to environmental inequality. State does not address the environmental inequality as it is supposed to be, there is a lack of awareness of environmental inequality in both administration and public level.
How does long-term exposure to ambient air pollution impact mortality in Chinese provinces? Are there any regional differences?
The findings show that the long-term exposure to ambient air pollution is estimated to cause 2.8 million deaths (43% of total reported deaths) in 2015. The increase in pollution, since 2010, is associated with 48% increase in ambient air pollution related deaths. Regional differences are evident as eastern provinces and nearby regions of central provinces suffer relatively more from pollution related deaths compared to other regions of the country. Provinces such as Hebei, Henan, Beijing, Shandong, Tianjin

and Hubei are observed to have pollution related death rates as more than 2.5 people per thousand.
How much does mortality decrease in case China achieve pollution abatement targets?
If China implements the Three-Year Action Plan not only in selected regions but across all the provinces and meets the targets by 2020, it would cause 16% decrease in pollution related deaths from the baseline deaths in 2015. In addition, if WHO interim targets IT-1, IT-2 and IT-3 were to achieve, the reduction in pollution related deaths would be 39%, 58%, and 79% from the baseline. Moreover, if the WHO Air Quality Guidelines met, there would be 91% of deaths from 2015 baseline avoided.

6.3. Development, health reforms and mortality change

China has experienced rapid decline in mortality rates, and the rates dropped below the world’s and high-income countries’ average, even before the economic reforms during the late 70’s and early 80’s. Life expectancy in China reached to the levels seen in high-income countries. We analysed the mortality trends and the associated socioeconomic factors underlying mortality decline during the period where economic growth was steady and rapid. The results showed that economic growth is not the most important factor affecting overall mortality in China. When the time controlled, it has no statistically significant impact on increasing life expectancy during the examined period. As the country reached to a certain level of economic growth, the benefits of economic growth on life expectancy tends to diminish. However, economic growth has direct impact on reducing under-five mortality and adult mortality. Economic improvements and better access to health care had immediate returns in terms of reducing infant and adult mortality.

Infant and child mortality seem more sensitive to the factors such as improvement in health care systems. The conditions of health care systems directly affect under-five mortality, especially the number of doctors is a strong indicator in predicting child mortality. Despite the rapid economic growth to the level observed in developed countries, statistics show that China still lags behind in social and health care aspects. According to OECD (2017), China ranks one of the lowest with 2 doctors per 1000, as it sits on the 27th place out of 28 OECD countries. This is a serious situation that requires attention.

Along with economic reforms in 1978, China went through a series of reforms in health sector. Before the economic reforms, health care system was mostly financed by the central government and through surpluses that medical facilities collected and transferred over to the government (World Bank Group; World Health Organization; Ministry of Finance, P.R.C.; National Health and Family Planning Commission, P.R.C.; Ministry of Human Resources and Social Security, P.R.C., 2016). With the health reforms after 1978, the government with intention of reducing financial burden adopted a decentralised approach and assigned more power to public hospitals. With this reform, public hospitals became eligible to make decisions as well as be able to use their surpluses. This led to a dramatic decline in government funding, from more than 50% to 30% of public hospital revenues (Meng, Yang, Chen, Sun, & Liu, 2015), and relied on patients' financial contributions. As a result, hospitals started to charge patients more than before, and this led to over-prescription of drugs and treatment as well as increase in overall medical costs. Because medical insurance did not cover much of the costs, out-of-pocket expenses increased dramatically from 20% of total health expenditure in 1978 to 60% in 2010 (National Bureau of Statistics of China, 2018). This put more burden on vulnerable groups in poor regions since rural cooperative medical scheme (CMS) had failed in 1980s (Banister & Zhang, 2005).

In order to address the problem, the government proposed new special health programmes for rural and urban populations. First, an urban employees' basic medical insurance (UEBMI) was implemented in 1998. Subsequently, during the 11th Five-Year-Plan, new rural cooperative medical scheme (NCRMS) was introduced. Then, urban residents' basic medical insurance (URBMI) was launched in 2007 (Dong K. , 2009; World Bank, 2010). All insurance schemes intended to relieve financial burden on residents for their health expenses by providing funding from government and citizens. Although the insurance schemes reached achieved great population coverage (i.e. NCRMS achieved 97% of the rural population and UEBMI and URBMI covered 264 and 271 million people in 2012 (Meng, Yang, Chen, Sun, & Liu, 2015)), there were still problems with sustaining the financial scheme, keeping the costs at minimum level, and the delivery of treatment and treatment package coverage. NCRMS faced increased financial burden on patients as well as quality of treatment delivery. For example, in rural areas, number of doctors per 1000 (i.e. 1.68 per 1000 people) and number of beds per 1000 (i.e. 4.19 per 1000 people) were approximately half of urban areas in 2017 (National Bureau of Statistics of China, 2018). This supports the regional discrepancy of mortality that we found in this study.

Due to limited access to health care, poorer regions, particularly western and some central provinces suffer from high under-five mortality in comparison to economically more developed coastal region. However, this does not mean urban areas do not experience problems with the new health care and insurance schemes. Urban areas, similar to rural areas, suffer from increased out-of-pocket expenses. Although the percentage of out-of-pocket expenses to total expenses, decreased over time, absolute values are constantly increasing. Out-of-pocket expenses increased from 2.3 billion yuan in 1978 to 1.5 trillion yuan in 2017 (National Bureau of Statistics of China, 2018). This caused heavy burden on citizens especially for floating populations because all insurance schemes function based on people's residence (*hukou*) status, employment and health care access, and reimbursement of treatment costs becomes complex.

Despite launching new policies that aimed to widen the health coverage and balancing financial system in the health care scheme, implementation of the policies was not very strict. The local governments prioritised economic growth over maintaining health equality, especially in western regions where the policy implementation was quite lax. Our results indicate that health expenditure of the government is not systematic as it is expected to be in favour of poorer and under-developed regions.

Adult illiteracy and income inequality are observed to have strong association with mortality trends in China. Eliminating illiteracy has always been a priority for the Chinese government. China followed UNESCO initiated Education for All (EFA) programme in 2000 as well as implemented its' national educational programme Guidance Opinion on Further Enhancing Literacy in 2007. With the help of these programmes, China managed to reduce adult illiteracy under 6% by the targeted year 2015 (UNESCO, 2015). In 2017, adult illiterate population was 4.85% of total population aged above 15 years (National Bureau of Statistics of China, 2018). This is much lower than the world average (13.5% in 2016 (World Bank, World Development Indicators, 2016)). However, the absolute number of illiterate adults equates to 56 million which is more than the size of many European countries. Therefore, further efforts to contain adult illiteracy rate are needed in China. There were 15 provinces that had the adult illiteracy rate above the national average and 9 provinces that were above EFA targets (i.e. 6% of total adult population) in 2017 (National Bureau of Statistics of China, 2018). The highest adult illiteracy rate (i.e. 35%) was observed in Tibet while the lowest was in Beijing (i.e. 1.23%). Illiteracy rate is influenced by other socioeconomic factors such as economic growth, income inequality, urbanisation and demography of the region, and hence the regional disparity is apparent. As UNESCO report (2005) suggested China should customize the literacy education according the needs of the region. In addition to regional disparity, there is a great gender disparity in terms of adult literacy. China's average female adult illiteracy rate was 7.34% while male adult illiterate rate was 2.42% of total adult population in 2017 (National Bureau of Statistics of China, 2018). This means almost 42 million adult females were illiterate. According to our results, reducing female illiteracy rate is very crucial in mortality decline and life expectancy improvements. As a result, China should focus on improving literacy among women.

6.4. Association between ambient air pollution and mortality

Our results show that air pollution is not a statistically significant factor that explains mortality trends at aggregate level. Other demographic (i.e. percentage of elderly people in total population) and socioeconomic factors (i.e. number of doctors, rural-urban economic inequality and adult illiteracy) are more significant in determining mortality. In 2010, air pollution was highly correlated with mortality in China then its effect on mortality was observed to be masked by the other socioeconomic factors, as mentioned earlier. However, this does not mean it has no effect on mortality. Air pollution is found to be important at individual level as our burden of diseases analysis suggests. It causes serious mortality risks. Ambient air pollution was the 5th leading cause of deaths globally, and all cities in China are exposed to the ambient air pollution levels above the WHO threshold (i.e. 10 μg/m^3) (Health Effects Institute, 2019). Our estimates show 2.8 million deaths attributed to long-term PM2.5 exposure in 2015. This corresponds to 43% of reported deaths in China. Exposure related deaths that are attributed to cardiovascular diseases, respiratory diseases and lung cancer corresponded to 25%, 5% and 4% respectively of reported deaths in 2015. Overall PM2.5 exposure related deaths had risen to 48% from 2010 levels because of increasing ambient air pollution in China.

Deaths due to cardiovascular diseases, respiratory diseases and lung cancer increased by 49%, 25% and 66% respectively. Although cardiovascular diseases contributed to more exposure related deaths, the increase in lung cancer was unprecedented. We found that 52% of the increase in estimated lung cancer deaths is due to the increase in ambient air pollution exposure (the rest is due to baseline mortality change and other factors) from 2010 levels. Male deaths are observed to be much higher than females, especially lung cancer death rates of males were more than two times higher than the females in 2015. Social, environmental and behavioural factors play great role in this distinction but genetic factors also suggest that men has less chance of survival in lung cancer than women since they lack hormonal predictive factors that women have (Carey, et al., 2007; LoMauro & Aliverti, 2018). In contrary, the rate of increase in lung cancer is observed to be higher in women in comparison to men. For example, women had 47% increase in exposure related lung cancer deaths while men had 39% increase from 2010. According to Guo et al. (2017; 2016), non-smoking people are more susceptible to PM2.5 exposure and the prevalence of smoking is very low among women than among men, therefore women are more susceptible to the increasing effect of PM2.5 exposure in China. According to Chinese health statistics (National Bureau of Statistics of China, 2016), PM2.5 associated non-communicable diseases such as cancer, cerebrovascular diseases and heart diseases are the top three causes of deaths in China, where cancer ranks as the highest in the list.

Due to rapid epidemiological transition shifting towards non-communicable diseases, Chinese centres of disease control and prevention (CDC) has been focusing on these diseases (Meng, Yang, Chen, Sun, & Liu, 2015). Because of the increasing threat of air pollution, our results suggests that CDC should prioritise prevention and treatment of lung cancers in both rural and urban China (National Bureau of Statistics of China, 2016), and lung cancer was the leading cause of cancer deaths in 2015 (Chen, et al., 2016).

Mortality rates demonstrate regional variation. Deaths unrelated to pollution exposure are observed to be higher in western China in comparison to eastern China. Eastern regions historically have always been more developed than any other regions of the country. Usually benefitted from preferential policies and investments, eastern regions have better economic and health care development than others. Therefore, the mortality rates are reasonably lower. However, air pollution associated deaths are much higher in that region and neighbouring central provinces. Hebei had the highest exposure related mortality rate as it was 3.19 deaths per capita in 2015. Neighbouring provinces such as Henan, Beijing, Shandong, Tianjin, Hubei had pollution associated mortality rates more than 2.5 deaths per capita. The mortality rate attributed to pollution in Xinjiang which is located in the western region of the country was 2.38 deaths per capita. This might be because Xinjiang has also high PM2.5 concentration due to increasing number of industrial facilities as well as being surrounded by the desert which frequents sand storms that contributes PM2.5 concentrations (Li, Liu, & Yin, 2018; Wang, Dong, Zhang, & Liu, 2004).

China experienced 25% increase in PM2.5 concentration from 2010. This caused 49% increase in pollution attributed death. We examined the causes of the increase in ambient air pollution. Our results show that industrial activities significantly affect the air pollution levels in cities but neither economic status nor economic inequality have any significant effect. We argue that pollution concentrations are mostly due to the operations of heavy industries rather than individual consumption.

Our results also indicate a regional disparity in terms of ambient air pollution. Eastern regions had been the most polluted region in China until recently. Due to recent shifting of heavy industry from eastern coast to central and western regions, air pollution displayed great increase in these regions. The industry transfer initially started because of economic purposes since the labour cost is relatively cheaper in western region. However, government promoted this relocation with issuing “Guiding Principles on Industrial Transfer to the Central and Western Regions” in 2010. The aim was to balance development disparity between coastal and inland regions by improving economic development of western and central regions as well as economic reconstructing of eastern coast (Ang, 2017).

Air Pollution Prevention and Control Law, launched in 2015, led China to close emitting industries and force strict environmental regulations for heavy industry. Thus, it also contributed greatly into the ongoing industry transfer.

Table 6.1 shows the domestic investment that indicates the industry relocation. Certain provinces like Hebei, Jiangsu, Shandong, Henan, Hubei and Anhui received the most domestic investment compared to other provinces. This also aligns with the increasing pollutions in these provinces as our findings indicates.

Table 6.1 Domestic Investment (100 million yuan) in 2010 and 2017

	2010	**2017**
Total	**260,914.4**	**616,322.2**
Hebei	14,691	32,536.4
Jiangsu	20,169.9	48,794.3
Shandong	21,905.5	52,993.8
Henan	16,181.6	43,883.3
Hubei	9,809.6	31,309.3
Anhui	11,091.5	28,618.9

Source: National Bureau of Statistics of China - Statistical Yearbook (2011) & (2018)

China introduced many control and prevention plans of air pollution throughout the years. Most recently a Three-Year Action Plan was introduced in 2018 (State Council, 2018). This plan included new key region “Fen-Wei Plains” which consists of Shaanxi, Henan and Shanxi. Moreover, previously assigned key region: Beijing-Tianjin-Hebei area expanded to include Shandong. This action plan aims to reduce PM2.5 concentrations of the key areas by 18% from 2015 until 2020. We estimated a scenario in which the plan had been implemented in the whole country and targets of 18% reduction from 2015 levels were achieved. Our results show that 16% of pollution related deaths would be avoided. Moreover, if the WHO first interim targets (35 $\mu g/m^3$) are attained, the avoidance of death would be around 39%. Furthermore, in case of achieving second and third interim targets

(25 μg/m^3 and 15 μg/m^3) as well as WHO Air Quality Guidelines (10 μg/m^3), 58%, 79% and 91% respectively of pollution attributed deaths from the levels of 2015 would be avoided. However, implementation of pollution abatement policies was found to be not strict inland and in western regions when compared to the eastern coast. As the industries started increasingly shifting to western region, it will cause further threat in the region in the future. Therefore, it is suggested that government expand their action plan coverage, introduce a nationwide framework of implementation of the action plan and monitor the implementation strictly.

Equality is key to successfully reducing mortality and pollution. Our results suggest that inequality directly affects mortality. Provinces with high rural-urban inequality displays high mortality rates. Inequality in implementing health care and literacy programmes as well as pollution control and prevention policies lead to increasing mortality rates. Therefore, China should address the inequality problem in health care, education and environmental sector thoroughly and create monitoring systems in order to maintain unbiased and sustainable policy implementation. Local governments should be encouraged to prioritize sustaining equality more than GDP growth.

6.5. Strengths and limitations

A major strength of this thesis is the use of recent data to examine trends in mortality and ambient air pollution. The analyses of mortality were based on WHO recommended methods for life table calculations and exposure-response functions. In addition, we complied an extensive daily ambient air pollution data for 3 years and we aggregated the daily data into annual data for the methodological purpose. Another strength is that this thesis follows a comprehensive approach of linking mortality with both environment and economic development factors specific to China.

However, it is worth mentioning some of the data challenges and limitations. China does not publish mortality data frequently, and therefore it limits our understanding of potential real fluctuations in mortality trends across geographical regions and over time. We used life tables to derive mortality and life expectancy estimates. Moreover, the city level age specific mortality rates are unavailable, therefore we relied on crude mortality rates for city level analysis. Because of this reason, the assessment of air pollution effect on mortality was not possible at the city level. Instead we estimated province level ambient air pollution associated deaths. Because of this, the results are relatively higher in comparison to the studies that utilized city level data. To illustrate, while other studies in the literature estimate pollution exposure associated deaths between the range 700 thousands and 1.6 million (Rohde & Muller, 2015; Fang, et al., 2016), our study estimated the deaths as 2.8 million.

In addition, we used mortality rates attributed to non-communicable diseases based on the Global Health Estimates published by World Health Organization (WHO, 2015), since China does not systematically provide data regarding on causes of deaths either on province level or city level. Statistical yearbooks and population censuses usually provide major causes of deaths as well as incident rate of infectious diseases, any other type of data such as death registrations with the causes are hard to find. Even if it is available for one province, it may not be available for another one. Therefore, we could not properly validate our results. Moreover, because there was no disposable income data for rural-urban regarding city levels, we used GDP per capita instead for calculating economic inequality between and within cities. Therefore, our results may not necessarily capture income inequality. Yet another weakness of the data is potential under-reporting or registration of death especially in rural areas, which could influence our mortality estimates.

6.6. Policy implications

China’s 13th Five-Year-Plan (2016-2020) highlights the importance of sustainable development. It aims to improve basic health care services, improve health care financing, increase coverage of social and health insurance of all citizens, reduce mortality, prevent and control chronic diseases, particularly targeting vulnerable groups like elderly, children, women as well as rural migrants. The plan further addresses the need to provide equity in providing health services and financial support, by stating that the government will ensure medical assistance to those who had financial burden of medical expenses as well as making health care services more accessible and affordable in poor areas. However, the plan does not clarify any methods or procedures to attain its objectives. Since implementation of policies are the core of health care systems in China, the latest Five-Year-Plan fails to bring concrete solution to the health care problems.

The plan aims to reduce ambient air pollution in overall China. More than 80% of the days in a year are targeted to be of good or excellent air quality as well as 18% reduction in PM2.5 concentration from 2015 levels in the cities at or above prefectural level.

In order to achieve the targets, the plan oblige industrial polluters to meet the emission standards, if not the companies will receive strict penalties like being blacklisted by the government, relocating or shut down. Heavy polluters that has been located in urban areas will be relocated to less developed western areas. On the other hand, the business with good environmental performances will be granted with emission permit. The emission permit and trading of it will be strictly controlled by the government. The plan states that there will be provincial level monitoring system solely for investigating performance the industrial companies, supervise them and take legal actions. The aim of this monitoring system will be maintaining the coordination of environmental actions between regions as well as increasing awareness of environmental issues and engaging public in to these issues.

Establishing a monitoring system for environmental protection is crucial. However, China still has not create a unified system for environmental taxation yet, therefore this crediting system based on the environmental performance of the companies could be tricky. Incentivizing local governments are essential in maintaining the system.

Moreover, the Five-Year Plan does not address the problems caused by closing or relocating a polluting facility. Since the environmental movement is grand scale, unemployment would increase. The plan should have addressed some protective measures to workers' status and insurances. Also relocating heavily polluting industries in underdeveloped areas like central and western regions showed great increase in pollution concentration in those areas. This creates further health and equality problems. It is a dynamic system, yet China must address the causes and effects together while taking precautions.

6.7. Future research

There is a lack of mortality data available for China. In the case of more mortality data being published, it would be possible to conduct a more comprehensive longitudinal analysis on mortality in China; in this way we could better capture the trends and externalities that impacts the trends. Also, we would be able to assess the relationship with mortality and air pollution exposure more systematically as the current lack of mortality data affects the quality of analysis (i.e. at present studies must resort to mortality estimates for certain geographies or time periods rather than published data on actual outcomes). As a result, we would be able to estimate pollution exposure associated deaths that are close to actual cases.

In particular, if city level data would be more available in the future, that would enable us to understand inter and intra city mortality dynamics as well as health, environment and economic inequalities. Since rural migration is a significant phenomenon in China, if more city level data were available over time, future research would also be able to address the issue of migration more explicitly than was possible in the present study.

Environmental inequalities are defined as regional disparities of pollution concentration in this study. However, with more disaggregated inter-city level data (i.e. county level, or rural-urban level), we would be able to calculate environmental inequality indices such as GINI coefficient and Theil index and further make cross country comparisons. In this way we could assess China’s position in global environmental inequality ranking.

For the future research, it would also be beneficial to include different sources of pollution in the analysis. This is crucial to understand the dynamics of pollution in the country and would help making policy recommendations.

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Appendix A Supplementary Material for Chapter 3

A.1 Descriptive Statistics

Table A.1 Descriptive Statistics of Dependent Variables

	LEX	*LEXm*	*LEXf*	*U5MR*	*U5MRm*	*U5MRf*	*AMR*	*AMRm*	*AMRf*
Mean	72.487	70.641	74.477	0.033	0.032	0.034	0.129	0.153	0.104
Standard Error	0.368	0.339	0.404	0.002	0.002	0.002	0.003	0.003	0.003
Median	72.446	70.616	74.631	0.027	0.025	0.026	0.128	0.155	0.099
Standard Deviation	4.920	4.532	5.402	0.027	0.027	0.028	0.037	0.037	0.041
Sample Variance	24.207	20.535	29.177	0.001	0.001	0.001	0.001	0.001	0.002
Kurtosis	-0.436	-0.232	-0.610	2.285	3.646	1.358	-0.207	0.245	-0.183
Skewness	-0.150	-0.098	-0.173	1.417	1.739	1.221	0.115	-0.079	0.546
Range	23.596	22.893	24.066	0.152	0.157	0.143	0.204	0.218	0.192
Minimum	59.100	57.800	61.808	0.001	0.001	0.001	0.044	0.057	0.030
Maximum	82.696	80.693	85.874	0.152	0.158	0.145	0.248	0.275	0.222
Sum	12975.193	12644.674	13331.388	5.929	5.669	6.044	23.035	27.441	18.694
Count	179	179	179	179	179	179	179	179	179

Table A.2 Descriptive Statistics of Independent Variables

	GDPpc	*Edu*	*Docs*	*H&E*	*Ineq*	*Urban*
Mean	14106.109	15.822	6.176	0.252	0.103	0.363
Standard Error	1089.881	0.829	0.271	0.004	0.005	0.014
Median	8453.642	13.430	5.635	0.246	0.093	0.335
Standard Deviation	14622.286	11.097	3.641	0.057	0.066	0.189
Sample Variance	213811250.109	123.136	13.259	0.003	0.004	0.036
Kurtosis	4.903	3.538	0.337	11.839	0.337	0.238
Skewness	2.101	1.522	0.647	2.178	0.773	0.748
Range	74882.266	65.720	18.130	0.544	0.347	0.816
Minimum	1191.734	1.860	0.390	0.089	0.002	0.077
Maximum	76074.000	67.580	18.520	0.633	0.349	0.893
Sum	2539099.648	2832.141	1111.640	45.423	18.587	64.986
Count	180	179	180	180	180	179

A.2 Life Table Samples

Table A.3 2010 Beijing abridged life table

	x	*n*	*ax*	*Mx*	*qx*	*px*	*lx*	*dx*	*Lx*	*Tx*	*ex*
<1	0	1	0.1	0.001303	0.001302	0.998698	100000	130.1523	99882.86	8235836	82.35836
1-4	1	4	0.5	0.000226	0.000905	0.999095	99869.85	90.36791	399298.7	8135953	81.46556
5-9	5	5	0.5	9.58E-05	0.000479	0.999521	99779.48	47.76147	498778	7736655	77.53753
10-14	10	5	0.5	0.000152	0.000759	0.999241	99731.72	75.72371	498469.3	7237877	72.57347
15-19	15	5	0.5	0.000167	0.000835	0.999165	99655.99	83.23844	498071.9	6739408	67.62672
20-24	20	5	0.5	0.00015	0.00075	0.99925	99572.76	74.66023	497677.1	6241336	62.68116
25-29	25	5	0.5	0.000168	0.00084	0.99916	99498.1	83.61135	497281.5	5743659	57.72632
30-34	30	5	0.5	0.000222	0.001109	0.998891	99414.48	110.288	496796.7	5246377	52.77276
35-39	35	5	0.5	0.00047	0.002348	0.997652	99304.2	233.1824	495938	4749580	47.8286
40-44	40	5	0.5	0.000839	0.004187	0.995813	99071.01	414.8278	494318	4253642	42.93529
45-49	45	5	0.5	0.001505	0.007496	0.992504	98656.19	739.4998	491432.2	3759324	38.10531
50-54	50	5	0.5	0.002574	0.012787	0.987213	97916.69	1252.059	486453.3	3267892	33.37421
55-59	55	5	0.5	0.003731	0.018481	0.981519	96664.63	1786.477	478856.9	2781439	28.77411
60-64	60	5	0.5	0.006299	0.031006	0.968994	94878.15	2941.762	467036.3	2302582	24.26883
65-69	65	5	0.5	0.011116	0.054078	0.945922	91936.39	4971.744	447252.6	1835546	19.96539
70-74	70	5	0.5	0.021085	0.100147	0.899853	86964.64	8709.208	413050.2	1388293	15.96388
75-79	75	5	0.5	0.037565	0.171699	0.828301	78255.44	13436.36	357686.3	975242.8	12.4623
80-84	80	5	0.5	0.066864	0.28644	0.71356	64819.08	18566.78	277678.4	617556.5	9.527388
85+	85	15	0.5	0.136085	1	0	46252.3	46252.3	339878.1	339878.1	7.34835

Source: Created by the author

Table A.4 2010 Beijing female abridged life table

	x	*n*	*ax*	*Mx*	*qx*	*px*	*lx*	*dx*	*Lx*	*Tx*	*ex*
<1	0	1	0.1	0.001265	0.001264	0.998736	100000	126.3971	99886.24	8447333	84.47333
1-4	1	4	0.5	0.000182	0.000726	0.999274	99873.6	72.53657	399349.3	8347446	83.58011
5-9	5	5	0.5	8.52E-05	0.000426	0.999574	99801.07	42.48517	498899.1	7948097	79.6394
10-14	10	5	0.5	0.000105	0.000527	0.999473	99758.58	52.58855	498661.4	7449198	74.67225
15-19	15	5	0.5	0.000107	0.000533	0.999467	99705.99	53.16655	498397	6950536	69.71032
20-24	20	5	0.5	7.59E-05	0.000379	0.999621	99652.83	37.80609	498169.6	6452139	64.74618
25-29	25	5	0.5	0.000113	0.000567	0.999433	99615.02	56.43737	497934	5953970	59.7698
30-34	30	5	0.5	0.000139	0.000696	0.999304	99558.58	69.31537	497619.6	5456036	54.80226
35-39	35	5	0.5	0.000327	0.001635	0.998365	99489.27	162.6342	497039.8	4958416	49.8387
40-44	40	5	0.5	0.000527	0.002632	0.997368	99326.63	261.4395	495979.6	4461376	44.91621
45-49	45	5	0.5	0.000931	0.004643	0.995357	99065.19	459.9911	494176	3965397	40.02815
50-54	50	5	0.5	0.001548	0.007708	0.992292	98605.2	760.0251	491125.9	3471221	35.20322
55-59	55	5	0.5	0.00252	0.012522	0.987478	97845.18	1225.247	486162.8	2980095	30.45725
60-64	60	5	0.5	0.004465	0.022078	0.977922	96619.93	2133.166	477766.7	2493932	25.81178
65-69	65	5	0.5	0.008242	0.04038	0.95962	94486.77	3815.365	462895.4	2016165	21.33807
70-74	70	5	0.5	0.016823	0.08072	0.91928	90671.4	7318.96	435059.6	1553270	17.13076
75-79	75	5	0.5	0.030919	0.143503	0.856497	83352.44	11961.32	386858.9	1118210	13.41545
80-84	80	5	0.5	0.059302	0.258225	0.741775	71391.12	18434.95	310868.2	731351.4	10.24429
85+	85	15	0.5	0.125941	1	0	52956.16	52956.16	420483.2	420483.2	7.940213

Source: Created by the author

Table A.5 2010 Beijing male abridged life table

	x	*n*	*ax*	*Mx*	*qx*	*px*	*lx*	*dx*	*Lx*	*Tx*	*ex*
<1	0	1	0.1	0.001337	0.001336	0.998664	100000	133.582	99879.78	8037682	80.37682
1-4	1	4	0.5	0.000266	0.001065	0.998935	99866.42	106.3862	399252.9	7937803	79.4842
5-9	5	5	0.5	0.000105	0.000525	0.999475	99760.03	52.41051	498669.1	7538550	75.56683
.10-14	10	5	0.5	0.000194	0.000968	0.999032	99707.62	96.54346	498296.7	7039881	70.60524
15-19	15	5	0.5	0.000221	0.001106	0.998894	99611.08	110.1541	497780	6541584	65.67125
20-24	20	5	0.5	0.000219	0.001092	0.998908	99500.92	108.6757	497232.9	6043804	60.74118
25-29	25	5	0.5	0.00022	0.001099	0.998901	99392.25	109.2264	496688.2	5546571	55.80486
30-34	30	5	0.5	0.000297	0.001485	0.998515	99283.02	147.4117	496046.6	5049883	50.86351
35-39	35	5	0.5	0.000596	0.002973	0.997027	99135.61	294.754	494941.2	4553836	45.93542
40-44	40	5	0.5	0.001112	0.005543	0.994457	98840.86	547.8844	492834.6	4058895	41.06495
45-49	45	5	0.5	0.002016	0.010028	0.989972	98292.97	985.6711	489000.7	3566060	36.27991
50-54	50	5	0.5	0.003548	0.017583	0.982417	97307.3	1710.995	482259	3077060	31.62209
55-59	55	5	0.5	0.004962	0.024507	0.975493	95596.31	2342.777	472124.6	2594801	27.14332
60-64	60	5	0.5	0.008208	0.040216	0.959784	93253.53	3750.307	456891.9	2122676	22.76242
65-69	65	5	0.5	0.014349	0.069258	0.930742	89503.22	6198.848	432019	1665784	18.61144
70-74	70	5	0.5	0.025933	0.121771	0.878229	83304.37	10144.04	391161.8	1233765	14.81033
75-79	75	5	0.5	0.044635	0.20077	0.79923	73160.34	14688.39	329080.7	842603.5	11.51722
80-84	80	5	0.5	0.075228	0.316596	0.683404	58471.95	18511.98	246079.8	513522.8	8.782379
85+	85	15	0.5	0.149415	1	0	39959.97	39959.97	267443	267443	6.692773

Source: Created by the author

A.3 Theil Index of Chinese provinces (1981 – 2010)

Table A.6 Theil Index of Chinese provinces (1981 – 2010)

Theil Index	1981	1990	1995	2000	2005	2010
China	0.04322	0.06368	0.116825	0.122615	0.143578	0.129657
Beijing	0.017271	0.009037	0.037116	0.040657	0.034493	0.025001
Tianjin	0.041689	0.017534	0.043556	0.049404	0.04527	0.042684
Hebei	0.027587	0.064804	0.070032	0.079708	0.113578	0.118446
Shanxi	0.054615	0.067439	0.123938	0.101866	0.148982	0.155159
Inner Mongolia	0.041351	0.051038	0.091937	0.102632	0.139591	0.132181
Liaoning	0.030851	0.044983	0.067255	0.073924	0.081507	0.08188
Jilin	0.010989	0.01431	0.054898	0.086007	0.103425	0.088868
Heilongjiang	0.025731	0.026538	0.050984	0.077419	0.09604	0.069446
Shanghai	0.015088	0.001966	0.014731	0.019101	0.020856	0.020761
Jiangsu	0.021414	0.017959	0.046442	0.050415	0.082292	0.081607
Zhejiang	0.025642	0.037749	0.067175	0.071516	0.083793	0.074291
Anhui	0.016976	0.085849	0.124245	0.122588	0.165358	0.140359
Fujian	0.03565	0.076118	0.068532	0.084982	0.118225	0.112868
Jiangxi	0.023018	0.032923	0.060611	0.090742	0.125933	0.114467
Shandong	0.031244	0.068987	0.101975	0.098158	0.118232	0.121064
Henan	0.01415	0.054448	0.091333	0.0867	0.14993	0.136208
Hubei	0.044317	0.068502	0.118088	0.097021	0.12815	0.113898
Hunan	0.034693	0.075562	0.167945	0.13247	0.151579	0.136837
Guangdong	0.021215	0.077656	0.124893	0.100256	0.11668	0.096896
Guangxi	0.030994	0.060698	0.157847	0.158691	0.208986	0.202588
Hainan	0.209787	0.079946	0.158646	0.098777	0.11577	0.127945
Sichuan	0.022569	0.104467	0.186878	0.154555	0.147674	0.147641
Guizhou	0.032101	0.153907	0.198227	0.207612	0.261835	0.236072
Yunnan	0.052022	0.100556	0.198245	0.254009	0.275973	0.234191
Tibet	0.048456	0.093699	0.163422	0.348817	0.277358	0.196095
Shaanxi	0.063263	0.098285	0.185949	0.195697	0.227454	0.194341
Gansu	0.087875	0.116201	0.193551	0.182436	0.240464	0.216068
Qinghai	0.095239	0.054282	0.149692	0.187517	0.203225	0.181265
Ningxia	0.065641	0.09758	0.182023	0.134934	0.159584	0.154014
Xinjiang	0.055162	0.057378	0.204592	0.189831	0.165091	0.136564

Source: Created by the author

Appendix B Supplementary Material for Chapter 4

B.1 Regression Results

Table B.1 Binary Logistic regression results (dependent variable: policy achievement, independent variables: city size dummies)

All dependent and independent variables are binary dummy variables. Policy achievement is zero when the pollution level of a given city increased from 2015 until 2016, otherwise 1. Independent variables are small city and large city which are based on Chinese city definition and the reference for the city size dummies are mega cities.

		B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**	**95% C.I. for EXP(B)**	
								Lower	**Upper**
Step 1^a	SmallCity(1)	.405	1.486	.074	1	.785	1.500	.082	27.607
	LargeCity(1)	-.847	1.070	.626	1	.429	.429	.053	3.492
	Constant	-1.638	1.493	1.204	1	.272	.194		

a. Variable(s) entered on step 1: SmallCity, LargeCity.

Table B.2 Binary Logistics Regression results (dependent variable: policy achievement, independent variables: region dummies)

All dependent and independent variables are binary dummy variables. Independent variables are region dummies such as central, western, north eastern. Provinces located in the categorized region is given 1 otherwise is given 0 value. The reference for these dummies is eastern region.

		B	**S.E.**	**Wald**	**df**	**Sig.**	**Exp(B)**	**95% C.I.for EXP(B)**	
								Lower	**Upper**
Step 1^a	Central(1)	-1.840	.523	12.359	1	.000	.159	.057	.443
	Western(1)	-2.067	.502	16.929	1	.000	.127	.047	.339
	NorthEastern(1)	.749	1.115	.452	1	.502	2.115	.238	18.812
	Constant	.411	1.408	.085	1	.771	1.508		

a. Variable(s) entered on step 1: Central, Western, NorthEastern.

Table B.3 Model 1 excluding Industrial Activity – Linear regression results

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B		Collinearity Statistics	
		B	Std. E	Beta			Lower	Upper	Tolerance	VIF
1	(Constant)	42.438	2.650		16.016	.000	37.222	47.654		
	GDP2015	8.448E-5	.000	.135	2.305	.022	.000	.000	.986	1.014
	Theil2015	-25.870	14.213	-.106	-1.820	.070	-53.849	2.110	.995	1.005
	PopDensity	.001	.000	.201	3.448	.001	.001	.002	.990	1.010

a. Dependent Variable: PM_2015

Note: Model 1 used 2015 data and had PM2.5 as dependent variable and Industrial Activity, GDP per capita, Theil Index and Population density of the given city but the Model 1 ran excluding industrial activity independent variable and Table B.3 shows this regression results.

Table B.4 Model 2 excluding Industrial Activity – Linear regression results

Note: Model 2 used 2015 data and had PM2.5 as dependent variable and Industrial Activity, GDP per capita, Theil Index, Population density, binary region dummies (i.e. western, central, north eastern) with reference to eastern region, binary city size dummies (i.e. small city and large city) with reference to mega cities. Model 2 was ran without including the Industrial Activity as an independent variable for the sensitivity analysis, the results are demonstrated in Table B.4 below.

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**	**95% Confidence Interval for B**		**Collinearity Statistics**	
		B	**Std. E.**	**Beta**			**Lower**	**Upper**	**Tolerance**	**VIF**
1	(Constant)	71.892	5.548		12.958	.000	60.970	82.814		
	GDP2015	6.476E-5	.000	.103	1.868	.063	.000	.000	.867	1.153
	Theil2015	-10.441	13.047	-.043	-.800	.424	-36.126	15.244	.928	1.077
	PopDensity	.001	.000	.103	1.847	.066	.000	.001	.854	1.172
	Central	6.585	2.737	.163	2.406	.017	1.196	11.973	.578	1.729
	Western	-10.132	2.591	-.275	-3.911	.000	-15.232	-5.032	.537	1.863
	NorthEastern	-3.213	3.293	-.058	-.976	.330	-9.696	3.270	.741	1.349
	SmallCity	-27.661	7.808	-.260	-3.543	.000	-43.033	-12.289	.494	2.024
	LargeCity	-25.755	5.274	-.347	-4.883	.000	-36.138	-15.372	.527	1.898

a. Dependent Variable: PM_2015

Appendix C

C.1 Regression Results

Regression model

$$SMR = \beta_0 + \beta_1 PM2.5_i + \beta_2 GDPpercapita + \beta_3 PopDensity + \beta_4 Doctors + \beta_5 Pop\%65 + \beta_6 Dummies + e$$

Table C.1 Summary of the regression results

	M1	Lag1	Lag5	Avg	Change
PM2.5	0.094	0.122	0.002	0.125	0.047
GDP per capita	0	0	0	0	$-9.4*10^{-05}$
Population Density	0.002	0.002	0.002	0.002	0.001
No Doctors	-2.36**	-2.385**	-2.17*	-2.372**	-2.278**
Above 65 population percentage	-4.17**	-4.403**	-3.847*	-4.235**	-4.089**
Central Dummy	-7.74	-7.902	-6.938	-7.87	-7.183
Western Dummy	-3.99	-3.888	-3.917	-4.448	-2.655
N	31	31	31	31	31
R sq	0.609	0.617	0.603	0.61	0.608

*** significant in 1% *significant in 5%*

Note: i = 2015, 2014 and 2010. Lag 1 refers to PM2.5 lags 1 year (2014), Lag5 refers to PM2.5 (2010). Avg is where PM2.5 is average of 2010-2015 and Change is PM2.5 change from 2010 until 2015. Dependent variable is standardized mortality rate (SMR) in 2015.

C.2 Summary of Meta-Analysis

Table C.2 Summary of Meta-Analysis

			Exposure-Response Function Coefficient β				**Standard Error (SE)**				
Cohort	**Reference**	**Year**	**All-cause**	**CVD**	**Respiratory**	**Lung Cancer**	**All-cause**	**CVD**	**Respiratory**	**Lung Cancer**	**Mean PM2.5**
North America											
ACS	(Turner, et al., 2016)	2016	0.007	0.007[a]	0.016	0.009	0.001	0.001	0.003	0.003	12.6
	(Pope, et al., 2014)	2015	0.007	0.012	-0.001		0.001	0.001	0.003		12.6
	(Jerrett, et al., 2013)	2013	0.006	0.011	0.008	0.011	0.003	0.004	0.009	0.01	14.1
	(Turner, et al., 2011)	2011				0.019				0.013	17.6
	(Krewski, et al., 2009)	2009	0.003[a]			0.01	0.001			0.003	14
	(Jerrett, et al., 2009)	2009	0.005	0.003			0.001	0.004			13.8
	(Jerrett, et al., 2005)	2005	0.016[a]			0.036	0.005			0.02	12.6
	(Pope C. , et al., 2004)	2004		0.012	-0.008[a]			0.002	0.003		17.1
	(Pope, et al., 2002)	2002	0.006			0.013	0.002			0.004	17.7
AHS	(Weichenthal, et al., 2014)	2014	0.005	0.014			0.022	0.021			9.5
CBC	(Gan, FitzGerald, Carlsten, Sadatsafavi, & Brauer, 2013)	2013			0.013				0.025		4.1
	(Gan, et al., 2011)	2011		0.006				0.011			4.1
CCM	(Crouse, et al., 2012)	2012	0.014[a]	0.015[a]			0.001	0.001			8.7
CCHS	(Pinault, et al., 2016)	2016	0.023[a]	0.017	0.042	0.015	0.003	0.005	0.01	0.009	6.3
CanCHEC	(Pinault, et al., 2017)	2017	0.016[a]	0.021[a]	0.019[a]	0.015	0.001	0.002	0.004	0.004	7.4
	(Crouse, et al., 2016)	2016	0.008				0.012				8.3
	(Weichenthal, et al., 2016)	2016	0.012	0.007	0.015	0.022	0.003	0.005	0.011	0.011	9.8

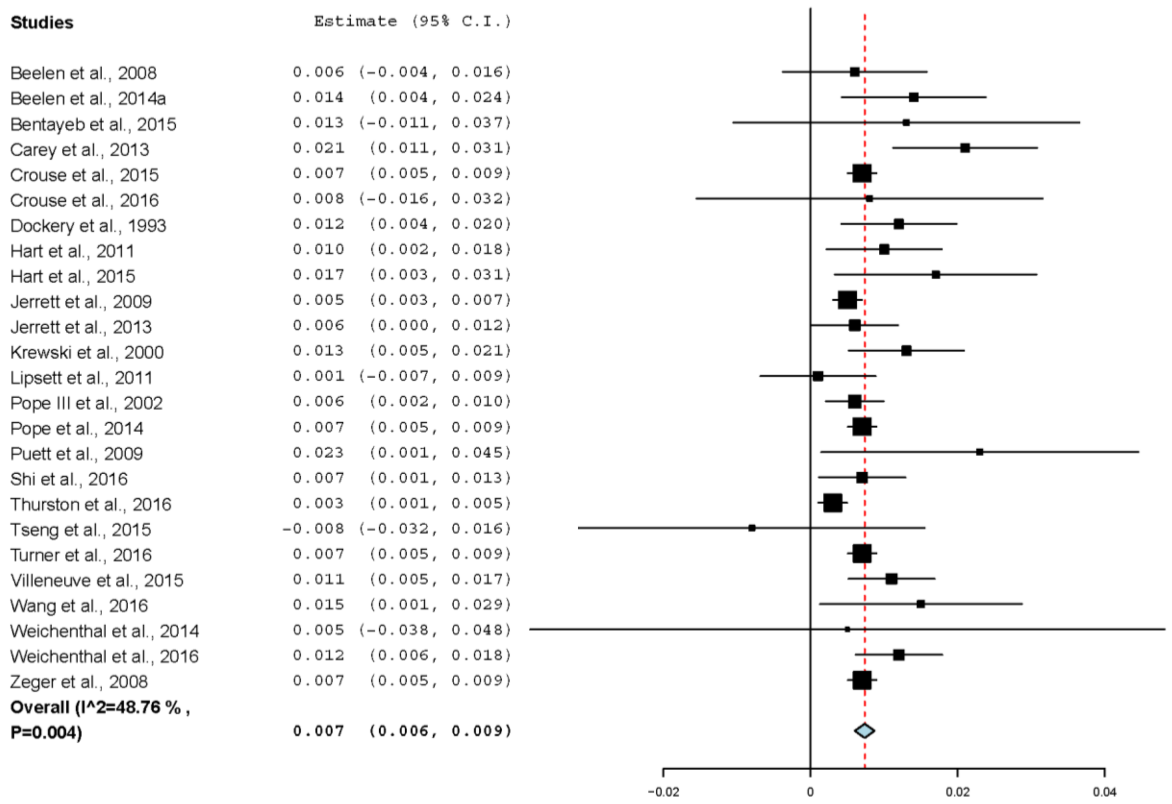
	(Crouse, et al., 2015)	2015	0.007	0.006[a]	-0.005[a]	0.006	0.001	0.001	0.002	0.002	8.9
CNBSS	(Villeneuve, et al.)	2015	0.011	0.027		-0.003	0.003	0.007		0.009	9.1
CTS	(Ostro, et al., 2015)	2015		0.017				0.005			17.9
	(Lipsett, et al., 2011)	2011	0.001	0.007[a]	0.019	-0.005	0.004	0.006	0.013	0.015	15.6
	(Ostro, et al., 2010)	2010	0.065[a]				0.013				17
Harvard Six Cities	(Lepeule, Laden, Dockery, & Schwartz, 2012)	2012	0.013[a]	0.023[a]		0.031	0.003	0.005		0.013	15.9
	(Laden, Schwartz, Speizer, & Dockery, 2006)	2006	0.015[a]	0.025[a]	0.008	0.024	0.004	0.006	0.016	0.014	16.4
	(Krewski, Burnett, Goldberg, Hoover, & Siemiatycki, 2000)	2000	0.013	0.017	-0.007	0.013	0.004	0.006	0.017	0.014	17.9
	(Dockery, et al., 1993)	1993	0.012			0.017	0.004			0.014	17.9
Health Professionals	(Puett R. , Hart, Suh,, Mittleman, & Laden, 2011)	2011	-0.015[a]				0.01				17.8
Medicare	(Di, et al., 2017)	2017	0.007[a]				0.0001				12.4
	(Wang, et al., 2017)	2017	0.021[a]				0.002				10.7
	(Shi, et al., 2016)	2016	0.007				0.003				8.1
	(Zeger, Dominici, McDermott, & Samet, 2008)	2008	0.007				0.001				13.2
NCHS	(Hao, et al., 2015)	2015			0.014				0.007		10.7
New Jersey US	(Wang, et al., 2016)	2016	0.015				0.007				11.3
NIH-AARP	(Thurston, et al., 2016)	2016	0.003	0.01	0.005		0.001	0.002	0.004		12.6
Nurses’ Health Study	(Hart, et al., 2015)	2015	0.017				0.007				12
	(Puett R. , et al., 2009)	2009	0.023				0.011				13.9
US trucking companies	(Hart, et al., 2011)	2011	0.01				0.004				14.1
WHI	(Miller, et al., 2007)	2007		0.057[a]				0.017			13.5
Europe											
ESCAPE	(Beelen, et al., 2014a.)	2014	0.014				0.005				13.7
	(Beelen, et al., 2014b)	2014		-0.002				0.009			13.7

	(Dimakopoulou, et al., 2014)	2014			-0.023				0.027		13.6
French electricity gas company	(Bentayeb, et al., 2015)	2015	0.013	0.013	-0.01		0.012	0.034	0.028		17.2
National English Cohort	(Carey, et al., 2013)	2013	0.021	0.01	0.06[a]	0.021	0.005	0.007	0.01	0.013	12.9
NLCS-AIR	(Beelen, et al., 2008)	2008	0.006	0.004	0.007	0.006	0.005	0.008	0.013	0.018	28.3
NSHD &SABRE	(Dehbi, et al., 2017)	2016		0.026				0.061			9.8
RoLS	(Cesaroni, et al., 2013)	2013	0.004[a]	0.006	0.003	0.005	0.001	0.001	0.003	0.002	23
Asia											
China	(Yin, et al., 2017)	2017	0.009[a]	0.009[a]		0.011	0.0001	0.0001		0.002	43.7
Hong Kong	(Wong, et al., 2016)	2016	0.012[a]			0.013	0.002			0.009	33.7
	(Wong, et al., 2015)	2015	0.013[a]	0.02			0.003	0.006			34.6
Japan	(Katanoda, et al., 2011)	2011			0.015	0.021			0.006	0.006	27.6
	(Ueda, Nagasawa, Nitta, Miura, & Ueshima, 2012)	2012	-0.002[a]	-0.011[a]			0.003	0.005			30.2
Taiwan	(Tseng, et al., 2015)	2015	-0.008	-0.022			0.012	0.032			29.7

[a] Excluded studies for maintaining low heterogenity

Cohort Abbreviations: ACS: American Cancer Society, AHS: Agricultural Health Study, CBC: Canada British Colombia, CCM: Canadian Census Mortality, CCHS: Canadian Community Health Survey, CanCHEC: Canadian Census Health and Environment Cohort, CNBSS: Canadian National Breast Screening Study, CTS: California Teachers Study, NCHS: National Centre for Health Statistics, NIH-AARP: National Institutes of Health AARP Diet &Health, WHI: Women’s Health Initiative, ESCAPE: European Study of Cohorts for Air Pollution Effects, NLCS: Netherlands Cohort Study, NSHD: National Survey of Health and Development, SABRE: Southall And Brent Revisited, RoLS: Rome Longitudinal Study

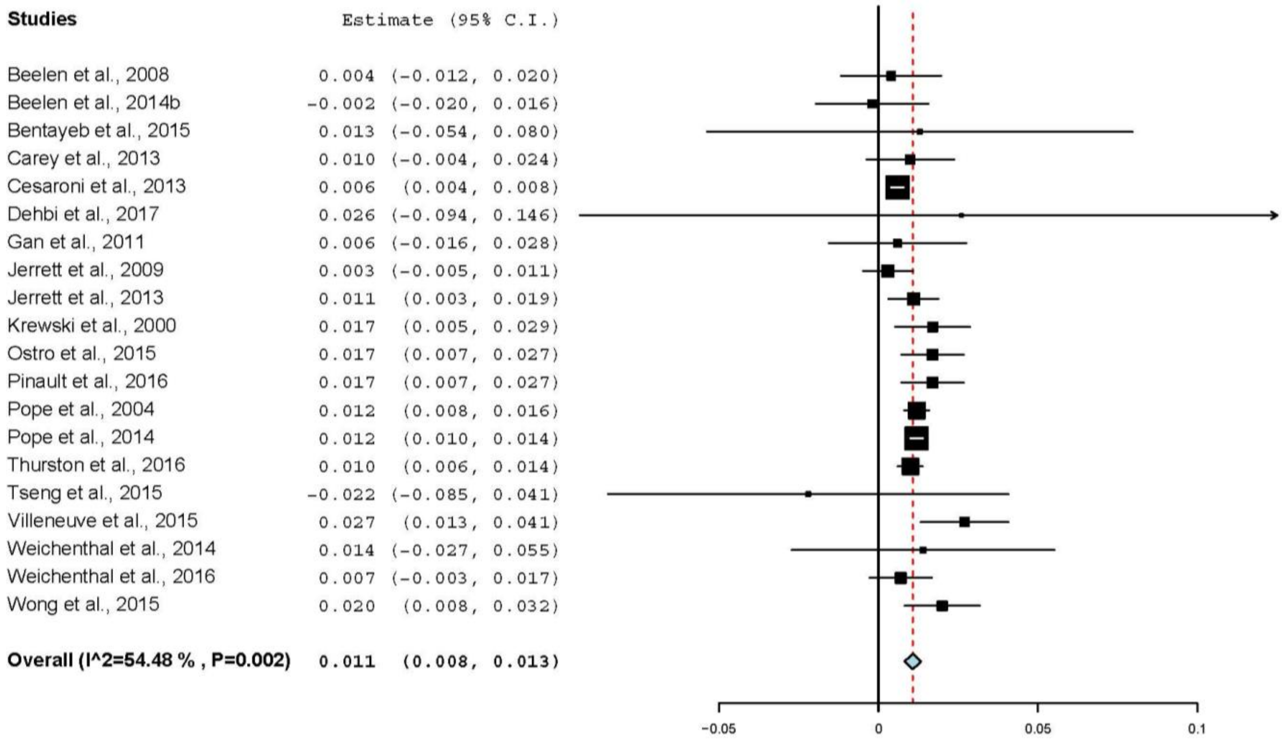
C.3 Meta-Analysis Forest Plots



Studies	Estimate (95% C.I.)
Beelen et al., 2008	0.006 (−0.004, 0.016)
Beelen et al., 2014a	0.014 (0.004, 0.024)
Bentayeb et al., 2015	0.013 (−0.011, 0.037)
Carey et al., 2013	0.021 (0.011, 0.031)
Crouse et al., 2015	0.007 (0.005, 0.009)
Crouse et al., 2016	0.008 (−0.016, 0.032)
Dockery et al., 1993	0.012 (0.004, 0.020)
Hart et al., 2011	0.010 (0.002, 0.018)
Hart et al., 2015	0.017 (0.003, 0.031)
Jerrett et al., 2009	0.005 (0.003, 0.007)
Jerrett et al., 2013	0.006 (0.000, 0.012)
Krewski et al., 2000	0.013 (0.005, 0.021)
Lipsett et al., 2011	0.001 (−0.007, 0.009)
Pope III et al., 2002	0.006 (0.002, 0.010)
Pope et al., 2014	0.007 (0.005, 0.009)
Puett et al., 2009	0.023 (0.001, 0.045)
Shi et al., 2016	0.007 (0.001, 0.013)
Thurston et al., 2016	0.003 (0.001, 0.005)
Tseng et al., 2015	−0.008 (−0.032, 0.016)
Turner et al., 2016	0.007 (0.005, 0.009)
Villeneuve et al., 2015	0.011 (0.005, 0.017)
Wang et al., 2016	0.015 (0.001, 0.029)
Weichenthal et al., 2014	0.005 (−0.038, 0.048)
Weichenthal et al., 2016	0.012 (0.006, 0.018)
Zeger et al., 2008	0.007 (0.005, 0.009)
Overall (I^2=48.76 % , P=0.004)	**0.007 (0.006, 0.009)**

Figure C.1 Forest plot: all-cause mortality β coefficient

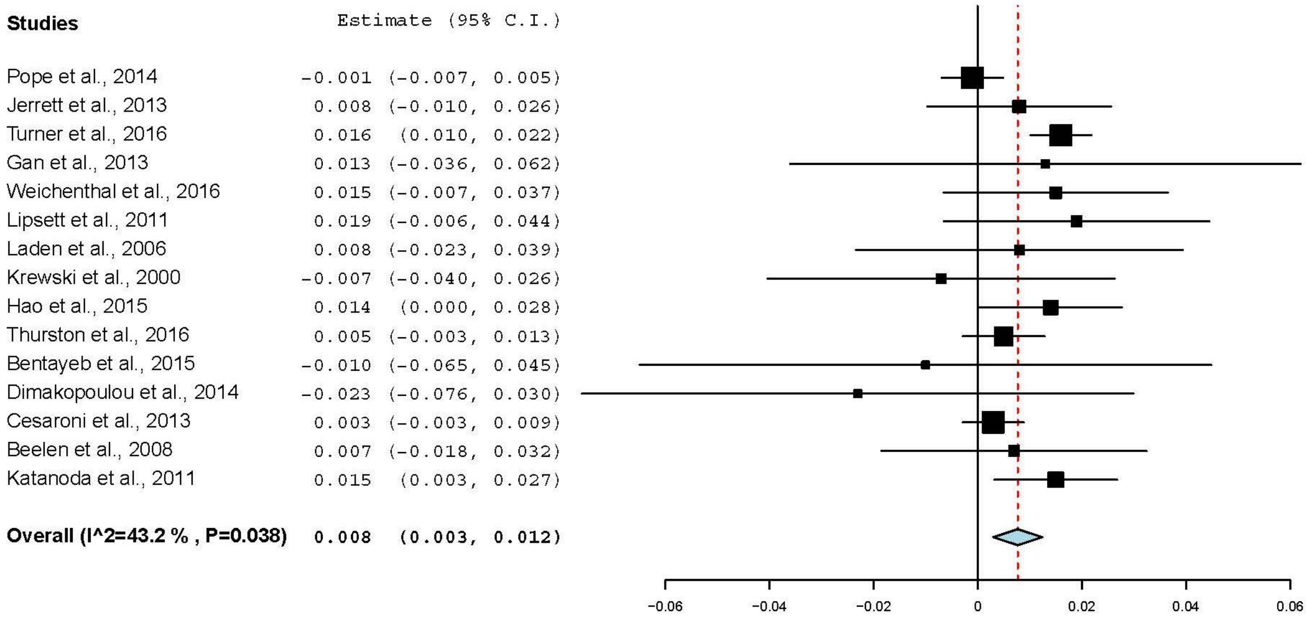
Source: Created by the author



Studies	Estimate (95% C.I.)
Beelen et al., 2008	0.004 (-0.012, 0.020)
Beelen et al., 2014b	-0.002 (-0.020, 0.016)
Bentayeb et al., 2015	0.013 (-0.054, 0.080)
Carey et al., 2013	0.010 (-0.004, 0.024)
Cesaroni et al., 2013	0.006 (0.004, 0.008)
Dehbi et al., 2017	0.026 (-0.094, 0.146)
Gan et al., 2011	0.006 (-0.016, 0.028)
Jerrett et al., 2009	0.003 (-0.005, 0.011)
Jerrett et al., 2013	0.011 (0.003, 0.019)
Krewski et al., 2000	0.017 (0.005, 0.029)
Ostro et al., 2015	0.017 (0.007, 0.027)
Pinault et al., 2016	0.017 (0.007, 0.027)
Pope et al., 2004	0.012 (0.008, 0.016)
Pope et al., 2014	0.012 (0.010, 0.014)
Thurston et al., 2016	0.010 (0.006, 0.014)
Tseng et al., 2015	-0.022 (-0.085, 0.041)
Villeneuve et al., 2015	0.027 (0.013, 0.041)
Weichenthal et al., 2014	0.014 (-0.027, 0.055)
Weichenthal et al., 2016	0.007 (-0.003, 0.017)
Wong et al., 2015	0.020 (0.008, 0.032)
Overall (I^2=54.48 % , P=0.002)	**0.011 (0.008, 0.013)**

Figure C.2 Forest plot: CVD mortality β coefficient

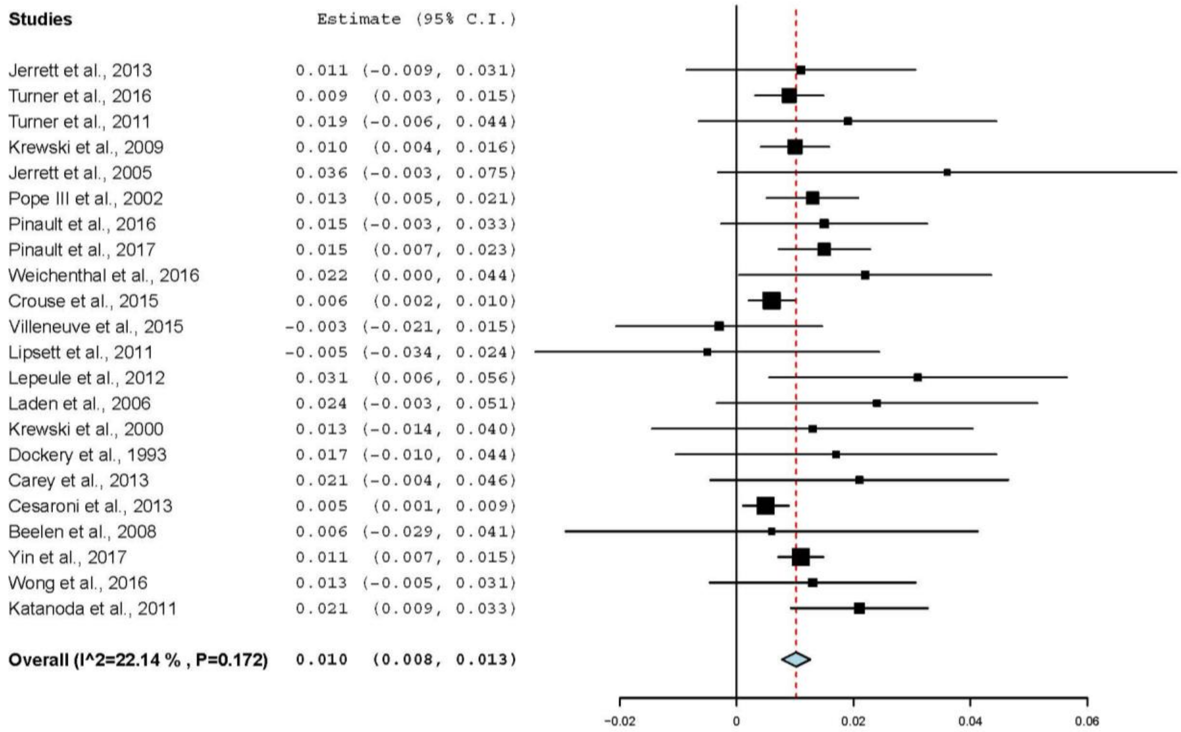
Source: Created by the author



Studies	Estimate (95% C.I.)
Pope et al., 2014	-0.001 (-0.007, 0.005)
Jerrett et al., 2013	0.008 (-0.010, 0.026)
Turner et al., 2016	0.016 (0.010, 0.022)
Gan et al., 2013	0.013 (-0.036, 0.062)
Weichenthal et al., 2016	0.015 (-0.007, 0.037)
Lipsett et al., 2011	0.019 (-0.006, 0.044)
Laden et al., 2006	0.008 (-0.023, 0.039)
Krewski et al., 2000	-0.007 (-0.040, 0.026)
Hao et al., 2015	0.014 (0.000, 0.028)
Thurston et al., 2016	0.005 (-0.003, 0.013)
Bentayeb et al., 2015	-0.010 (-0.065, 0.045)
Dimakopoulou et al., 2014	-0.023 (-0.076, 0.030)
Cesaroni et al., 2013	0.003 (-0.003, 0.009)
Beelen et al., 2008	0.007 (-0.018, 0.032)
Katanoda et al., 2011	0.015 (0.003, 0.027)
Overall (I^2=43.2 % , P=0.038)	**0.008 (0.003, 0.012)**

Figure C.3 Forest plot: Respiratory diseases mortality β coefficient

Source: Created by the author



Studies	Estimate (95% C.I.)
Jerrett et al., 2013	0.011 (-0.009, 0.031)
Turner et al., 2016	0.009 (0.003, 0.015)
Turner et al., 2011	0.019 (-0.006, 0.044)
Krewski et al., 2009	0.010 (0.004, 0.016)
Jerrett et al., 2005	0.036 (-0.003, 0.075)
Pope III et al., 2002	0.013 (0.005, 0.021)
Pinault et al., 2016	0.015 (-0.003, 0.033)
Pinault et al., 2017	0.015 (0.007, 0.023)
Weichenthal et al., 2016	0.022 (0.000, 0.044)
Crouse et al., 2015	0.006 (0.002, 0.010)
Villeneuve et al., 2015	-0.003 (-0.021, 0.015)
Lipsett et al., 2011	-0.005 (-0.034, 0.024)
Lepeule et al., 2012	0.031 (0.006, 0.056)
Laden et al., 2006	0.024 (-0.003, 0.051)
Krewski et al., 2000	0.013 (-0.014, 0.040)
Dockery et al., 1993	0.017 (-0.010, 0.044)
Carey et al., 2013	0.021 (-0.004, 0.046)
Cesaroni et al., 2013	0.005 (0.001, 0.009)
Beelen et al., 2008	0.006 (-0.029, 0.041)
Yin et al., 2017	0.011 (0.007, 0.015)
Wong et al., 2016	0.013 (-0.005, 0.031)
Katanoda et al., 2011	0.021 (0.009, 0.033)
Overall (I^2=22.14 % , P=0.172)	**0.010 (0.008, 0.013)**

Figure C.4 Forest plot: Lung cancer mortality β coefficient

Source: Created by the author

C.4 Provincial Pollution Related Estimated Deaths Detail

Table C.3 Exposure – Response Function results for 31 Provinces

2015					*Estimated Deaths*			
Provinces	**RRs**	**95% CI**	**Mean PM2.5**	**SMR**	**All Cause**	**CVD**	**Respiratory**	**Lung Cancer**
Anhui	1.48	(1.40 - 1.65)	61.5	95.4	143044.3	84842.5	15168.7	12303.2
Beijing	1.68	(1.56 - 1.95)	80.1	66.9	63166.5	36353.3	6646.1	5310.0
Chongqing	1.40	(1.33- 1.54)	53.9	83.1	62106.0	37311.2	6607.6	5393.8
Fujian	1.16	(1.14 - 1.21)	27	107.2	38073.6	24004.4	4100.8	3429.3
Gansu	1.33	(1.28 - 1.44)	46.6	110.1	46663.6	28389.6	4980.7	4091.5
Guangdong	1.20	(1.17 - 1.26)	31.8	94.5	129807.7	81106.8	13949.6	11612.8
Guangxi	1.15	(1.13 - 1.20)	26	115.9	45762.1	28902.0	4931.1	4127.2
Guizhou	1.07	(1.06 - 1.09)	15.6	113.5	16990.5	10945.8	1840.0	1555.4
Hainan	1.11	(1.09 - 1.14)	20.5	109.3	6402.2	4086.4	691.7	582.0
Hebei	1.80	(1.65 - 2.13)	89.6	114.9	237913.2	134938.8	24936.4	19778.5
Heilongjiang	1.41	(1.35 - 1.56)	55.4	83.6	80587.1	48291.5	8568.2	6985.4
Henan	1.72	(1.59 - 2.01)	83.3	111.5	286658.9	164164.2	30121.9	24007.0
Hubei	1.56	(1.46 - 1.77)	69	101	150761.3	88316.0	15935.7	12845.3
Hunan	1.39	(1.33 - 1.53)	53.2	92.2	138332.5	83201.6	14721.9	12024.4
Inner Mongolia	1.30	(1.25 - 1.39)	42.8	86.2	41277.4	25283.4	4413.4	3637.8
Jiangsu	1.44	(1.37 - 1.60)	57.9	102.2	175377.3	104650.2	18626.3	15153.4
Jiangxi	1.30	(1.25 - 1.40)	43.4	119.1	76194.3	46622.6	8144.6	6709.8
Jilin	1.47	(1.39 - 1.64)	60.5	80.3	63274.1	37585.9	6712.3	5448.4
Liaoning	1.51	(1.42 - 1.70)	64.8	87.1	106850.7	63024.0	11314.4	9151.5
Ningxia	1.34	(1.29 - 1.46)	47.7	95.1	12241.0	7433.1	1305.9	1071.7
Qinghai	1.34	(1.29 - 1.46)	47.7	121.7	10798.3	6557.2	1152.0	945.4
Shaanxi	1.42	(1.35 - 1.57)	56	95.9	81016.6	48494.7	8611.4	7016.7
Shandong	1.57	(1.47 - 1.78)	70	91.5	257137.8	150375.9	27167.9	21880.7
Shanghai	1.39	(1.33 - 1.53)	53.4	80.2	49114.0	29532.4	5226.5	4268.3
Shanxi	1.41	(1.34 - 1.56)	55	115.9	76978.6	46156.3	8185.8	6675.6
Sichuan	1.43	(1.36 - 1.59)	57.1	96.9	178737.3	106791.4	18989.4	15458.6
Tianjin	1.57	(1.47 - 1.78)	70	112.4	40173.3	23496.4	4244.6	3418.8
Tibet	1.14	(1.11 - 1.18)	23.9	135.8	2795.5	1772.6	301.5	252.9
Xinjiang	1.49	(1.41 - 1.68)	63.2	92.4	56419.5	33366.5	5978.3	4841.9
Yunnan	1.17	(1.14 - 1.22)	27.8	149.9	48801.4	30722.3	5254.3	4390.6
Zhejiang	1.35	(1.29 - 1.47)	48.8	84.6	103589.1	62784.8	11046.1	9056.8

Source: Created by the author

Table C.4 Death rates (per thousand) due to PM2.5 exposure

	2015				*2010*			
	all cause	**CVD**	**Respiratory**	**Lung Cancer**	**all cause**	**CVD**	**Respiratory**	**Lung Cancer**
Anhui	2.32	1.38	0.25	0.20	1.63	0.95	0.20	0.12
Beijing	2.92	1.68	0.31	0.25	1.93	1.11	0.24	0.15
Chongqing	2.05	1.23	0.22	0.18	1.43	0.85	0.18	0.11
Fujian	0.99	0.62	0.11	0.09	1.10	0.66	0.14	0.09
Gansu	1.79	1.09	0.19	0.16	2.30	1.30	0.28	0.17
Guangdong	1.20	0.75	0.13	0.11	0.92	0.56	0.12	0.07
Guangxi	0.95	0.60	0.10	0.09	1.05	0.63	0.13	0.08
Guizhou	0.48	0.31	0.05	0.04	1.33	0.79	0.17	0.10
Hainan	0.70	0.45	0.08	0.06	0.55	0.34	0.07	0.04
Hebei	3.19	1.81	0.33	0.27	1.40	0.83	0.18	0.11
Heilongjiang	2.11	1.26	0.22	0.18	1.43	0.85	0.18	0.11
Henan	3.01	1.72	0.32	0.25	1.69	0.99	0.21	0.13
Hubei	2.57	1.51	0.27	0.22	1.55	0.91	0.19	0.12
Hunan	2.03	1.22	0.22	0.18	1.50	0.88	0.19	0.11
Inner Mongolia	1.64	1.00	0.18	0.14	1.43	0.84	0.18	0.11
Jiangsu	2.20	1.31	0.23	0.19	1.53	0.90	0.19	0.12
Jiangxi	1.66	1.02	0.18	0.15	1.20	0.72	0.15	0.09
Jilin	2.29	1.36	0.24	0.20	1.32	0.78	0.16	0.10
Liaoning	2.43	1.43	0.26	0.21	1.57	0.92	0.20	0.12
Ningxia	1.83	1.11	0.19	0.16	1.47	0.87	0.18	0.11
Qinghai	1.83	1.11	0.19	0.16	1.98	1.14	0.25	0.15
Shaanxi	2.13	1.28	0.23	0.18	1.77	1.03	0.22	0.13
Shandong	2.60	1.52	0.28	0.22	1.63	0.96	0.20	0.12
Shanghai	2.04	1.22	0.22	0.18	1.26	0.75	0.16	0.10
Shanxi	2.10	1.26	0.22	0.18	1.32	0.79	0.17	0.10
Sichuan	2.17	1.30	0.23	0.19	1.32	0.78	0.17	0.10
Tianjin	2.60	1.52	0.27	0.22	1.54	0.91	0.19	0.12
Tibet	0.86	0.54	0.09	0.08	0.71	0.43	0.09	0.06
Xinjiang	2.38	1.41	0.25	0.20	1.98	1.14	0.25	0.15
Yunnan	1.02	0.64	0.11	0.09	1.26	0.75	0.16	0.10
Zhejiang	1.87	1.13	0.20	0.16	1.48	0.87	0.19	0.11

Source: Created by the author

Table C.5 Change in PM2.5 associated deaths from 2010 to 2015 and the effecting factors

	Baseline Rate Change (%)				*Exposure change effect (%)*				*Total Change (%)*			
Provinces	**AllC.**	**CVD**	**Res.**	**LC**	**AllC.**	**CVD**	**Res.**	**LC**	**AllC.**	**CVD**	**Res.**	**LC**
Anhui	-1%	-3%	-17%	9%	45%	49%	39%	54%	47%	49%	25%	67%
Beijing	-9%	-15%	-25%	-1%	65%	71%	56%	77%	67%	67%	41%	86%
Chongqing	0%	-1%	-16%	11%	46%	50%	40%	55%	51%	53%	28%	71%
Fujian	14%	21%	-2%	34%	-25%	-27%	-21%	-30%	-6%	-2%	-20%	9%
Gansu	27%	44%	11%	56%	-50%	-61%	-44%	-65%	-21%	-15%	-31%	-6%
Guangdong	6%	9%	-10%	21%	26%	27%	22%	30%	36%	40%	16%	56%
Guangxi	14%	21%	-3%	34%	-23%	-26%	-20%	-28%	-5%	0%	-18%	10%
Guizhou	29%	47%	12%	59%	-94%	-109%	-83%	-118%	-63%	-60%	-68%	-56%
Hainan	8%	12%	-8%	25%	20%	21%	17%	23%	34%	38%	14%	53%
Hebei	-23%	-35%	-38%	-24%	155%	157%	132%	175%	136%	126%	98%	155%
Heilongjiang	-1%	-3%	-16%	9%	48%	52%	41%	57%	47%	49%	25%	66%
Henan	-14%	-23%	-30%	-11%	93%	98%	80%	109%	80%	77%	52%	99%
Hubei	-8%	-14%	-24%	-2%	76%	80%	65%	89%	70%	69%	44%	90%
Hunan	2%	2%	-14%	14%	35%	38%	30%	41%	40%	43%	20%	59%
Inner Mongolia	8%	12%	-8%	24%	7%	8%	6%	9%	17%	21%	0%	35%
Jiangsu	-1%	-3%	-17%	10%	46%	49%	39%	54%	46%	48%	24%	65%
Jiangxi	3%	4%	-13%	16%	36%	39%	31%	43%	42%	46%	21%	62%
Jilin	-7%	-12%	-22%	0%	81%	86%	70%	95%	75%	75%	48%	96%
Liaoning	-5%	-9%	-20%	3%	60%	65%	52%	71%	56%	57%	32%	75%
Ningxia	6%	7%	-11%	20%	20%	23%	18%	25%	32%	36%	13%	51%
Qinghai	18%	27%	1%	40%	-26%	-30%	-23%	-32%	-3%	3%	-17%	13%
Shaanxi	6%	8%	-10%	20%	15%	16%	13%	18%	22%	26%	4%	40%
Shandong	-7%	-12%	-23%	0%	69%	74%	59%	81%	64%	64%	39%	84%
Shanghai	-3%	-6%	-19%	7%	67%	72%	58%	79%	69%	71%	44%	91%
Shanxi	-3%	-6%	-19%	7%	63%	67%	54%	74%	63%	64%	38%	84%
Sichuan	-4%	-8%	-20%	4%	70%	75%	61%	83%	68%	69%	43%	89%
Tianjin	-10%	-17%	-28%	-3%	92%	98%	79%	108%	101%	100%	70%	124%
Tibet	9%	12%	-8%	26%	14%	15%	12%	17%	32%	37%	13%	52%
Xinjiang	5%	7%	-12%	20%	16%	18%	14%	20%	30%	34%	11%	49%
Yunnan	17%	26%	0%	39%	-36%	-41%	-32%	-44%	-16%	-11%	-28%	-2%
Zhejiang	5%	6%	-11%	19%	22%	24%	19%	26%	28%	32%	10%	47%

Note: AllC. refers to all-cause deaths, CVD refers to cardiovascular diseases, Res. Refers to respiratory diseases, LC refers to lung cancer

Source: Created by the author

C.4.1 Map representation of estimated deaths

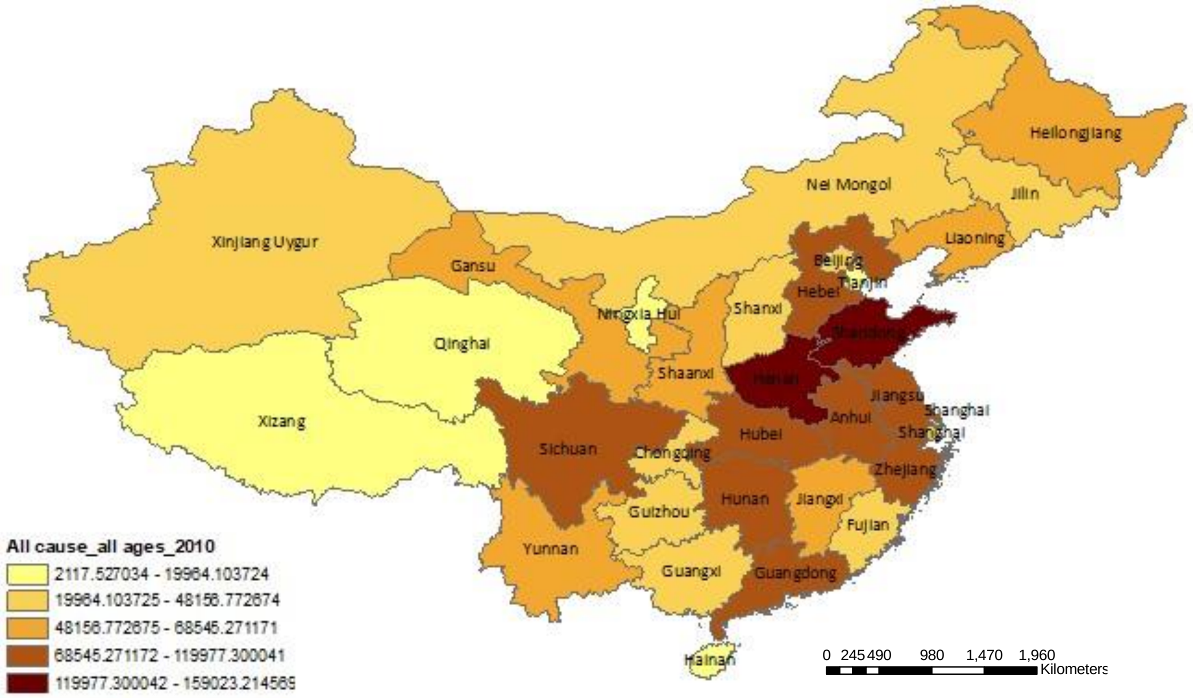


Figure C.5 PM2.5 associated deaths (all-cause) across Chinese provinces (2010)

Source: Created by the author

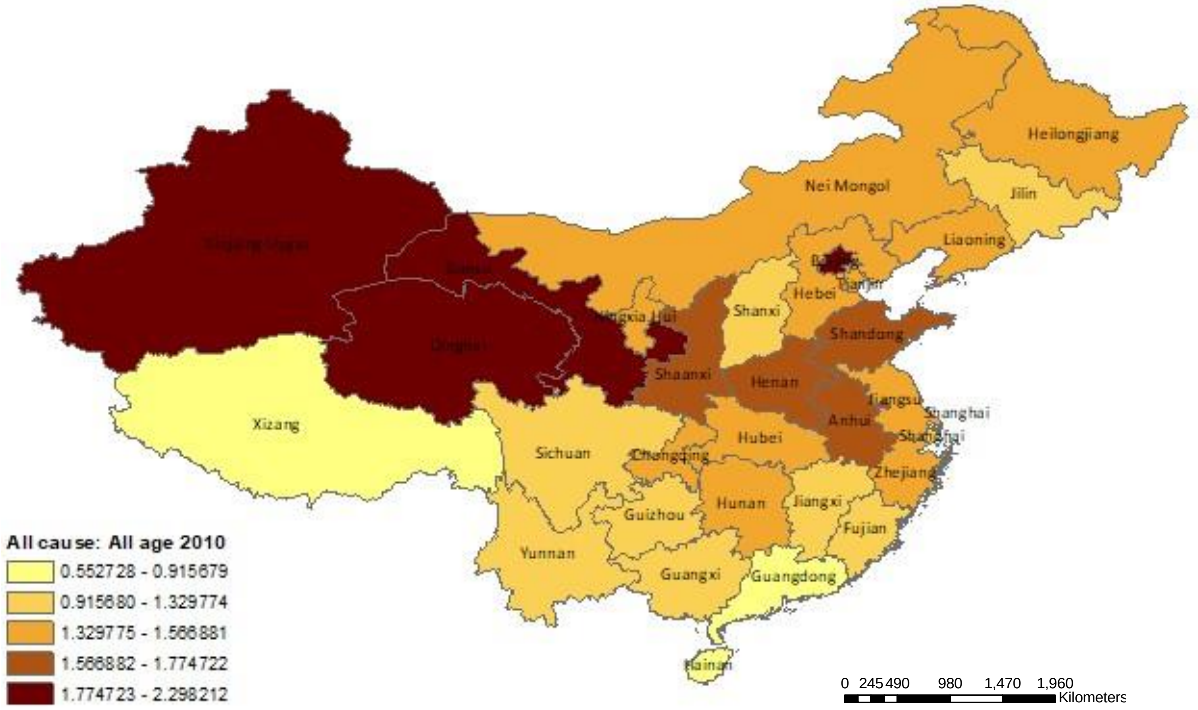


Figure C.6 PM2.5 associated deaths rates (all-cause) across Chinese provinces (2010)

Source: Created by the author

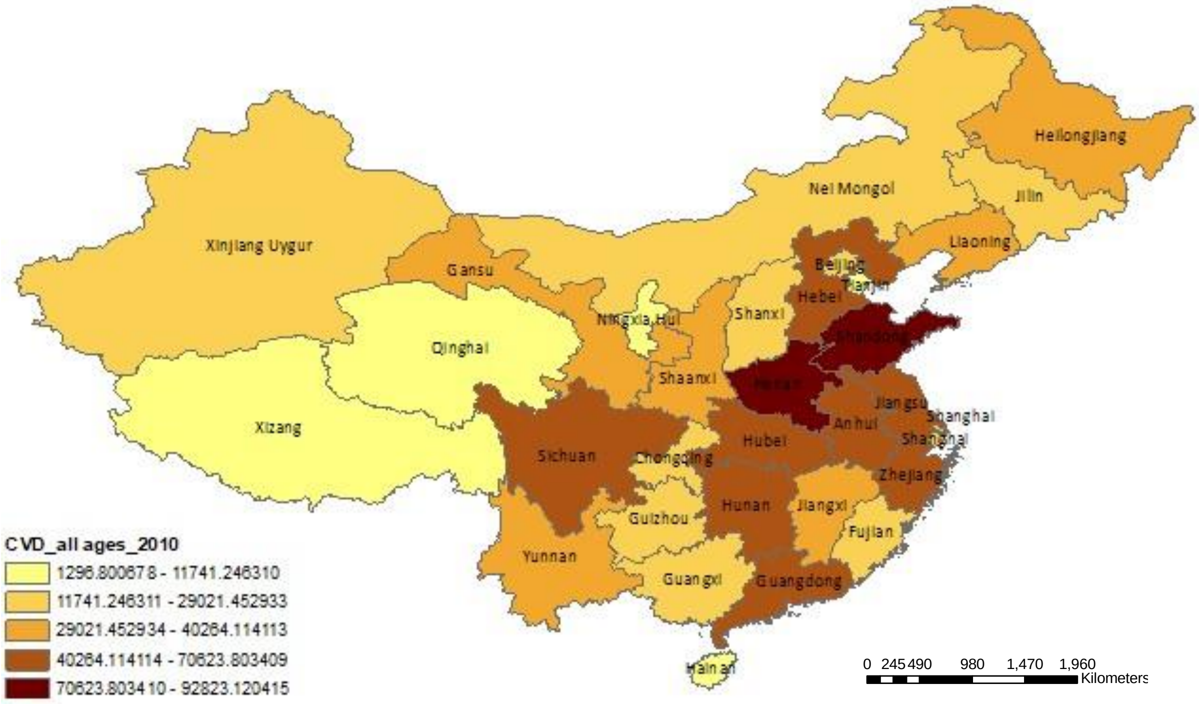


Figure C.7 PM2.5 associated deaths (CVD) across Chinese provinces (2010)

Source: Created by the author

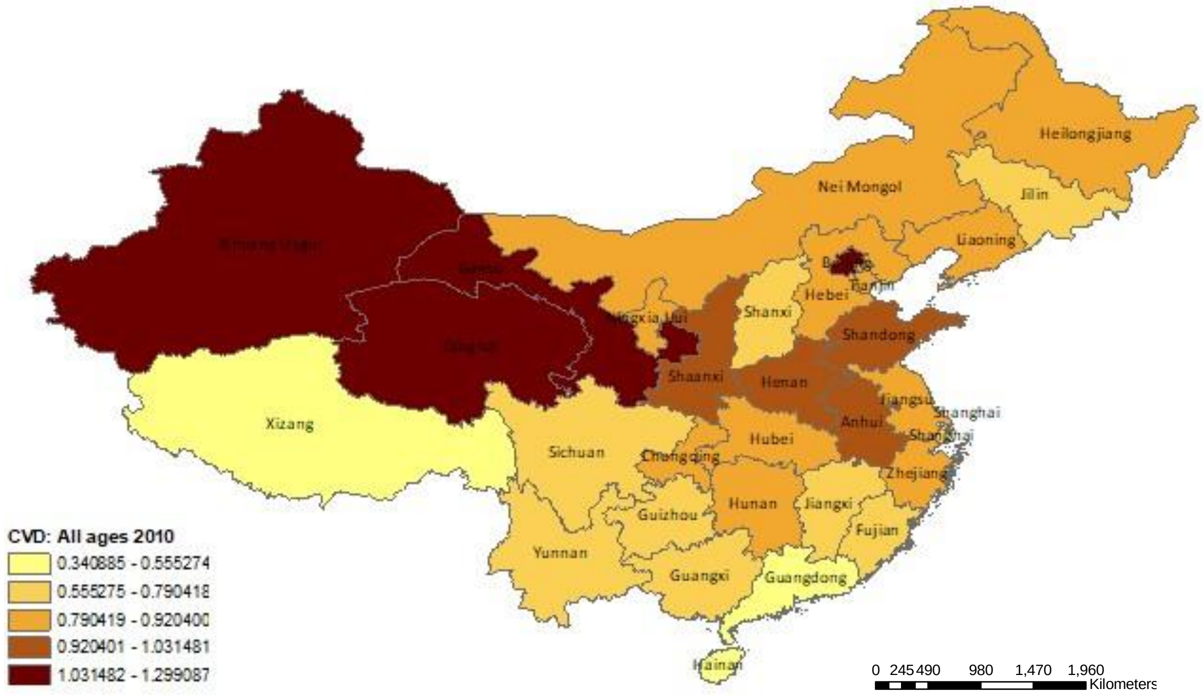


Figure C.8 PM2.5 associated deaths rates (CVD) across Chinese provinces (2010)

Source: Created by the author

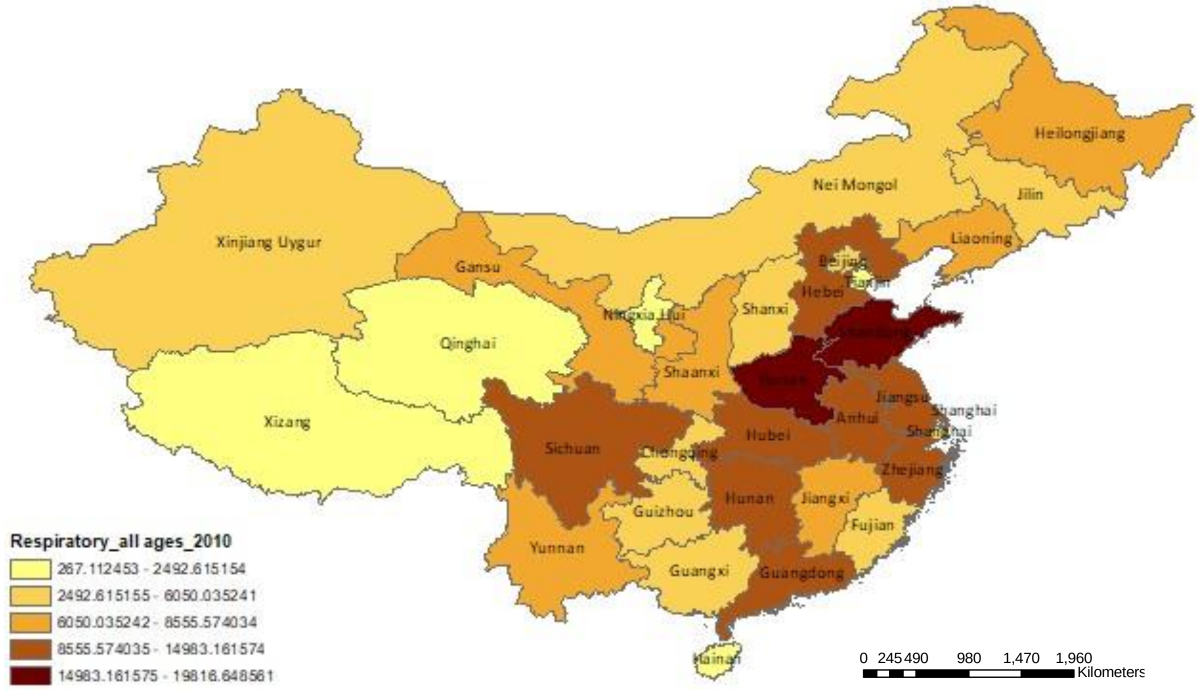


Figure C.9 PM2.5 associated deaths (Respiratory Diseases) across Chinese provinces (2010)

Source: Created by the author

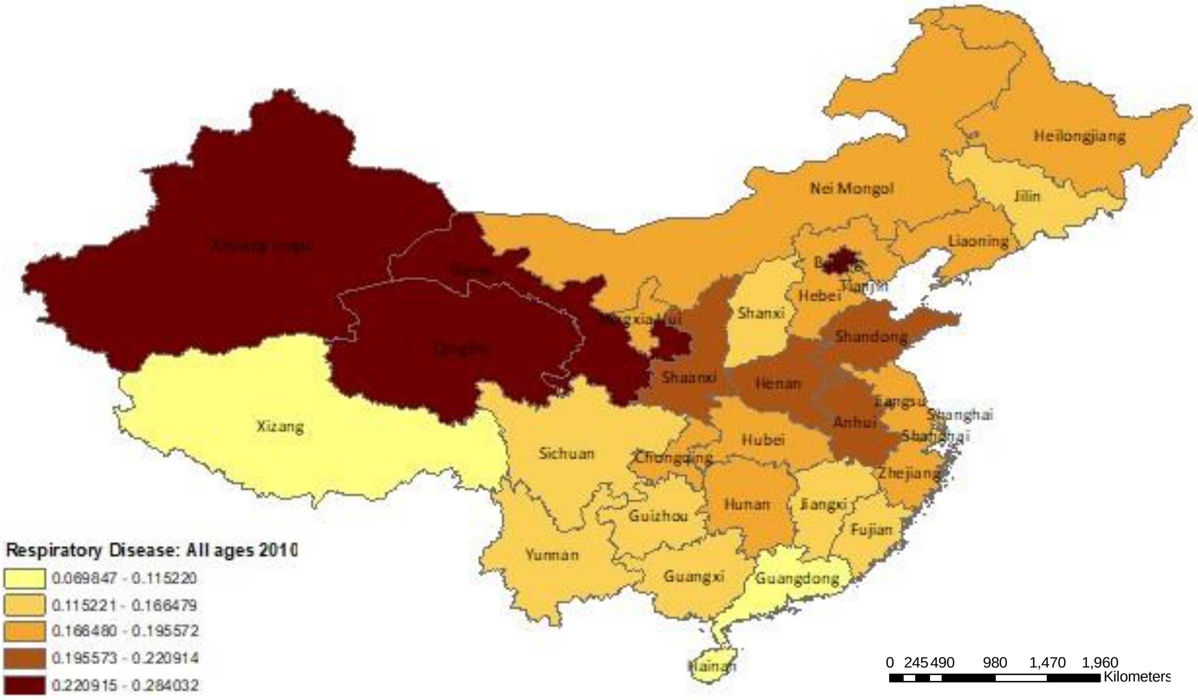


Figure C.10 PM2.5 associated deaths rates (Respiratory Diseases) across Chinese provinces (2010)

Source: Created by the author

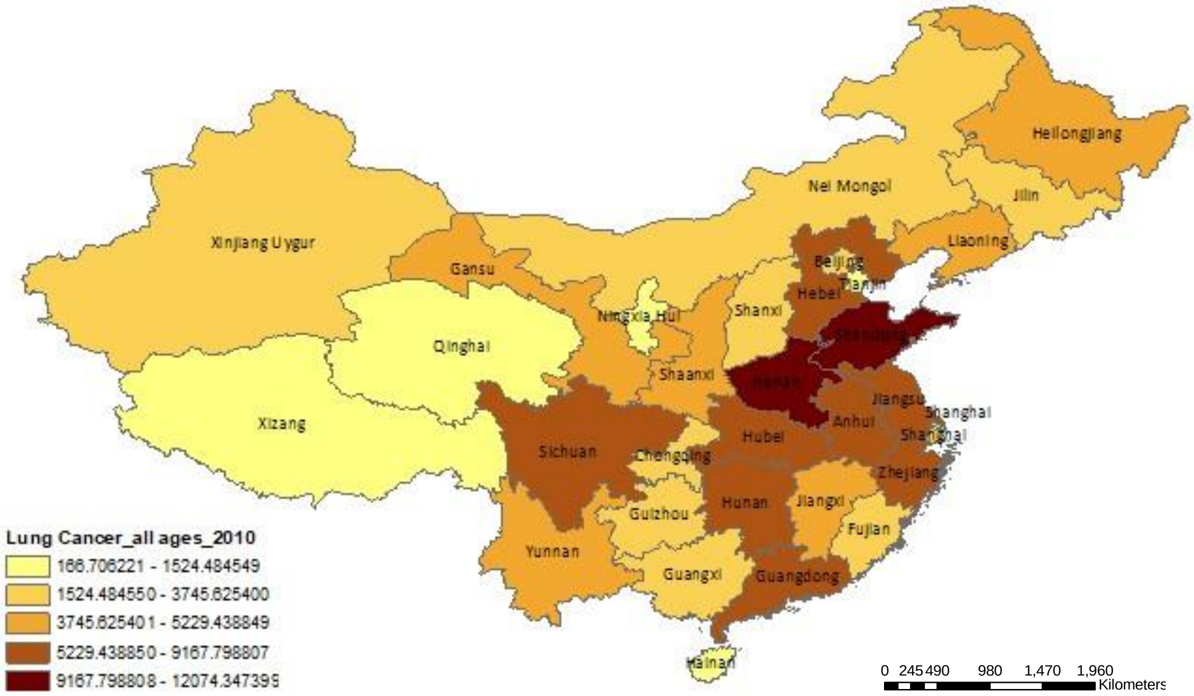


Figure C.11 PM2.5 associated deaths (Lung Cancer) across Chinese provinces (2010)

Source: Created by the author

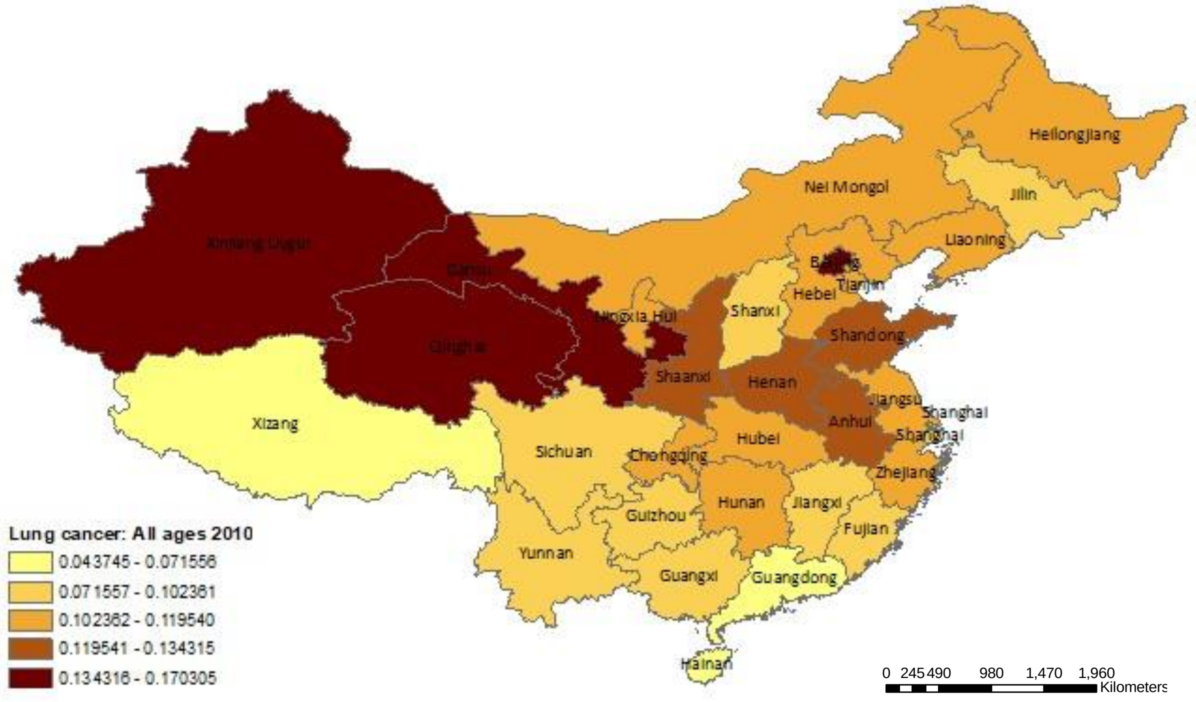


Figure C.12 PM2.5 associated deaths rates (Lung Cancer) across Chinese provinces (2010)

Source: Created by the author

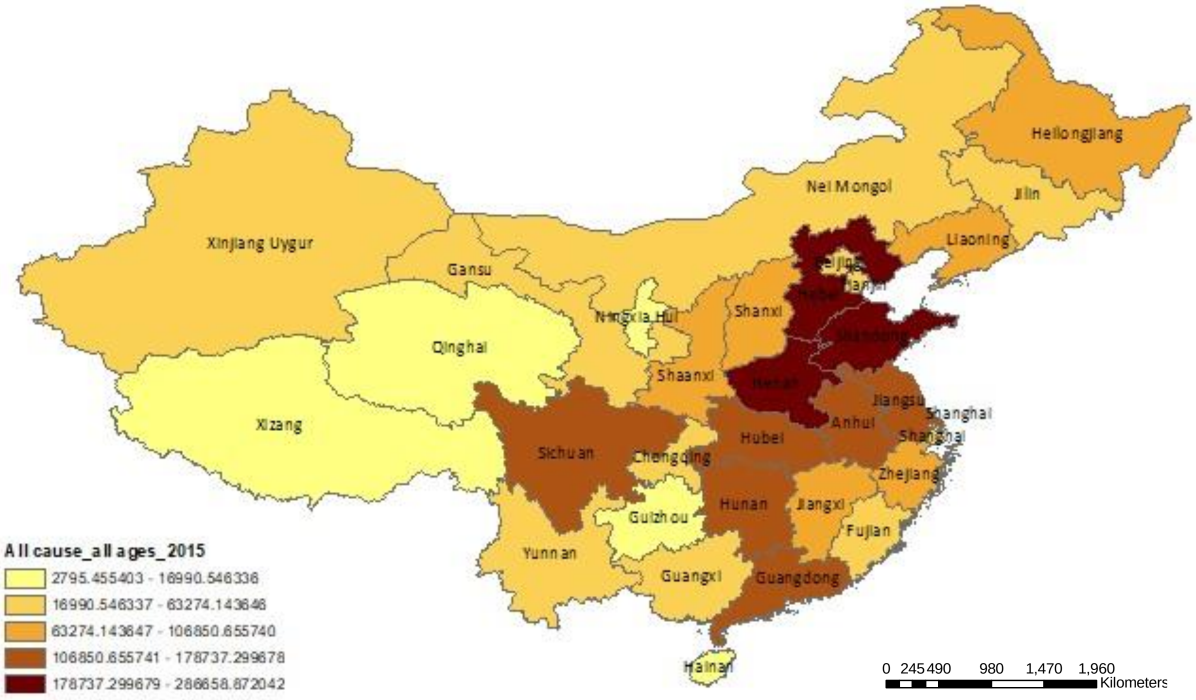


Figure C.13 PM2.5 associated deaths (all-cause) across Chinese provinces (2015)

Source: Created by the author

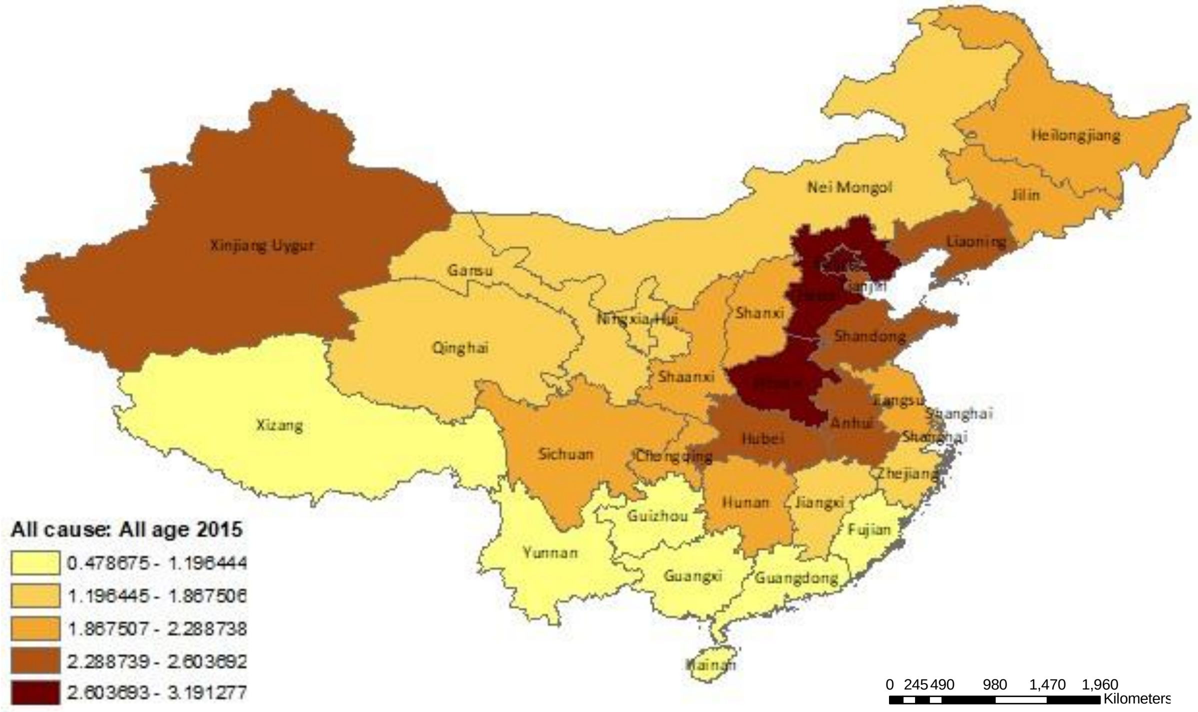


Figure C.14 PM2.5 associated deaths rates (all-cause) across Chinese provinces (2015)

Source: Created by the author

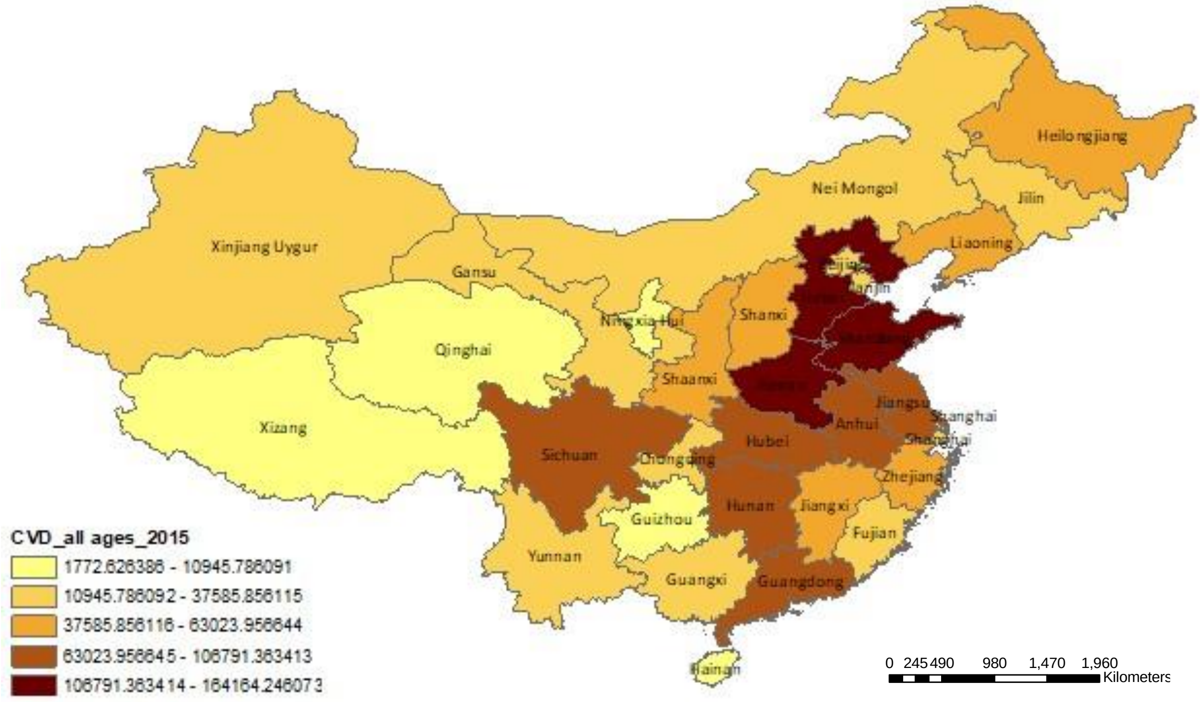


Figure C.15 PM2.5 associated deaths (CVD) across Chinese provinces (2015)

Source: Created by the author

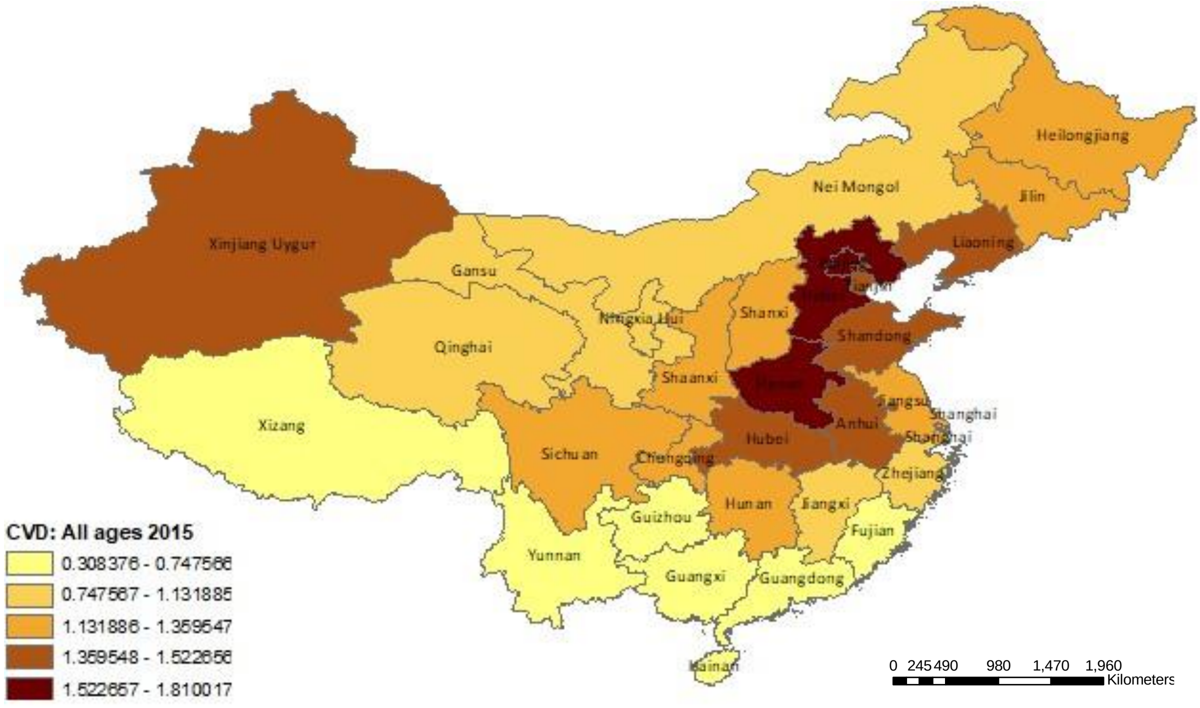


Figure C.16 PM2.5 associated deaths rates (CVD) across Chinese provinces (2015)

Source: Created by the author

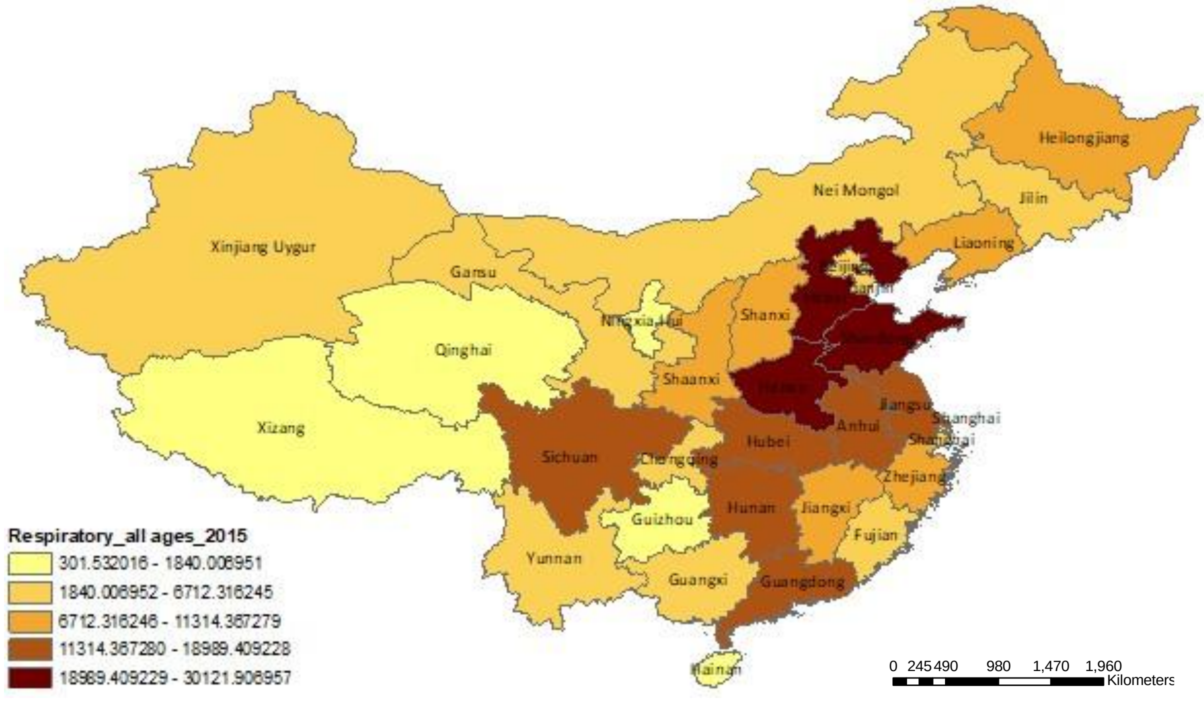


Figure C.17 PM2.5 associated deaths (Respiratory Diseases) across Chinese provinces (2015)

Source: Created by the author

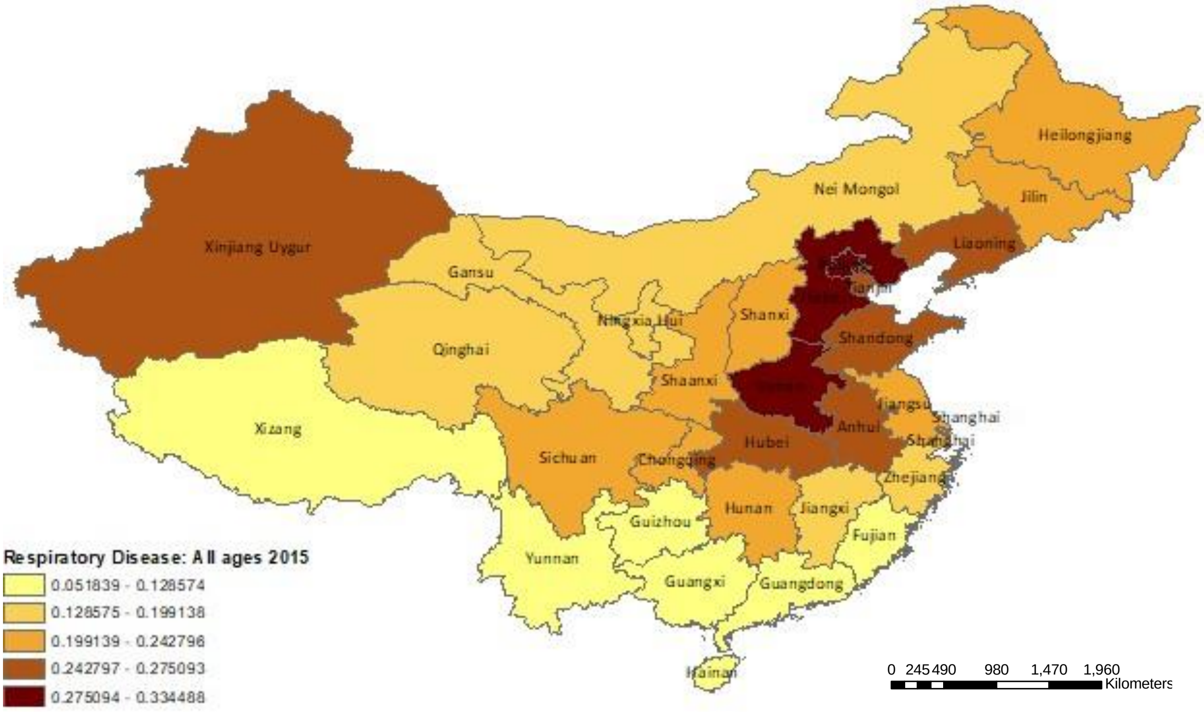


Figure C.18 **PM2.5 associated deaths rates (Respiratory Diseases) across Chinese provinces (2015)**

Source: Created by the author

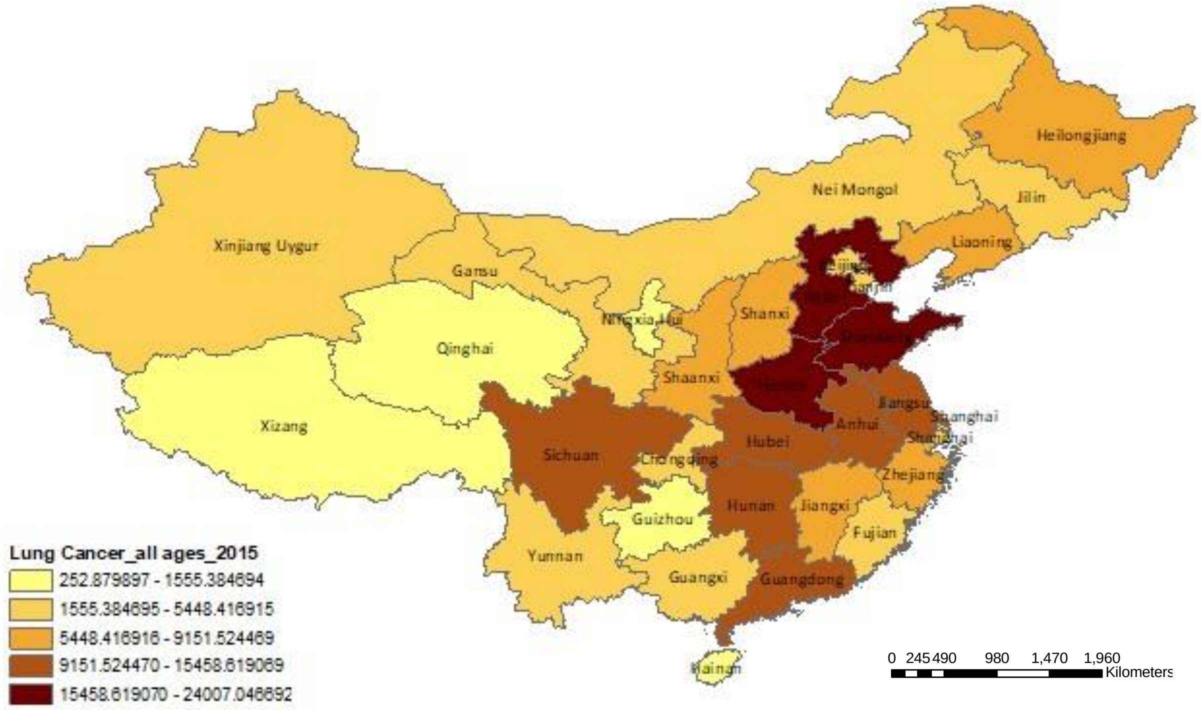


Figure C.19 **PM2.5 associated deaths (Lung Cancer) across Chinese provinces (2015)**

Source: Created by the author

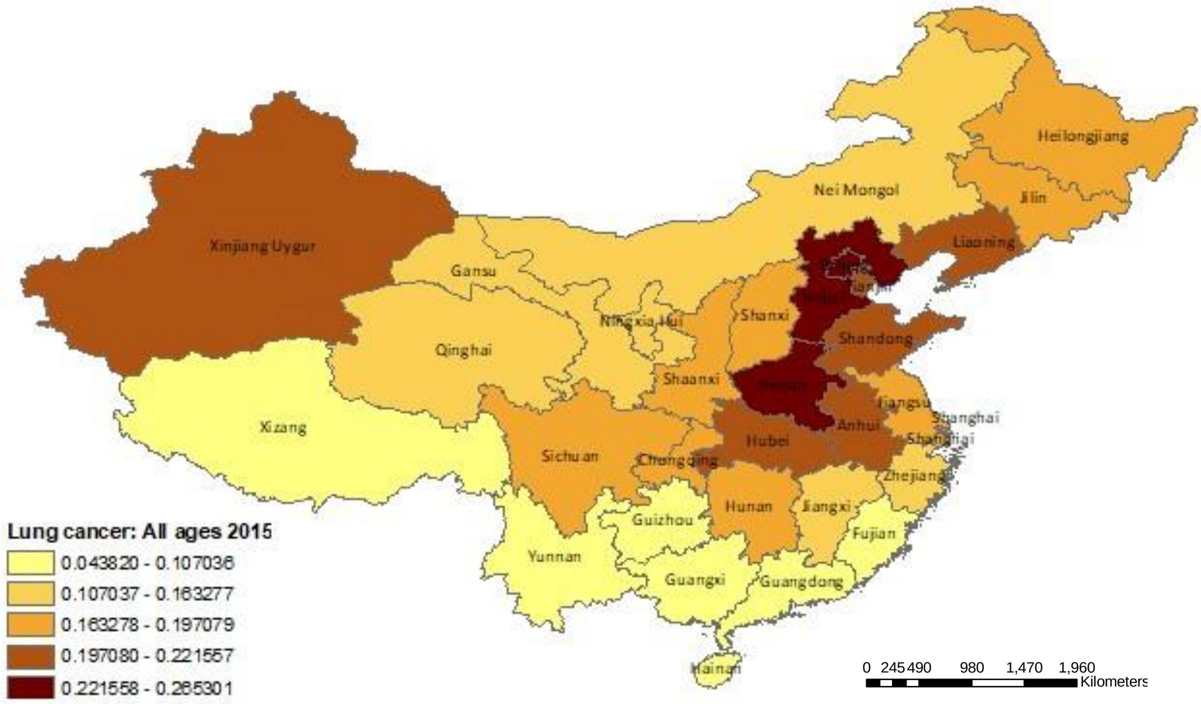


Figure C.20 PM2.5 associated deaths rates (Lung Cancer) across Chinese provinces (2015)

Source: Created by the author