CHINA'S ECONOMIC DEVELOPMENT AND SOFT TARGET ON HUMAN HEALTH: A MEDICAL GEOGRAPHY STUDY OF HAZE POLLUTION IMPACTS ON MATERNAL AND INFANT HEALTH IN XIANYANG 2008-2016

By

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ABSTRACT

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Since the adoption of economic reform in 1978, China has invested heavily in industry, commercial and residential construction, and transportation in the country. The rural-to-urban migration in search of economic opportunities has led to rapid sprawling of China's large and mid-sized cities. Outdated environmental policies and lack of strict regulation and control of harmful stationary and mobile sources of air pollution have led to high haze concentrations and growing public health concerns in China. As one of the most vulnerable population groups, as well as the core of every family, the public is concerned that haze will cause detrimental health effects on the people in general, and among pregnant women, mothers and infants in particular.

The goals of this dissertation research are to understand the history and evolution of Chinese environmental policies and to investigate the impacts of maternal haze exposure on maternal health and adverse birth outcomes in a mid-sized city in China. The objectives are (1) to review and summarizes the evolution of environmental policies and regulations from a structuralist perspective to understand the origin and persistence of rising haze in the country; (2) to utilize remote sensing imagery and ground monitoring sites, to conduct a haze assessment in Xianyang City, a mid-sized city experiencing rising levels of haze due to urban expansion and increased vehicle transportation and industrial emissions; and (3) to conduct an investigation of haze impacts on maternal and infant health in Xianyang City, utilizing a primary dataset of a sample of infants born at Shaanxi University of Chinese Medicine First Affiliated Hospital from January 2008 to

December 2016. A Human Ecology conceptual framework is used to understand the relationships among haze, maternal and infant health, and environmental and health policies.

The findings from this study showed even though China has a long history and rich variety of environmental policies and regulations, the hierarchical structure in the Target Pyramid System and the highly consistent party consciousness in the "One Position Two Jobs" system have limited government officials from enacting environmental protection to ensure public health. The effect of this limitation is demonstrated by observations of aerosol loading using satellite imagery, specifically the Ultraviolet Aerosol Index (UVAI) obtained from the Ozone Monitoring Instrument (OMI) carried by Aura satellite. OMI imagery data showed that Xianyang has experienced significant increasing trends in severity, duration, and coverage of haze from 2008 to 2016. In terms of public health, maternal exposure to increasing haze levels during the first and third trimesters had significant effects on lowering infant's birth weight. Maternal co-morbidities including Cardiomyopathy, Chronic Maternal Co-Morbidity, Diabetes, Gynecology, Hypertension and Obstetric Maternal Co-Morbidity mediate the haze exposure and reduced birth weight relationships. These findings demonstrate that chronic exposure to high dosages of haze has negative effects on mother's health, which in turn impacts infant health as evidenced by significant lowering of birth weight.

In conclusion, under the Chinese Communist Party's managing priority pyramid, maintaining the bureaucratic legitimacy of the party and pursuing economic development are Superior Target goals. However, to ensure population health, it is important to entitle public health and health care professional to receive authoritative power to provide environmental health education particularly for susceptible population groups such as pregnant women, mothers and infants about the untoward health effects of environmental pollution.

This dissertation is dedicated to every mother for bringing hope to this world.

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Last but not least, this dissertation is for the millions of ordinary people in (and out of) my field, whose sufferings and stories are my incentives to change this world.

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KEY TO ABBREVIATIONS

UVAI	Ultraviolet Aerosol Index
OMI	Ozone Monitoring Instrument
VOCs	Volatile Organic Compounds
SO_2	Sulfur Dioxide
NO_x	Nitrogen Oxides
CO	Carbon Monoxide
PM	Particulate Matter
AOT	Aerosol Optical Thickness
AQI	Air Quality Index
WTO	World Trade Organization
GDP	Gross Domestic Product
MEP	Ministry of Environment Protection
EPA	Environmental Protection Agency
CNEMC	Chine National Environmental Monitoring Center
AOD	Aerosol Optical Depth

AI	Aerosol Index
TOMS	Total Ozon Mapping Spectrometer
NASA	National Aeronautics and Space Administration
MODIS	Moderate Resolution Imaging Spectroradiometer
MLS	Microwave Limb Sounder
HIRDLS	High Resolution Dynamics Limb Sounder
TES	Tropospheric Emission Spectrometer
ESA	European Space Agency
GOME	Global Ozone Monitoring Experiment
WHO	Worldwide Health Organization
SGA	Small for Gestational Age
NGA	Normal for Gestational Age
LGA	Large for Gestational Age
ACME	Average Causal Mediating Effects
ADE	Average Direct Effects
AHA	American Heart Association
OA	Occiput Anterior

OP	Occiput Posterior
OT	Occiput Transverse
LOA	Left Occiput Anterior
ROA	Right Occiput Anterior
LBW	Low Birth Weight
VIF	Variance Inflation Factor

CHAPTER I

Statement of the Problem

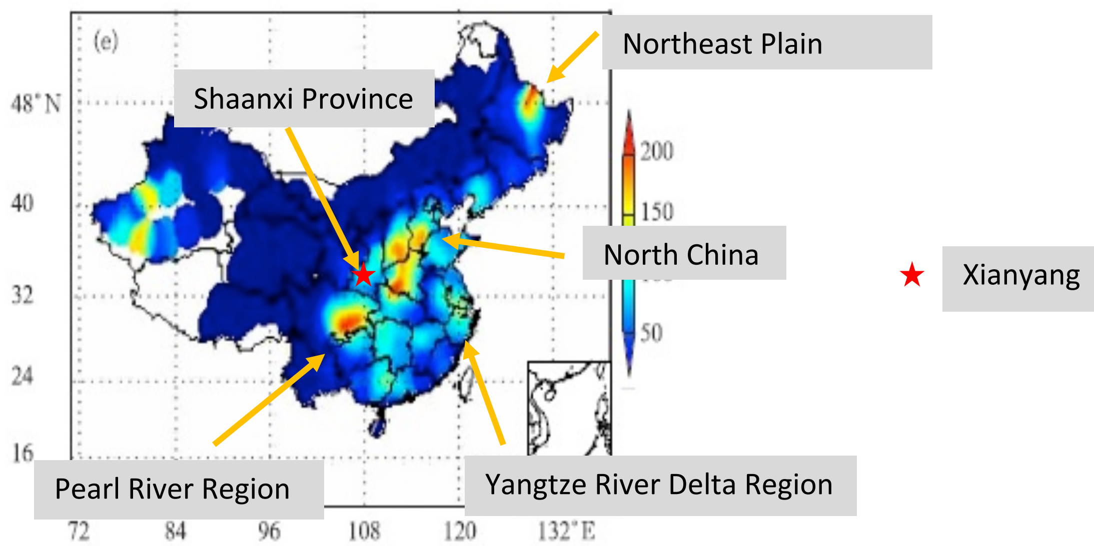
1.1. Introduction

Since the adoption of economic reform in 1978, China has invested heavily in industry, commercial, and residential construction, and transportation throughout the country. The World Bank (2019) national accounts data and OECD National Accounts data, show that China achieved a continuous average of 9.5% GDP annual growth over the past 39 years (1979~2018) and gradually became the second-largest economic country worldwide (World Bank, 2019). This rapid growth in economic development also greatly promoted the process of urbanization by attracting massive rural-to-urban migration seeking economic opportunities, which also led to rapid sprawling of China's large and mid-sized cities. For example, between 1978 to 2017, the urban population increased from 170 million to 810 million (376.4% increase), and urban rail transit systems were constructed and operated in an additional 31 cities, including Beijing (Ni, 2018).

However, outdated environmental policies and lack of strict regulation and control of harmful stationary and mobile sources of air pollution have led to extraordinarily high haze concentrations. Furthermore, there remains a complete lack of environmental health policies that has led to growing public health concerns in China. As one of the most vulnerable population groups as well as the core of every family, the public is concerned that haze will cause detrimental health effects among pregnant women, mothers, and infants. This study therefore addresses this growing concern of environmental and public health particularly among these susceptible population groups in China.

Ma et al. (2012) elegantly reported that the primary pollutants in China are carbonaceous aerosols, including carbon-based gaseous pollutants –e.g., volatile organic compounds (VOCs), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from coal combustion (~70% of energy consumed) (Ma et al., 2012) and biomass and fuel burning (Pui et al., 2014). Aside from ozone, all of these pollutants are anthropogenic –i.e., are largely produced and directly emitted by human activities, including coal combustion, gasoline and diesel emissions, and wood burning in residential activities (cooking and heating) as well as high temperature processes in industrial production (biomass burning in smelters, steel mills, and power plants) (Pui et al., 2014). Ozone is produced from the oxidation of hydrocarbons and carbon monoxide (CO) in the presence of NO_x and sunlight. New particles are formed from the mixture of aerosols and condensation of gases on pre-existing particles to create particulate matter (PM), chemically complex particles of 10 and 2.5 micrometers (mm) and ultrafine. In general, photochemical smog occurs in the presence of high atmospheric ozone and PM and lower relative humidity conditions. Haze fog also occurs in the presence of high PM but generally under higher relative humidity conditions at higher altitudes. It is not uncommon to experience both photochemical smog and haze fog in highly polluted regions and cities of China, including the Northeast Plain Region (e.g., Heilongjiang province) and megacity Harbin, the North China Region (e.g., Hebei province) and the megacities Beijing and Tianjin, the Yangtze River Delta Region (e.g., Jiangsu province) and the megacity Shanghai, and the Pearl River Region (e.g., Sichuan province) and megacities Guangzhou and Hong Kong (Ma et al., 2012; Wu et al., 2010). This dissertation research took place in Xianyang located in the central part of Shaanxi Province, which is directly west of North China and north of the Pearl River Region (Figure 1.1.).

Figure 1.1. Haze Fog Levels in Shaanxi Province and Other Polluted Regions of China.



Source: Wu, D., X.J. Wu, F. Li, H.B. Tan, J. Chen, Z.Q. Cao, X. Sun, H. H. Chen, and H. Y. Li. (2010). Temporal and spatial variation of haze during 1951-2005 in Chinese mainland. Acta Meteorologica Sinica. 68(5);680-688.

In January 2013, the first extreme haze outbreak occurred in China and lasted about one month and extended to a total area of ~2.3 million km^2 (An et al., 2019) with nearly 800 million people affected. This outbreak forced the central government to officially recognize for the first time the existence of haze as a problem in China. Then haze governance was prioritized in the 2014 annual "Report on the Work of the Government" delivered in the Twelfth National People's Congress, followed by a variety of legislative actions from central to local governments to mitigate haze accumulation, such as the "Air Pollution Prevention and Control Action Plan", traffic restrictions based on the license plate number, a license-plate lottery system, the temporary shut-down of heavy-pollution-related manufacturing facilities, and others (Jie et al., 2015). Eventually, in 2014, the average haze density for the top ten most heavy polluted provinces decreased 11.92% (Jie et al., 2015). However, the marginal effect of these actions was gradually offset by the unstoppable and increasing development agenda in China. The extreme haze event continued escalating in the following years. In 2015, 1.1 million deaths were believed caused by the long-term exposure to high levels of haze (Cohen et al., 2017). In December 2016, China experienced the worst strike of winter haze ever, which covered 1.42 million square kilometers and influenced 460 million people in 11 provinces (China News, 2016a). During this outbreak, a total of 61 cities issued air pollution alerts, including 24 cities that issued red (Class I) highest alerts, 21 cities orange (Class II) alerts and 16 cities yellow (Class III) alerts (China News, 2016b). The most detrimentally affected were cities with the density of $PM_{2.5}$ over 300 μg/m^3, compared to 24-hour mean 75μg/m^3 and annual mean 35μg/m^3 regulated by the Ministry of Environmental Protection (MEP), such as Xianyang City (December 2016: maxi 408 μg/m^3, min 38 μg/m^3, average 161 μg/m^3; January 2017: maxi 522 μg/m^3, min 38 μg/m^3, average 185 μg/m^3) (Zhenqi Wang, 2018). In Xianyang City, an emergency response to elevated haze was also initiated, which included closing all educational institutions, limiting the use of automotive vehicles by plate number and type, decreasing the number and areas that allowed vehicles on the roads, and encouraging the use of public transportation by reducing bus fees (China News, 2016c). In winter 2017, a large-scale haze episode occurred in central and north China with Xianyang City among the top 10 most highly polluted cities ($PM_{2.5}$:79.8 ug/m^3) (ranking 9th) (Greenpeace, 2018). In November 2018 and 2019, two severe haze episodes occurred in central and south China, including North China Region and Yangtze River Delta Region.

During these extreme haze occurrences however, relevant environmental health policy was completely lacking. The centralized power structure of the government determined that environmental health policy could be issued only if the central government recognized its importance and necessity. Also, the power hierarchy of executive departments further diminished the important association between the environment and public health. The Ministry of Finance is responsible for economic development and contains three ministries at the national level—the mission of the Ministry of Finance to oversee economic development, supersedes the role of the Ministry of Environmental Protection, which supersedes the role of the National Health and Family Planning Commission to protect public health. This political structure minimizes authoritative power within the public health system to advocate and manage environmental health. This observation is highlighted by the lack of environmental health education. At the provincial and city levels—the Shaanxi Province Ministry of Health and the Health and Family Planning of Xianyang City websites—no information on the long-term effects of haze, nor the risk(s) of haze on pregnancy health or infant health is available. Furthermore, while the Ministry of Environmental Protection provides daily haze reports on its website, there does not appear to be follow-up education for the public in general, and for pregnant women in particular on how to protect their health during high haze days.

Meanwhile, the development of health geography also lags in China. Due to the limitation of both haze data and health data, few if any studies have been conducted to examine the health consequences caused by haze in China. For haze data, neither a complete, mature protocol nor a public platform has been established by the government to collect, store, publish, and share real-time and/or historical haze data. For health data, national hospital networks/birth and death registration systems do not exist and all health information on hospital or emergency room or clinic visits are fragmented. In addition, most previous studies to our knowledge to-date, including in vitro or in vivo, have been conducted under two conditions: a) animal experiments to assess the impact(s) of short-period exposure to high-dosages of haze; and b) human studies to assess the impact of chronic exposure to low-dosages of haze. However, the most critical condition—the health impact of chronic exposure to high and low- dosages of haze—have been left out and not tested. The reasons are clear and obvious. The short life of mice limits the temporal span that can be tested, and it is unethical to endanger human subjects' health by intentionally exposing them to highly polluted air. Given to the extraordinarily high level of haze, China provides a rare opportunity for this study to find the last piece of the puzzle by studying the aftermath of extreme air pollution -i.e., chronic exposure to high-dosages of haze.

By overcoming challenges of various types, this research established an international collaborative partnership with a Chinese medical facility and collected a unique and highly valuable dataset of mothers who were exposed to varying levels of haze and their infant health outcomes. With the addition of the health data in this study, it will become know whether China's haze is capable of causing detrimental damage to the health of the next generation. The findings will also begin to address people's concerns by providing epidemiological evidence for translation it into health education for mothers, public health professionals and health care providers and especially environmental health policymakers in China. Furthermore, by identifying the mediating and moderating effects of maternal health conditions in the haze and birth outcome relationship, can also help to better understand the mechanisms by which health differences arise and provides more options for designing policy solutions. It is hoped that this study will enhance Chinese government's determination to win the battle of environmental protection, which will eventually ensure optimal maternal and infant and population health outcomes.

1.2 Research Goal and Objectives

The goals of this dissertation research are to understand the history and evolution of Chinese environmental protection policies and to investigate the impacts of maternal haze exposure on adverse birth outcomes in a mid-sized city of China. A sample of infants born at Shaanxi University of Chinese Medicine First Affiliated Hospital in Xianyang City from January

2008 to December 2016 is the focus of this study. The findings from this study on air quality and maternal and infant health can feed back to the establishment and application of improved environmental and public health policies in China.

To achieve this goal, this research has three objectives:

1. To understand the history and evolution of environmental policies and regulations in China and explore the impact of Chinese bureaucratic structures and authoritarian strategy on the establishment, development, and implementation of environmental protection policies.

2. To demonstrate the use of satellite products as a substitute for ground monitoring data to measure the haze compound and show the changes in haze in Xianyang Area. Ozone Monitoring Instrument (OMI) products -i.e., the Aerosol Optical Thickness (AOT) and Ultraviolet Aerosol Index (UVAI) are evaluated and validated with monthly ground monitoring Air Quality Index (AQI) and particulate matters (PM_{10}, $PM_{2.5}$) during the 2014~2016 time period (period-2) within Xianyang Municipality. Using the best OMI product, the monthly, seasonal, and annual trends in haze across Xianyang Area and Xianyang Municipality are measured during the 2008~2016, time period (period 1).

3. To estimate the direct impacts of maternal exposure to haze during different trimesters of pregnancy and overall pregnancy on birth outcomes (birth weight), controlling for maternal and infant level confounding. This objective will also examine indirect pathways –i.e., mediating maternal medical risks in the maternal haze exposure and birth outcomes relationships, controlling for maternal and infant level confounding. It is hypothesized that haze exposure will increase the likelihood of pre-pregnancy and pregnancy-related medical conditions, which will in part contribute to poor infant outcomes—in this study lower birth weight.

1.3. Dissertation Outline

This dissertation investigates the impacts of haze exposure during pregnancy on maternal and infant health outcomes. The dissertation is structured to begin with a description of the study area followed by the conceptual framework used in this study (Chapter II). Three research studies follow each addressing critical components of the conceptual model. First, the evolution of environmental policy in the Chinese government and bureaucratic barriers to the creation and implementation of effective and efficient environmental policies are presented to understand the political contexts of haze pollution and maternal and child health in Xianyang Area (Chapter III). Second, the spatial and temporal trends of haze pollution in Xianyang Area and Xianyang Municipality are presented between 2008 and 2016 using remote sensing imagery to measure long-term air quality (Chapter IV). Third, a sample of maternal records and birth outcome data are spatially joined to haze data to assess trimester level exposures on maternal and infant outcomes, controlling for potential confounding variables (Chapter V). These three research studies serve to bridge research in the fields of health geography, remote sensing, human-environmental interaction, and public and public health policies together to shed light on the new direction in the understanding of air pollution on public health, particularly haze on maternal and infant health, an area that has received scarce care, attention, and resources from the authorities of China—topics covered in the Discussion Section of this dissertation (Chapter VI). A Conclusions and Recommendations Section (Chapter VII) follows that provides insights into future directions of research and policy and practice to reduce haze pollution and empower women to improve maternal and infant health outcomes in China.

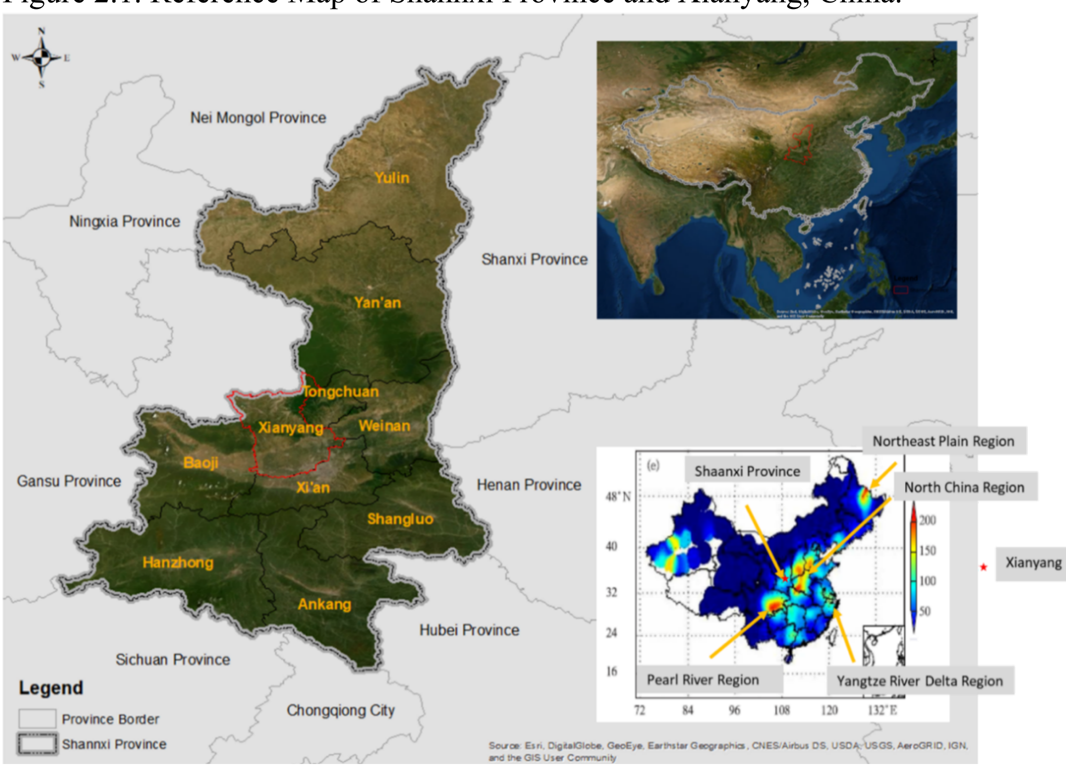
CHAPTER II

Research Background

2.1. Study Area

This dissertation research took place in the second largest economic region of China called Xinayang, in Shannxi Province (Figure 2.1.). Shannxi Province lies between northern highland China and southern mountain China and the topography can be divided into three regions with distinctive features: The Loess Plateau of northern Shannxi (Yulin and Yan'an), the Guanzhong Plain of central Shannxi (Baoji, Xianyang, Xi'an, Tongchuan, and Weinan), and the Qinling Mountain of southern Shanxxi (Hanzhong, Ankang, and Shangluo). Xianyang is located in the central belt of Shannxi Province (Figure 2.1.).

Figure 2.1. Reference Map of Shannxi Province and Xianyang, China.



Source: Base map source: Esri. DigitalGlobe. GEoEye, Earthstar Geographics. CNES/Airbus Ds. USDA. USGS. AeroGrid.IGN, and the GIS User Community; The shapefiles source: National Catalogue Service for Geographic Information (www.webmap.cn). Wu, D. et al. (2010). Temporal and spatial variation of haze during 1951-2005 in Chinese mainland. Acta Meteorologica Sinica. 68(5);680-688.

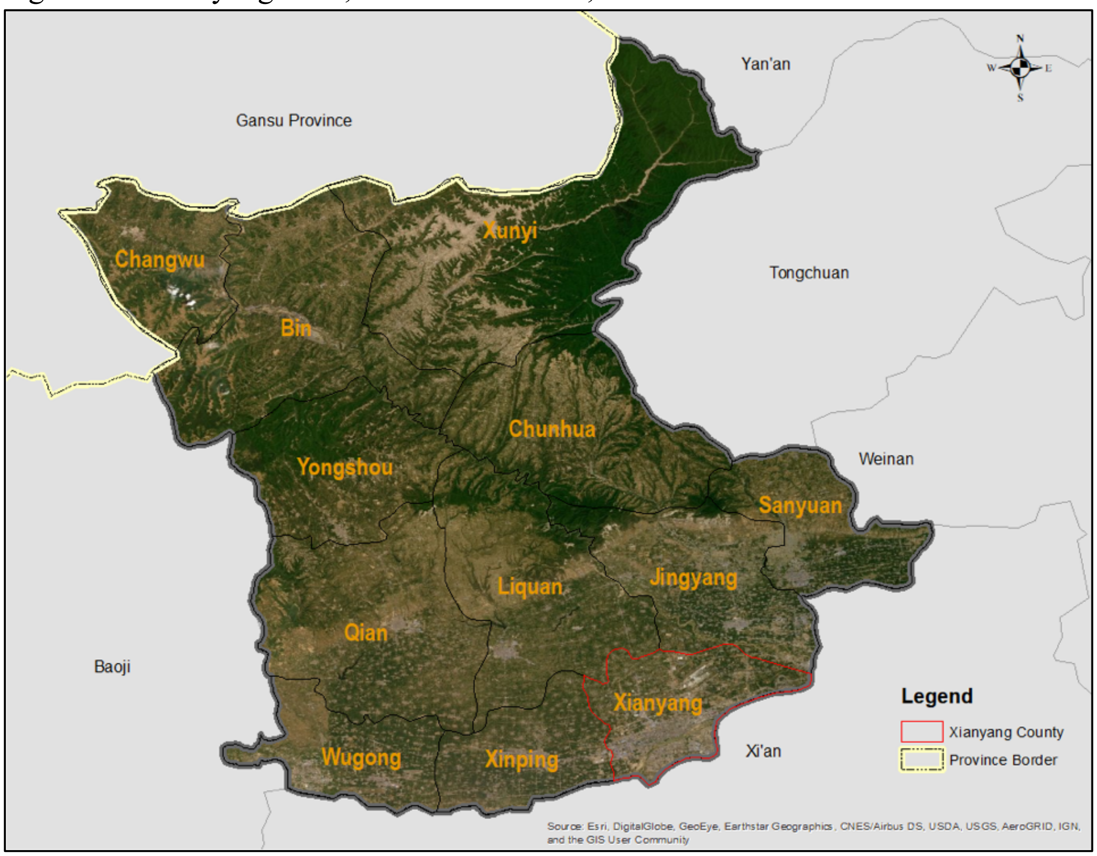
In this dissertation, Xianyang was studied at three scales: Xianyang Area (10,189.4 km^2), Xianyang County (528.2 km^2), and Xianyang Municipality (Xianyang Bureau of Statistics, 2013) (Figure 2.2.). Xianyang Area is located in the central part of Guanzhong Plain of Shannxi Province with highlands in north (Bin, Changwu, Chunhua, Xunyi, Yongshou counties) and the Wei River basin in the south (Jingyang, Liquan, Qian, Sanyuan, Wugong, Xianyang, Xingping counties). Xianyang Area is defined by culture and economics. It is the origin of Chinese history and culture, containing the first ancient capital of Qin Dynasty. The first immigrants were recorded in the Late Shang Dynasty, around 17^{th}-11^{th} century BC (China Culture, 2003). There are 4,951 historical sites which draws active tourism throughout the year (Xianyang Bureau of Statistics, 2013).

Xianyang Area is also one of the largest inner land transportation hubs bridging East and West China by intersecting 6 national highways and 9 railways (Xianyang Bureau of Statistics, 2013). During the Chinese National 12^{th} 5-Year Development (2011-2015) period, Xianyang government invested 37.694 billion Chinese Yuan (=$5.62 billion USD) in road construction (Xianyang Transportation, 2016). The development of transportation also stimulated the boom of industry within area, which eventually lead to the increased emission of industrial air pollution. According to reports from the Shaanxi Ecology and Environment Bureau (2019), the total emission of industrial smog and dust in 2012 was 15,684 tons, reaching its peak in 2014 (41,483 tons) (164.5% increase), with a small reduction in 2015 (35,353 tons) (14.5%).

The population in Xianyang Area is 4,972 million (2015) with an annual growth rate = 3.95 per 1,000 population. There were approximately 50,000 births each year within 151 general medical facilities (hospital and health stations) and 14 maternal hospitals (crude birth rate = 10.13 births per 1,000) (Xianyang Bureau of Statistics, 2013), which is slightly lower than the national crude birth rate=12.07 (World Bank, 2016).

Xianyang Area is thus, a growing industrial center within Shannxi Province that is experiencing population growth and urban expansion. The combined increase in vehicle transportation and industrial emissions has led to a rise in haze pollution—an observation noted in the hometown of the author of this dissertation. Her concern for the welfare of mothers and infants in Xianyang exposed to such haze led to a focus on this study area.

Figure 2.2. Xianyang Area, Shannxi Province, China.

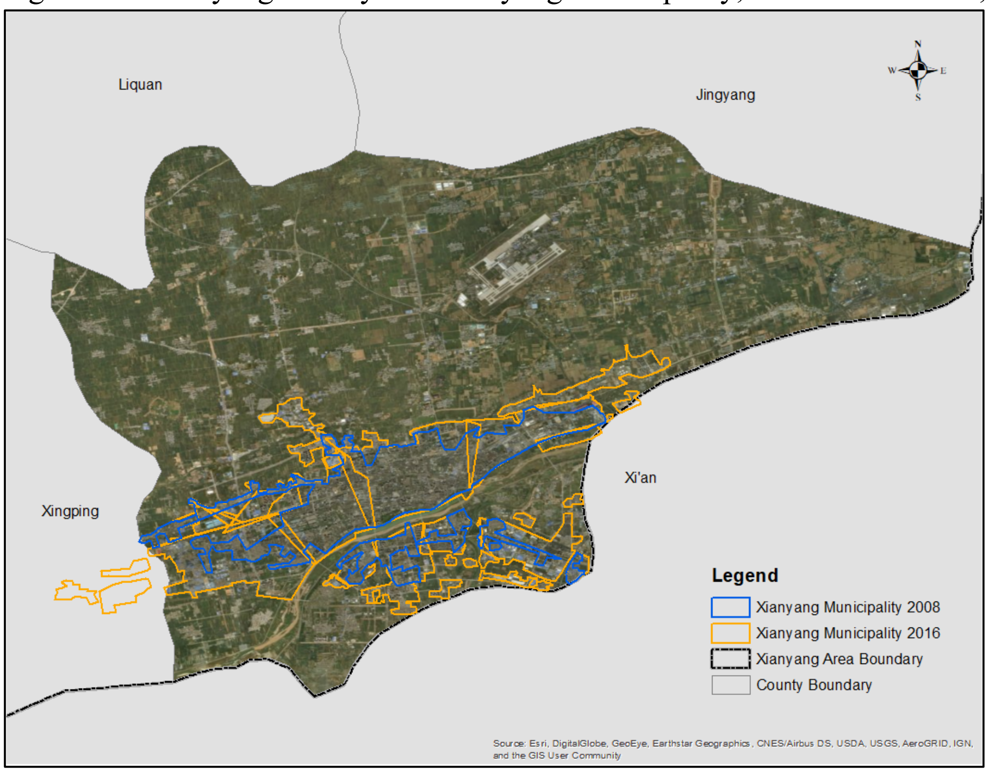


Source: Base map source: Esri. DigitalGlobe. GEoEye, Earthstar Geographics. CNES/Airbus Ds. USDA. USGS. AeroGrid.IGN, and the GIS User Community; The shapefiles source: National Catalogue Service for Geographic Information (www.webmap.cn).

Xianyang county contains rural areas in the north and an urbanized area (Xianyang Municipality) in the south (Figure 2.3.). Xianyang county is the geodetic center of China. It also contains the only international airport in Shannxi Province, Xi'an-Xianyang International Airport.

Xianyang Municipality's boundaries have changed over time due to urban expansion. In particular, the west boundary has extended into neighboring Xingping County. Xianyang Municipality is situated within the southern basin area with the Weishui River passing through, which is surrounded by a northern highland area and southern Qinling Mountain area. It also is adjacent to the only metropolitan city, Xi'an Municipality, the capital of Shaanxi Province. The climate is continental with 537~650 millimeters (mm) rainfall per year and average temperatures between 9 ˚C~13.2 ˚C. (Shi et al. 2013).

Figure 2.3. Xianyang County and Xianyang Municipality, Shannxi Province, China.



Source: Base map source: Esri. DigitalGlobe. GEoEye, Earthstar Geographics. CNES/Airbus Ds. USDA. USGS. AeroGrid.IGN, and the GIS User Community; The shapefiles source: National Catalogue Service for Geographic Information (www.webmap.cn); The Xianyang Municipality is manually drawn on the basis of historical images (2008~2016) from Google Earth Pro.

2.2. Conceptual Framework

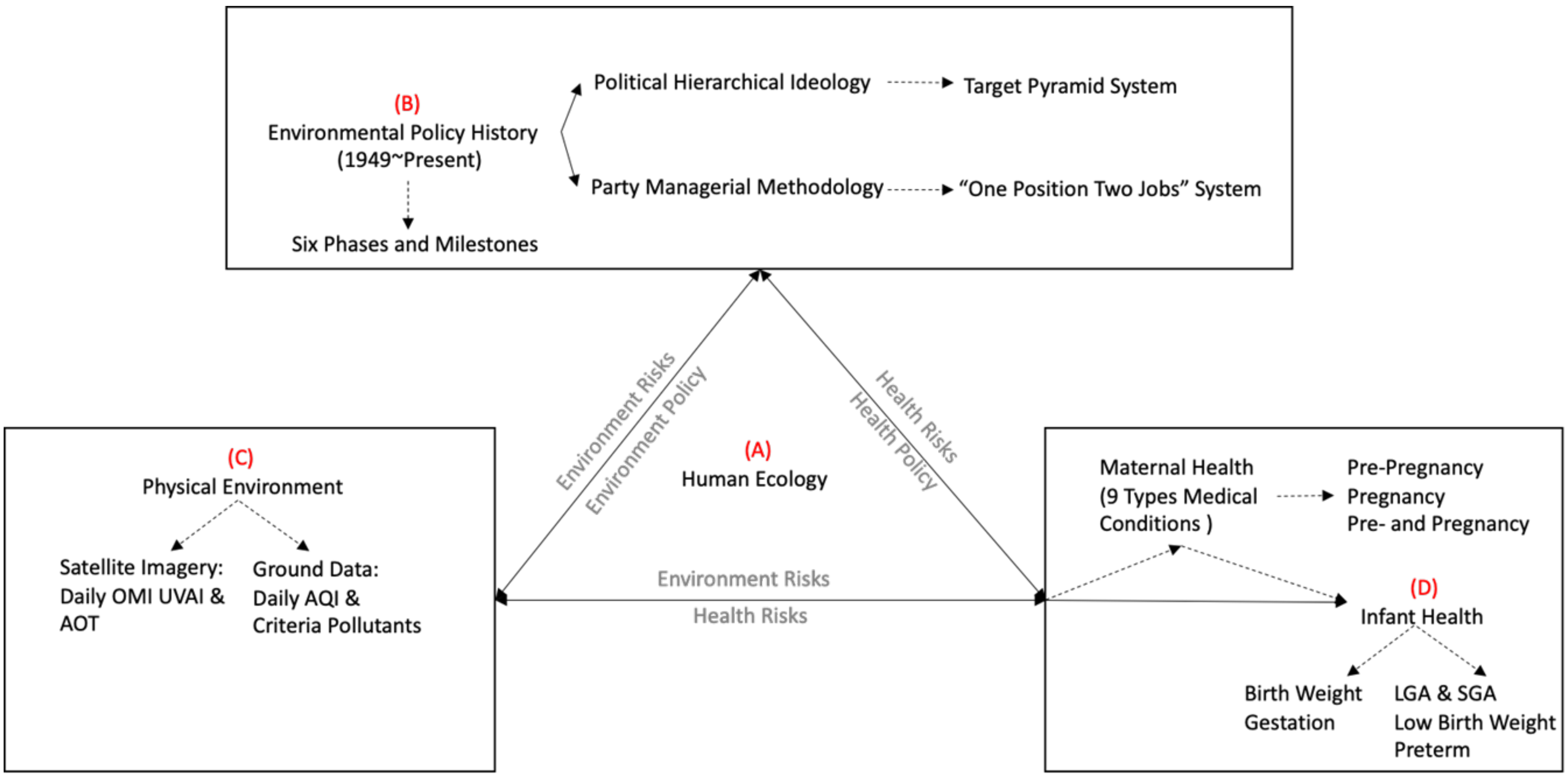
A Human Ecology conceptual framework is used to understand the relationships between the physical environment (haze) and maternal and infant health and their feedback role of improving Chinese environmental and health policies (Figure 2.4.).

Learning the effects of cultural behavior, mostly governmental policies, sheds light into the structural barriers that diminish the efficacy of environmental protection and human health protection while assigning responsibility for governmental agencies that are responsible for the poor air quality. The hierarchical structures in party ideology and political methodology are studied through the lens of structuralist theory (Figure 2.4-B) to explain 1) How Chinese Communist Party's target pyramid system determine the importance of environment protection, 2) How the authoritative structures in administrative supervision and evaluation diminish the levels of influence to regulate air quality and communicate the health risks from haze to the public, and 3) How the double-identity system infiltrate the daily life of and shape the behavior of every social entity. Authoritative action(s) to address the health needs of pregnant women and the next generation of newborns and children is a particular concern that is not widely discussed in the literature. Economic transformation brought on by economic development and the privatization of industry, residential and commercial construction, and transportation resulting in poor air quality seems to be at odds with ensuring a healthy population as will be shown in this study. There is also a need to investigate that if these structures respond and air quality is improved then what the time frame within which the incidence of adverse birth outcomes declines. With this knowledge, there will be stronger evidence of the need to enact environmental policies that protect people in general, and mothers and newborns in particular.

Within this theoretical framework, a positivist approach in health geography was utilized to investigate (a) the spatial and temporal association between haze and maternal and infant health outcomes; and (b) the mediating theory that examines maternal medical conditions as an intermediating pathway by which haze impacts infant birth weight (Figure 2.4-D). The contextual effects were explored through the lens of geographic health inequality (place: city vs. village), while the compositional effects of individual-level risks (maternal haze exposure amount) were studied by analytical regression modeling. Meanwhile, the mediating pathway effects of maternal medical conditions resulting from haze exposure at different trimesters of pregnancy and overall were identified to demonstrate the importance of improving air quality –i.e., to improve maternal health in addition to focusing solely on infant health outcomes.

In recognizing the dual effect of socio-economic-political structure and biomedical uniqueness of human agency, it is important to understand the causes of the health injustices and inequality experienced by mothers and infants –susceptible population groups in China. Health inequality generally refers to the differences between groups despite the causes (Arcaya et al., 2015). Economic inequality determines the uneven allocation of economic benefits to social entities, especially the bi-directional extremization of economic groups between urban area and rural area. In order to avoid declining into poverty, people are forced to abandon their lands and move to urbanized area pursuing more monetary opportunities. Under the influence of this macro-economic inequality, the micro-economic inequality caused by biological disadvantages can be observed in maternal and infant health. The unique biological structure of being female decides that compared to men women have to endure extra risks of ensuring reproductive health and carrying and producing the next generation. The physical immaturity determines the vulnerability of the newborns. In this case, first producing power are not influenced, which also means prioritized economy and the privilege of social structures remain unchanged. Meanwhile, not being first producing power in the economy determines the disadvantaged positions of maternal and infant groups in the political structure. That also aggravates their health inequality without policies to protect them. Moreover, unlike infectious disease or acute disease that can instantly cause intensive social panic and draw massive attention, the effects of haze on maternal and infant health can be nuanced, hard to isolate, easily distorted, and unrevealed only in the long term. Therefore, it is not surprising to see that policymakers in neither environmental protection nor in public health acknowledge the necessity and urgency of establishing environmental health policy for maternal and infant health in China. This study will address this inequity to promote and ensure the health of the people of China.

Figure 2.4. Theoretical Framework Human Ecology.



CHAPTER III

Environmental Policy Assessment in China: Historical to Present

Abstract

This study conducted a chronological review of environmental policies and regulations in China to understand the persistence of the deteriorating environmental quality in the country. While a long history and rich variety of Chinese environmental policies and regulations were found on paper, these national strategies need to be further understood through the lenses of the Target Pyramid System and the "One Position Two Jobs" System. In summary, under the Chinese Communist Party's managing priority pyramid, maintaining the bureaucratic legitimacy of the party and pursuing economic development and social stability are still the most important national goals. Public health and health care professionals have little authoritative power to protect the public from the untoward health effects of chronic exposure to high dosages of environmental pollutants. China would benefit from elevating authoritative power and freeing the voices of public health and health care professionals to promote environmental health education within local administrations as well as across the entire society.

Keywords: Environmental pollution, Public health, Policy history, Political target pyramid, Environmental cadre evaluation, One Position Two Jobs, China

3.1. Introduction

Air pollution is one of the most serious environmental health risks in the world today, contributing to approximately 7 million premature deaths per year (IQAir, 2019). While China Mainland (2018) ranked 11th among the most polluted countries of the world as defined by average annual airborne particulate matter ($PM_{2.5}$) concentrations (39.12 µg/m^3), it had 48 of the top 100 most polluted cities in the world (IQAir, 2019). The 10 countries with higher concentrations of pollutants were Iraq (39.60), Uzbekistan (41.0), Nepal (44.46), Bahrain (59.80), Indonesia (51.71), India (50.08), Afghanistan (58.80), Mongolia (62.00), Pakistan (65.81) and Bangladesh (83.30). Air quality is challenged by China's reliance on coal as part of its energy mix (BP Statistical Review of World Energy, 2019) and diesel emissions from transport (International Council on Clean Transportation, 2019) both sources of which also pollute China's water and soils. In 2019, only 2.0% of 400 Chinese cities (n=8) achieved the World Health Organization's (WHO) annual PM2.5 target of <10µg/m^3 (WHO, 2016), while 53.0% of cities (n=212) met China's own less stringent annual target of <35.0 µg/m^3 (Zang and Samet, 2015).

This study investigated the history and factors underlying the persistence of deteriorating environmental quality in China today by 1) chronologically reviewing and summarizing the evolution of the country's environmental policies and regulations; 2) examining environmental pollution through the lenses of the Target Pyramid System; and 3) discussing the government's managerial strategies, the "One Position Two Jobs" System. The study discusses the findings within the context of public health and health care governance to inform population health. Finally, recommendations for future research and interventions to address China's environmental pollution are provided.

3.2. Materials and Methods

This review and assessment of China's environmental policy began with a literature review using the key terms "China Environmental Protection Policy", "China Haze Policy", "China Environmental Policy", and "China Air Pollution Policy". Other policy related articles were identified from these articles' references to ensure quality and reliability. In addition, the same keywords were used to find articles from news resources, including Chinese national news media. Policy documents from the Chinese Communist Party's websites were also obtained to further study the temporal trend in environmental policies.

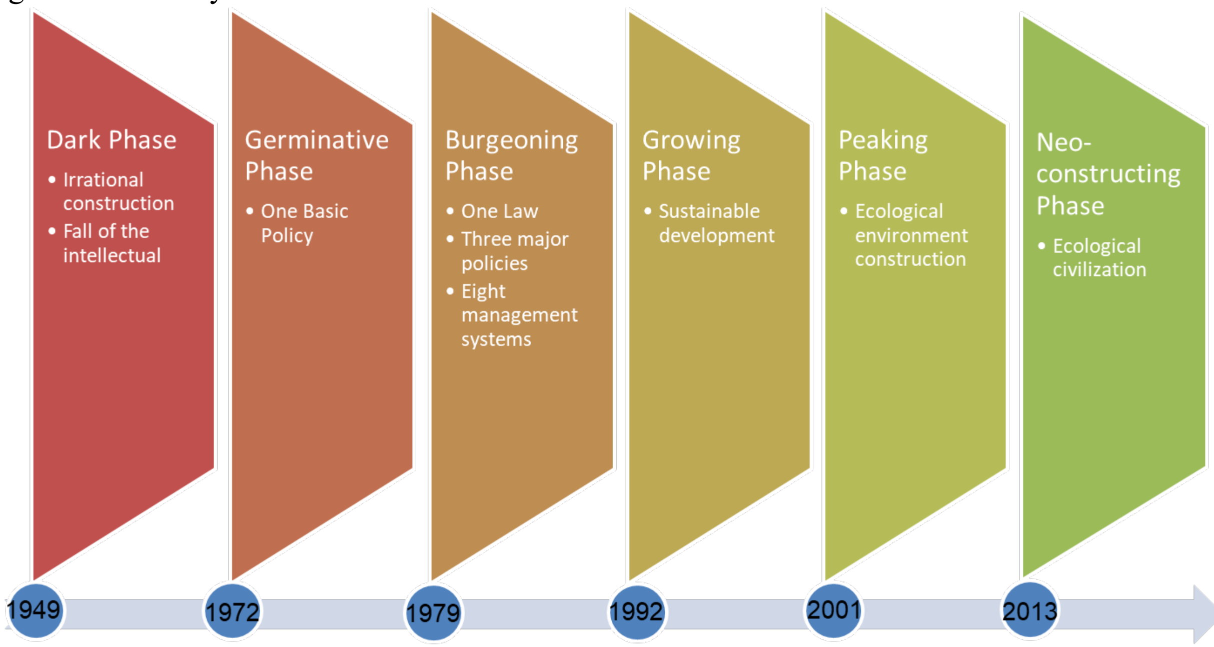
An expert summary on the development of environmental protection policies were segmented based on the outstanding changes in Chinese governmental history. Each segment summarized the major contributions in environmental policies, laws, and executive facilities. Additionally, the associated environmental problems and factors underlying were discussed. The discussion on the barriers to environmental protection led to further understanding of China's managerial organizational structure as well as political strategies. To better understand the relative association between environmental protection and other political targets, a Target Pyramid System was used to illustrate the hierarchy of political priorities in Chinese bureaucracy. Finally, a managerial strategy involving double identities (One Job Two Positions) was examined from the perspectives of legislation, jurisdiction, media, and the health system.

3.3. Results

3.3.a. Evolution of Environmental Policies and Regulations in China

The evolution of China's environmental policies and regulations can be best explained by six milestones in its history beginning in 1949 with the establishment of the People's Republic of China (Figure 3.1.) and ending with the current administration today.

Figure 3.1. History of Chinese Environmental Protection Policies.



Milestone 1 – The Dark Phase (1949-1971): Irrational Construction and the Fall of the Intellectuals

After the People's Republic of China declared its establishment in 1949, the nation was in profound need of reconstruction and recovery following a century of war, conflict, and chaos (1840 [First Opium War] ~1949). China's economy at that time was based on agriculture, with industry lagging behind the public's increasing material needs. With the establishment of the People's Central Government and local governance, a series of actions escalated industrial production, such as the “Great Leap Forward” and “Emulating Da-Zhai on Agriculture” (Liu, 2011; Wang et al., 2019). The “Great Leap Forward” was a national action that originated from the personal fanaticism of the Chinese leader, Chairman Mao Zedong, aiming to rapidly increase agricultural food production and industrial production of goods for consumption, at the cost of massive deforestation and extraction of mineral resources. A rise in private small-scale industrial refineries with outdated equipment and managerial strategies escalated the destruction of the natural environment. At the same time, the byproducts, “three wastes” (wastewater, waste gas, and solid waste) of steelmaking were released into the environment without the expectation of post-processing or post-cleanup (Zhang, 2010). Chairman Mao’s action of “Emulating Da-Zhai on Agriculture” exponentially increased annual food production in response to increasing poverty, thereby sacrificing additional forests, grasslands, and waterbodies rather than exploring innovative technologies (Liu, 2011). Innovation was limited during the rise of the “Cultural Revolution” in 1966 by the oppression and systematic arrest and execution of scholars with advanced training in academic subfields and technologies, including environmental protection. The loss of educated elites made it impossible to incorporate parallel environment protection to attenuate the waste produced in this phase.

Milestone 2 – Germinative Phase (1972~1978): One Basic National Policy

Following the Maoist period, Prime Minister Zhou Enlai led China into an enlightenment period of environmental protection. He dispatched 40 government representatives from national critical fields to attend the United Nations Conference on the Human Environment in Stockholm, Sweden, in June 1972 (Qu, 1999). Here, China learned of theories and strategies from Western countries’ environmental protection experiences. The final conference report presented to Zhou showed that pollution in China’s growing urban areas in particular, was more severe than in

Western countries and the ecological destruction in rural areas was worse. This report concluded that environmental pollution was a critical and growing problem with immense potential negative impacts on economic development (Wang et al., 2019). This report prompted Zhou to initiate the First National Environmental Protection Conference the following year, 1973, in Beijing. During this conference, the first political document on environmental protection in China titled *Several Regulations on Protect and Improve Environment* (1973) was issued (Zhang, 2010). It highlighted the need for governmental leaders to add oversight of environmental protection to all levels of government, within the scope of their responsibilities. In October 1974, China's First environmental governance leading group, the China State Council Environmental Protection Leading Group, was established to expand local environmental protection branches throughout the country (Xie, 2019). Environmental protection was incorporated into the Constitution of the People's Republic of China and the "Four Modernizations," a strategy to increase economic development in four areas—agriculture, industry, science and technology, and defense.

However, outside of national policy and the commitment of the leaders within the People's Central Government, the local branches of government were limited in their authority to manage activities due to a lack of complete regulations, executive powers to enforce compliance, and professional knowledge of and training on environmental protection. Moreover, unlike Western countries that created environmental policies and regulations based on Industrial Revolution experiences, China still had an agriculture-centered structure of production with unique environmental problems left over from the Dark Phase. There was no transition or time for policymakers and environmental specialists to study Chinese environmental issues and develop a unique set of regulations before China entered into its first economic take-off. In December 1978, during the meeting of the Third Plenary Session of the 11th Central Committee of the Communist

Party of China, government leaders decided to introduce economic reform and opening-up of private investment(Xie, 2019).

Milestone 3 – Burgeoning Phase (1979~1991): One Law, Three Major Policies, Eight Management Systems

In 1979, Prime Minister Deng Xiao Ping selected Shenzhen and 14 other coastal plain cities as the first economic zone to accept international investment (Xie, 2019). With the establishment of this special economic zone, production in southern China shifted from heavy industry controlled by the government to labor-intensive industrial production owned and regulated by private manufacturers. Within a short period, the startup of small-scale factories grew exponentially, and still without effective pollution regulations and a like in the previous era, pollutants from these industries were freely released into the environment.

Facing such environmental emergency, a growing number of environmental policy makers within the People's Central Government worked to catch up with the pace of economic growth, reacting to the rising need action by forming frameworks of environmental protection in three governmental sectors: law, human resources, and policy. In 1979, the First environmental law, titled *Environmental Protection Law of the People's Republic of China,* was issued to promote environmental protection at all governmental levels -i.e., from the People's Central Government to local branches within and outside of the economic zone (Zhang, 2010). As one of the milestones in Chinese history, this law highlighted a shift in environmental protection from a political call to judicial regulation, creating the foundation for the development of an environment protection law system. In addition, it created standards for environmental impact evaluations, regulations, and fines.

In May 1982, the 23rd meeting of the Fifth National People's Congress Standing Committee created the Ministry of Urban and Rural Construction and Environmental Protection by integrating the National Construction Committee, National Urban Construction Bureau, National Construction Bureau, National Bureau of Surveying and Mapping, and the State Council of Environmental Protection Leading Group. In 1988, the National Bureau of Environmental Protection was separated from the Ministry of Urban and Rural Construction and Environmental Protection as an independent department under the direct supervision of the State Council, which had its own intellectual, financial, and material resources (MEE, 2020). The Bureau of Environmental Protection assumed responsibility for civil service reform by adding positions to oversee scientific and technical requirements for environmental protection. This laid the foundation for technical assistance and professional management in national environmental protection (Xie, 2019).

In April 1989, the Third National Environmental Protection Conference was held in Beijing, which had a fundamental effect on further building of the environmental protection system (Qu, 2013). This meeting brought the concept of "environmental governance". Unlike traditional environmental management based heavily on laws and executed solely by the People's Central Government, environmental governance emphasized the importance of participation of multiple subjects, including the leading role of local government, the assisting role of private enterprises, and the monitoring role of the public. This led to the formalization of an environmental policy system, "Three Major Policies and Eight Management Systems," at all levels of government (Qu, 2013).

Despite these efforts, the focus of the People's Central Government was still target driven, with the assumption that additional oversight regulations (on the amounts of pollutants emitted) and increasingly severe punishment would be enough to control pollution levels. Less emphasis was given to the polluting end-pipe of polluting factories themselves, such as the quality of the coal used, or whether factories installed waste/pollutant-post-clean machinery. The speed of economic development continued to exceed the monitoring and implementation of environmental protection policies and regulations; thus, air, water, and land pollution continued to increase.

Milestone 4– Growing Phase (1992~2000): Sustainable Development

Due to the economic success in the coastal plain cities, in 1992, the economic reform and opening-up of private enterprises escalated by expanding to larger regions and towards cities in the interior of mainland (Xie, 2019). Meanwhile, the conflict between economic development and environmental protection became increasingly evident as massive ecological damage, deforestation, appropriation of farmland, and continued high levels of emissions continued. Environmental pollution in this phase started to adversely impact social stability as the public witnessed and experienced the severity of the pollution. To respond, the People's Central Government began to identify new pathways to alleviate this stress and bring balance back into society.

In 1992, the United Nations held the Environment and Development Conference in Rio de Janeiro, Brazil, and introduced the concept of "sustainable development". Chinese central governmental leaders were inspired by this concept and believed it could fit into the ideology of socialism with adaptations for China. Two months later, the central government issued "Ten Strategic Policies for Environment Development" to advertise "sustainable development" as its promotional slogan (Wang, 2010). Furthermore, in 1994, the State of Council, acting under Prime Minister Jiang Zeming's authority, drafted a detailed strategic plan called "China's Agenda 21" about how to fully develop and apply sustainable development in all levels of governmental activities (Wang, 2010). Environmental protection in this period focused primarily on controlling the total discharge volume of pollutants by selectively approving new construction projects. Pollutants emitted by new projects had to be offset by the cancellation or the shut-down of prior projects (Xie, 2019).

During this period, the central governmental leaders believed they had found a way to address the conflicts between economic development and environmental protection needs. By promoting “sustainable development”, environmental issues were integrated into the framework of economic development and no longer viewed as a conflicting agenda, but rather the stimulus to modernization.

Milestone 5 — Peaking Phase (2001~2012): Ecologic Environmental Construction

After nearly two decades of rapid development in economic reform and opening-up, China joined the World Trade Organization (WTO), which provided access to international markets and advancd gross domestic product (GDP) growth in both the heavy chemical and light manufacturing industries. However, the exponential increase in pollution was an unanticipated side effect of this opportunity.

This led to an updated version of “sustainable development,” called “Ecological Environmental Construction,” brought forth by the central government under the leadership of Prime Minister Hu Jintao. It aimed to build a “natural-resource-conserving and environment-friendly society” (Wang et al. 2019). The Sixth and Seventh National Environmental Protection Conferences confirmed the importance of building an ecological environmental society via the pathway of “actively seeking protection within economic development and developing economy within environmental protection” (Wang et al. 2019).

The pressure to build ecologic environments was stronger than ever, thus the central government initiated stricter regulations on the total allowable amount of pollutants. In the 11th Five-Year Planning Period (2006-2010) (Traditional Chinese Five-Year Plans beginning 1953-1957 to the present, focusing on social and economic development initiatives), extensive efforts were applied in "structural emission reduction, constructional emission reduction, and managerial emission reduction" (Wang et al. 2019). Structural emission reduction would control total discharge volumes of certain pollutants, while constructional emission reduction would control approval of new construction projects. Managerial emission reduction was another critical revolution during this period as it now became a "hard target" (Wang, 2013). Managerial emission reduction meant that administrative leaders' performance assessments would in part be based on restricting pollutants to target thresholds.

Meanwhile, the political structure of environmental management changed from being decentralized (Milestone 3 Burgeoning Phase) to centralized (Milestone 4 Growing Phase) and back again to decentralized with the intent of holding each level of government accountable. In 2008, the National Bureau of Environmental Protection integration was upgraded to the Ministry of Environmental Protection with six sub-level/regional headquarters in China East, China South, Northwest, Southwest, Northeast, and China North (Wang et al., 2019). Officials at these headquarters became the regional leaders of the Ministry of Environmental Protection. Their role was to oversee local administrative leaders' performance assessments on environmental protection, called "the environmental cadre evaluation" with stricter personnel punishment if pollutants exceeded expected/regulated quotas in their local area.

Milestone 6 -- Neo-constructing Phase(2013-present): Ecological Civilization

Today, Prime Minister Xi Jingpin developed an ideology of Ecological Civilization in government work to emphasize environmental protection. In 2013, the Third Plenary Session of the Eighteenth Central Committee acknowledged that the Ecological Civilization Program was the core of five civilization tasks (Political Civilization, Economic Civilization, Social Civilization, Cultural Civilization, and Ecological Civilization), to be written into the Constitution of the Communist Party (Amendment) (Wang et al., 2019). Furthermore, in 2017, the Nineteenth Central Committee stated, “The major social conflict in our country is the one between the increasing need for a better living standard and unbalanced, incomplete development” (Xie, 2019). Two major methods were employed to promote ecological civilization in local governments. First, to solve the deep-rooted problem of lack of executive power in local environmental bureaus, the central government assumed the monitoring role, while local branch administrators were expected to execute regulatory power. Local officers are evaluated by the People’s Central Government using the environmental cadre evaluating system. Second, more ecological marketing policies were issued to advance pollution remediation, such as natural resource taxation and a consumption tax. Before 2018, the fee and trade system of pollutant discharge rights collected 19 billion yuan (~ $2.7 billion U.S.) (Wang et al., 2019).

The management of environmental protection experienced further structural reform. The Ministry of Environmental Protection began a central inspection system of ecological and environmental protection by dispatching groups of central inspectors to the provinces to review and evaluate local governmental environmental works. In 2017, the Ministry of Environmental Protection divided its responsibilities into three departments, focusing on different polluting mediums: air, water, and soil (Xie, 2019). Since environmental issues required increasing collaboration among the three departments, the major tasks became how to effectively build ecological environmental monitoring and evaluation systems, supervising system of enforcement and compliance, and inspection and accountability systems. In 2018, the First Session of the Thirteenth National People's Congress approved structural reformation within the State Council by forming the Ministry of Ecology and Environment (Xie, 2019).

Moreover, the legal system in environmental protection also expanded vertically and horizontally. In 2014, the Environmental Protection Law was updated to its third revision in what was claimed to be the strictest law thus far for environmental protection (Xie, 2019). It granted enforcement power to the Environmental Protection Bureaus at local levels, including closing factories that violated the law. It also added an environmental resource tribunal in the Supreme Court. In addition, the Atmospheric Pollution Prevention and Control Law was revised to enforce the new law. Before 2018, a total of 186,000 administrative punishment cases against non-compliant industries were processed, contributing 15 billion yuan (~$2.2 billion U.S.) to the government, which was 4.8 times higher than in 2014 (Wang et al., 2019).

History shows that the Chinese environmental protection policy system started in the early stage of environmental pollution and was built on the intellectual foundation of Western countries. The system grew very fast in the past two decades to cover every aspect of environmental pollution (air, water, soil, noise, and so on). None-the-less, environmental conditions continued to deteriorate. Some scholars attributed this to the lack of matching power between regulation and punishment by the Environmental Protection Bureau (Peng, 2015). Subsequently, during the Peaking Phase when the Bureau of Environmental Protection became one of the core departments within the central government, this bureau received more executive power to both regulate and punish non-compliant industries.

To understand the dynamics behind the paradox of increasing power in the central government and the continued deterioration of environmental quality, this study used a structuralist lens to examine China's political ideology, specifically the Target Pyramid System as an authoritarian strategy; and the One Position Two Job strategy.

3.3.b. Target Pyramid System

In China, a "one-level down" supervision system is used in cadre personnel evaluations (Edin, 2003). In other words, the top party leaders and government officials beginning at the Bureau of Environmental Policy down to officials at the local level (provincial, municipal, or county) are responsible for evaluating an official's performance at one level lower. In this "top-down" political structure, meeting performance targets becomes the standard to quantify an offer's the performance, which is critical to bureaucratic ranking and career development within the system. Naturally, the target that could facilitate the best career development is regarded as the most important task in every official's career planning. A Target Pyramid is used here to illustrate the comparative importance among political targets/priorities divided into Supreme Target, Veto Target, Hard Target, and Soft Target (Figure 3.2.) (Edin, 2003; Wang, 2013).

Figure 3.2. Target Pyramid System.

*One Child Policy has been degraded from Veto Target level to Hard Target level after 2003. Ecological Civilization is the updated version of Environmental Protection.

The Communist Party leads the country. The Supreme Target in political ideology is maintaining absolute legitimate authoritative power that transfers power to each new leadership. Any activity that may jeopardize this authoritarian status is intolerable and will lead to both administrative and penal punishment. For example, the Fa Lun Gong, an organization promoting the comparatively new practice of Qi Gong—a Chinese traditional breathing exercise—created by Li Hongzhi in 1992, was first recognized and recommended by the government as a successful substitute for physical exercise to reduce medical expenses and promote social stability (Palmer, 2007). However, when more people became loyal believers in Fa Lun Gong, including some political leaders, the People's Central Government infiltrated the organization by establishing a

Communist Party branch from within. However, Li Hongzhi rejected this semi-mandatory "suggestive" incorporation. Due to his confrontation with the party's authoritarian power, under the leadership of Prime Minister Jiang Zeming (a radical objector to Qi Gong), Fa Lun Gong was banned as a cult and a massive suppression campaign ensued (Palmer, 2007).

The Veto Target that emphasizes economic growth and social stability is the critical target second only to securing authoritarian legitimacy. Poor performance on a Veto Target could result in severe administrative punishment and could not be counteracted by subsequent good performance on other targets. For example, in the Dark Phase (1949-1978), when China's GDP per capita ($131) (Qu, 2013) was low, government leaders believed that this gap in economic status compared to Western high-income countries was the cause of all China's problems, including rising levels of pollution. The goal of economic growth has, therefore, been a Veto Target since the party won ruling power in 1949. Since the economic revolution and opening-up (Milestone 3 Burgeoning Phase), China has continuously achieved more than 9% average annual growth -i.e., in the past 39 years (1979~2018) to realize this Veto Target (World Bank, 2020). In addition, social stability is another Veto Target addressed at all levels of government. Even though ecological civilization is classified as a lower-level Hard Target, the public's anxiety about poor air quality has recently triggered another societal unrest, which became a Veto Target that needed to be more seriously addressed to prevent social instability. For example, since the public has had a strong desire to know daily air quality, the Ministry of Environmental Protection (MEP) adopted the U.S. Air Quality Index (AQI) classification system that broadcasts air quality levels defined by categories within the index each day. However, to alleviate societal anxiety from knowing the true level of air pollution, ministry leaders changed the break points within the classification scheme to widen the intervals for Good air quality (192%), Moderate air quality (67%), and Slightly

Polluted (96%) when controlling the same starting point in the Heavily Polluted category (Zhang and Samet, 2015). Table 3.1. shows the structure of the two schemes. By changing these classes in the AQI index, more days fell into the first three categories, thus presenting a pseudo-better air quality situation. Taking the ground monitoring data (2014~2016) collected for a haze assessment in Qiong et al. (2021, forthcoming) as an example, the only commonality is no Heavily Polluted month with a starting point around index=251.

In comparison with the U.S. Environmental Protection Agency (EPA) standard, the distribution curve shows an approximately normal shape by having most months with Light Polluted (IV:20/55.6%) air, followed by Slightly Polluted (III: 10/27.8%) months. When the MEP standards were changed, air quality appeared much better, shifting from polluted to unpolluted status. More than half of the months (II: 21/58.3%) had moderate air quality. The number of months with good air quality (I:5/13.9%) was even larger than slighted polluted months (II:4/11.1%) and light polluted months (IV: 4/11.1%). This classification scheme greatly eased the public's intense sentiment and maintained social stability. However, from a public health perspective, the results of this "clever" change were that the public received misleading information that it did not discourage them from outdoor activities. In actuality, the air was very harmful for sensitive groups of people, such as those with cardiovascular and respiratory diseases or pregnant women without proper preventive protection.

Table 3.1. Particulate Matter ($PM_{2.5}$) Comparison Classification Schemes: United States (U.S.) and China.

Level	Description	AQI	$PM_{2.5}$ Breaking Point		$PM_{2.5}$ Frequency	
			US	China	US	China
I	Good	0-50	0-12	0-35	0	5
II	Moderate	51-100	12.1-35.4	36-75	4	21
III	Slightly Polluted: Unhealthy for Sensitive Groups	101-150	35.5-55.4	76-115	10	4
IV	Light Polluted: Unhealthy	151-200	55.5-150.4	116-150	20	4
V	Moderately Polluted: Very Unhealthy	201-300	150.5-250.4	151-200	2	2
VI	Heavily Polluted: Hazardous	301-500	250.5-	251-	0	0

Source: United States Environmental Protection Agency (EPA) (https://www.epa.gov/criteria-air-pollutants) and National Air Ambient Quality Standards (NAAQS) Table; Zhang, J., and J.M. Samet. (2015). Chinese haze versus Western smog: Lessons learned. Journal of Thoracic Diseases. 7(1):3-13. doi: 10.3978/j.issn.2072-1439.2014.12.06.

The Hard Target is also mandatory. Poor performance on a Hard Target could result in administrative punishment, which to a certain degree could be counteracted by excellent performance on the Veto Target. Overpopulation is an urgent global issue, particularly for developing and undeveloped countries, and imposes a heavy burden on economic and environmental resources. Therefore, to further stimulate economic growth and improve living standards, the “chief designer” of economic reform, Deng Xiaoping, promoted the “population problem” as one of the Veto Targets in 1960s. The political priority of the One Child Policy was imposed on every Chinese citizen, and the results were remarkable. Within two decades (1970-1994), the birth rate decreased from 33.4% to 17.7% and the natural population growth rate decreased from 25.8% to 11.2% (The State Council Information Office of the People’s Republic of China, 1995). However, behind such accomplishments, heavy pressure on executive officers, usually local officers, caused a series of draconian actions to limit birth rates, such as notorious forced abortions and sterilizations. Less radical actions included refusing to provide an official letter to assist a mother to be hospitalized, issuing a birth certificate, registering the baby, revoking a financial reward for having only one child, punishing parents' careers, and charging an exorbitant fine for an extra birth. Meanwhile, another unplanned aftermath of this policy was the imbalanced infant gender (Fong, 2016). The preference for a male baby was inherited from thousands of years of patriarchy rooted in Chinese culture. With ultrasound technology, parents could learn the sex of the fetus and chose to abort if it was a girl. The One Child Policy thus led to the intentional deaths of millions of female fetuses and newborn female infants. In 2013 when China acknowledged it had met its population goals, the One Child Policy was demoted to a Hard Target. Since then, the government has become more lenient on having a second baby and has strictly forbidden checking the gender of a fetus. In 2016, the government permitted having a second baby and lifted the One Child Policy.

Another new Hard Target was ecological civilization, which was established only after entering the millennium. History shows that the policy predecessors of the ideology of ecological civilization were environmental protection and sustainable development. Environmental protection was originally settled as the Soft Target in 1978 when pollutants started to accumulate exponentially in the environment after the economic resolution and opening up. After China joined the WTO in 2001, worsening pollution accompanied the escalated round of economic growth, which in turn imposed a greater impact on economic growth and social stability (Veto Targets). Chen and Zhao (2005) found that environmental degradation during economic growth could reduce China's GDP by as much as 15%. Meanwhile, the National Bureau of Statistics of China counted more than 51,000 disputes related to pollution in 2005, which could be viewed as a great threat to social stability (Miao, 2006; Wang, 2013). With this knowledge, the new generation of government, under current Prime Minister Xi, further refined environmental protection and sustainable development as ecological civilization and promoted it to the level of Hard Target.

Finally, the Soft Target can also be called a “guidance” target with less perceived importance within the bureaucratic system. The Soft Target usually is a suggested goal to support the work of other important targets. It largely depends on the discretion of local administrators to prioritize efforts and to decide what actions to take. Poor performance on a Soft Target could not result in administrative punishment and could mostly be counteracted by excellent performance on other targets. Environmental protection successfully combined with sustainable development evolved into ecological civilization and was then elevated to Hard Target level. However, other topics related to environment protection still within the Soft Target level are mostly neglected, such as human-environmental health education. Even though there were consequences of ecological civilization, the One Child Policy and the contribution of economic growth to a growing number of potential adverse health conditions, the most orthodox approach, health education, had never been properly introduced into citizens’ life due to its potential disruption of Veto Targets (social stability) and Supreme Target (authoritarian legitimacy). Government education on this topic today is minimal and extremely fragmented. This study found that at the national level, a very brief article (only 3,000 words) on the website of the Ministry of Education discussed the negative effects of haze air pollution on general health, which was posted in the Retirement Section. The same article was published on the website of the National Health Commission of the People’s Republic of China. A small portion of this article described the mechanism of and listed the diseases caused by chronic exposure to high dosages of haze pollution. Noticeably, there were no articles found on the national or lower-level governmental websites about the influences of haze on pregnancy, infant and child health, or population groups highly susceptible to the untoward effects of pollution. At the provincial and city levels, the Shaanxi Province Ministry of Health and the Health and Family Planning of Xianyang City websites "re-twittered" a similar but shorter article pertaining to high haze days and precautions to take outdoors—targeting susceptible people such as those with asthma, respiratory diseases, and heart disease. Again, there was no information on the long-term effects of chronic exposure to high dosages of haze pollution, nor the risks of haze on pregnancy health.

3.3.c. One Position Two Jobs (One2)

As the largest political party with more than 40 million members in China, the Communist Party represents an enormous political structure covering every corner of the country (Wang, 2013). To "effectively and efficiently maneuver such a giant political machine" on environmental issues is, therefore, a challenging task. A managerial approach, "One Position Two Jobs" (Yi Gang Shuang Ze, called One2 herein) System, was developed to combine every citizen's "party responsibility" and "social responsibility" as follows.

In the *legislative system*, the National Representative Congress and Standing Committee had the power to select and name key personnel for the Ministry of Ecology and Environment, the Supreme Court, and the Procuratorate from candidates nominated by the prime minister herein, referring to Prime Minister Xi. Noticeably, most representatives in Congress and the Standing Committee came from lower government appointments and state enterprises and were selected by other communists from each organization's Communist Party pool. Furthermore, candidates nominated by the prime minister were also communists who had demonstrated excellent party awareness. To some degree, this party commonality could advance cooperation among various sectors due to the same political ideology and willingness to conform. For example, the ideology pertaining to environmental protection from top leaders can be quickly formalized into political calls or environmental laws and regulations and applied to all levels of lower administrative government. Since the appearance of the first environmental law in 1979, a total of 13 environmental protection laws, 20 natural resources protection and management laws, and 30 ecological civilization political regulations have been enacted (Wang et al., 2019). None-the-less, other problems evolved. For example, the absence of different voices to challenge the thinking and rational of specific policies simplified not only the process but also the messaging. This strict requirement of political consensus deemed that no different voice could be heard, and no alternative options were discussed, which has led to incomplete legislation. In addition, the fallacy inherent within these imperfect policies and laws may not be spotted or corrected until the consequences of such actions occur. Even more important, without an effective feedback mechanism or pathway, a mistake could continue for a long period before being noticed. For example, in the 1980s the green economy was a strategy designed to stimulate the willingness of engaging local agencies and small enterprises in environmental protection. However, some local governors capitalized on financial opportunities from this policy: To advance their personal political achievements, they intentionally produced more pollution to earn financial compensation, which was then used to promote further economic development.

In the *judiciary system*, the inseparability between party and law is also evident. The judiciary consists of two "seemly independent but closely associated" systems, the court and the procuratorate. The court oversees judging environmental lawsuits, as well as publishing its judicial interpretation, while the procuratorate is responsible for launching environmental criminal lawsuits, administrative litigation, and public prosecution against individuals, local executive agencies, and enterprises. However, at the center of these two systems is the same central-nomination mechanism. The leading groups in both systems, including the chief procurator and the chief justice, are nominated and selected by the Standing Committee of the National People's Congress from the same candidate pool, where both competition and support stand. At the subnational level, the association among local governments, local courts, and local procuratorates is even closer. They all belong to the same community with a shared vision. If a local administrator violates environmental law and is exposed by a local procuratorate, the political and judicial punishment imposed by the People's Central Government can extend to all three subnational sectors (government, courts, and procuratorate) at every level (province, city, county, and town).

Therefore, it is not uncommon for local governments, courts, and procuratorates to protect each other. A judge and/or the procurator could ignore environmental problems caused by local administrations intentionally "turnning big problems into small ones and making small ones disappear". The monitoring function of the procuratorate is thus lost and an environmental problem could go undetected until it rises to a more harmful level for public health and results in social instability. Environmental laws are not favored by local administrators, either. First, local governors are afraid that the legal procedures would slow economic development. Second, the public could use environmental laws as a weapon against state interests and cause social instability. No matter which scenario occurs, ultimately there would be political and career punishment for failing to meet Veto Targets. Since a Hard Target cannot exceed the priority of the Veto Target, environmental laws play a secondary role in the judiciary system. They can either be freely breached when in conflict with higher level targets or vigorously implemented when in accordance with bureaucratic targets.

This One2 mechanism also applies in *mass media*. As Communist Party General Secretary Xi pointed out, the media should "keep the correct political direction, speak for the party, protect the party's authority and unification, help turn government's policies into conscious actions of the people, [and] focus on delivering positive news and views" by performing four roles (Peng 2016) that support the party's targets. First, according to Xi, the media should function as a portal to inform the public with "positive stories and good deeds". Due to heavy pressure from the hierarchical governmental supervising structure, local governments may aggressively limit the reporting of environmental pollution. Second, the media is responsible for educating the public that the party's and country's interests always supersede the people's interests. According to Marxist theories, "media must serve political parties, classes, or other interest groups because news cannot avoid political class" (Yin, 2018). Due to the political essence of the media, it is not surprising to see the media take the role of watchdog for the government and guard the authoritarian legitimacy of the party. Third, the media is responsible for channeling communication between the authorities and the public. The media is used as a sophisticated medium of propaganda to bridge the party's targets and the public's actions, to publicize the governmental policies and regulation, to mold public opinion about the government, and to persuade people to trust and follow the party (Liu, 2016). Fourth, the media is responsible for scrutinizing authorities (government employees). The media's scrutiny role is performed under the government's direction in the name of national interest and social stability thereby fulfilling the Supreme and Veto Targets.

In health education, this One2 mechanism is hidden even more covertly under bureaucratic control particularly involving doctor-patient education. During the recent global health disaster, coronavirus (COVID-19), one of the first whistle blowers, Dr. Wenliang Li, a 34-year-old ophthalmologist at Wuhan Central Hospital, sent out a message in a private chat group on WeChat (an instant message app, similar to WhatsApp) on December 30, 2019 and tried to warn his coworkers and medical school colleagues of the possible existence of a rare new coronavirus highly similar to SARS. Shortly thereafter, the Wuhan Municipal Health Commission summoned him to explain his "untrue" message and by the Hospital Inspection Department for his inappropriate action. He was forced to write a statement, named "The introspection and self-criticization for spreading untrue information," to apologize for his "outrageous behavior" (Bao et al., 2020). On January 3, 2020, politic summoned him and seven coworkers for spreading rumors and societal panic. He was detained for less than one day and released after signing a police statement admitting that he committed an illegal action by sending an untrue message, demonstrating that he understood the significant punishment he may receive if he continued to spread such rumors, and promising to "voluntarily stop his inappropriate behavior immediately". Despite these frightful and unpleasant experiences, Dr. Li continued to work and fought the coronavirus by treating more and more infected patients. On January 10, 2020, he was admitted to the intensive care unit with severe infectious symptoms and diagnosed as coronavirus-positive on February 1, 2020. Meanwhile, after the coronavirus spread domestically and internationally, he finally was able to explain everything and post his police statement online without being rebuked under the country's strict and relentless internet censorship. Unfortunately, Dr. Li did not survive and died on February 10, 2020. His death set fire to Chinese social media and sparked grief, outrage, and disgust over the bureaucratic control of the doctor and other health care providers. Apparently, the authorities had formed a very sophisticated monitoring network to oversee any allegedly abnormal, illegal, or risky public behavior that could potentially interfere with social order and cause instability. After identifying any "inappropriate" behavior, the One2 system kicked in to ensure that corresponding punishments are imposed as soon as possible. The health consequences of pollution on the most susceptible populations in China, namely mothers, infants, and children, may result in chronic conditions that could be complicated by other confounders, such as nutrition, lifestyle behaviors, etc. Physicians are, therefore, confronted by the need to limit the education they give to their patients and patients who are unaware of their vulnerability do not ask questions. The health impacts of chronic exposure to high dosages of air pollution are thereby, not discussed with patients.

3.4. Conclusion

To provide a more holistic understanding of Chinese environmental protection policy and the role of the People's Central Government, this study reviewed the establishment and development of the environmental protection policy system in China from 1949 to the present. There was a focus on the executive system from a structuralist perspective, including the Target Pyramid System and One2 system in the bureaucracy. The study found that the hierarchical structure in the Target Pyramid System not only determined the rank of different political priorities but also revealed the problem of mismatched power structure and ownership of responsibility inherited within the executive. The department responsible for monitoring and protecting air quality lacks the corresponding power to regulate or punish industries that are non-compliant, which is consistent with the findings of previous studies (Yang Peng, 2015; Xu et al., 2016). Meanwhile, even though the One2 system could result in highly consistent party awareness to facilitate the efficient policy applications, it also creates a governmental monitoring atmosphere filled with high political pressure, greatly limiting the activeness of public participation in environmental protection.

In light of this paradoxical and conflicting environmental situation, it is critical for the government to alleviate social stress and stimulate ecological civilization. First, it is important to free the different voices of health care providers, public health specialists, and scholars to speak publicly about the issue. No matter whether or not the legislative or judicial system take action, the country's highly homogeneous political identity could facilitate the execution of environmental protection policies and laws, and a public platform that entertains differing opinions would further increase the feasibility of regulations of pollution. Moreover, freeing the mass media from censorship and encouraging divergent voices would promote its channeling and authority-scrutinizing roles. Second, it is necessary to promote environmental education of local administrations. By changing the stereotyped image of an incompatible relationship between economic development and environmental protection, local officials would be motivated to encourage environmental protection by recognizing the beneficial impact of a healthy environment on local economic development. Lastly, enhancing environmental health education across the entire society would encourage broad public cooperation and participation, including international governments, non-governmental organizations, private actors, and academia. That, in turn, would facilitate the efficiency and effectiveness of environmental protection and further solidify the Communist Party's Supreme Target.

CHAPTER IV

Haze Assessment in Shannxi Province and Xianyang Area, China

Abstract

In Chinese economic developmental history, the adoption of economic reform and opening of a domestic market in 1978 symbolized the start of economic takeoff, which unfortunately resulted in a severe air pollution problem of haze in China. There is a need to study Chinese haze ground monitoring, but these data are limited due to the lack of ground monitoring stations in areas of high haze density. The purpose of this study is to describe the haze pattern between 2008 and 2016 in a middle-sized city, Xianyang, using satellite imagery. This study first visually and mathematically validated the temporal trends of two OMI (Ozone Monitoring Instrument) satellite products, Aerosol Optical Thickness (AOT) and Ultraviolet Aerosol Index (UVAI), using available ground monitoring data (Air Quality Index) AQI and its major components—particulate matters (PM_{10}, $PM_{2.5}$). This study found that UVAI was a superior substitutional measurement of haze. Then this study examined the spatial and temporal development of haze by mapping the monthly, seasonal, and annual UVAI. A clear haze hotspot was detected in southeastern Xianyang Area. The findings in this study demonstrated that UVAI can be used as a successful satellite product to holistically measure haze compound. Clear spatial and temporal increasing patterns of haze in severity, duration, and coverage were detected.

Keywords: Haze pollution, Ozone Monitoring Instrument, Ultraviolet Aerosol Index, Particulate Matter, China.

4.1. Introduction

Haze is a weather phenomenon by which horizontal visibility deteriorates to less than 10 km. This deterioration is caused by evenly suspended high ambient concentrations of fine particulate matter (particles with diameter ≤ 2.5 micrometers) ($PM_{2.5}$) in the atmosphere (Liu et al., 2015; Zhong and Zaveri, 2016). $PM_{2.5}$ is either directly emitted into the atmosphere (referred to as primary PM) or is formed in the atmosphere (referred to as secondary PM) through gas-to-particle conversion (Zhang et al., 2015; Fuzzi et al., 2015; An et al., 2019). Primary PM consists of a highly complex mixture of inorganic (IA) and organic aerosols (OA) that are largely generated by anthropogenic activities, including gasoline and diesel combustion, biomass burning as part of residential activities (cooking and heating) and industrial production (smelters, steel mills and power plants) (Pui et al., 2014; An et al., 2019). Primary PM usually occurs in the presence of high PM with higher relative humidity (RH) as exhibited during the famous London fog event in 1952. Secondary PM consists of an abundance of secondary organic aerosol (SOA) produced by SO_2, NH_3, or NO_x and secondary inorganic aerosols (SIA) produced by volatile organic compounds (VOC) (An et al., 2019). The formation of secondary aerosols is generally subject to several complex chemical processes such as the presence of high atmospheric ozone and low RH as exhibited during photochemical smog events in Los Angeles (Pui et al., 2014). Importantly, China is facing a unique and timely challenge by simultaneously experiencing both fog and photochemical smog (both herein referred to as Haze) due to high primary PM emissions and efficient secondary PM and gaseous formations.

Air quality in China is monitored by the Ministry of Environmental Protection (MEP) (see study Chapter III). The Environmental Protection Law and the Prevention and Control of Atmospheric Pollution Law of the People's Republic of China created the Standard of

Environmental Air Quality (GB3095-2012) amended in 2012 to include five criteria air pollutants—ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), $PM_{2.5}$ and PM_{10} and a composite index called the air quality index (AQI) (Lead (Pb) is not included). These five criteria air pollutants are monitored at approximately 377 sites in cities across China (MEE, 2019). The Chinese MEP adopted the same classification scheme used by the United States Environmental Protection Agency (EPA) to report levels of criteria air pollutants and interpret the degree of air quality "healthiness" to the public on a daily routine. The AQI is divided into 6 levels, ranging from very healthy and good air quality conditions to very unhealthy and heavily polluted air conditions (Table 4.1.). For each category, there are corresponding actions recommended to the public. The China National Environmental Monitoring Center (CNEMC) started reporting real-time monitoring data to the public in 2013 on the China Environmental Monitoring Terminal (http://113.108.142.147:20035/emcpublish/) (CNEMC, 2018).

Table 4.1. Air Quality Index (AQI) Classification Levels and Health Concerns with Recommended Actions Report in China.

Level	Description	AQI	Health Concerns	Recommended Action
I	Good	0-50	Air quality is satisfactory and poses little or no health risk.	The entire population can have normal activities.
II	Moderate	51-100	Air quality is acceptable. May pose a moderate health concern for a very small number of individuals. People who are unusually sensitive to ozone or particle pollution may experience respiratory symptoms.	Sensitive people should decrease **outdoor activities.**
III	Slightly Polluted: Unhealthy for Sensitive Groups	101-150	Members of sensitive groups may experience health effects, but the general public is unlikely to be affected. People with heart or lung disease, older adults, and children are considered sensitive and therefore at greater risk	People with heart or lung disease, older adults, and children need decrease the strength and duration of **outdoor exercise**.
IV	Light Polluted: Unhealthy	151-200	Everyone may begin to experience health effects; Members of sensitive groups may experience more serious health effects	People with heart or lung disease, older adults, and children need decrease the strength and duration of outdoor exercise; Everyone should decrease **outdoor activities**.
V	Moderately Polluted: Very Unhealthy	201-300	Health alert: Everyone may experience more serious health effects.	People with heart or lung disease, older adults, and children need **stop outdoor exercise and stay indoors**. Everyone should decrease **outdoor exercise**.
VI	Heavily Polluted: Hazardous	301-500	Health warnings of emergency conditions. The entire population is even more likely to be affected by serious health effects.	People with heart or lung disease, older adults, and children need **stay indoors and stop exercise**; The entire population should avoid **outdoor activities.**

Sources: China Ministry of Environmental Protection (China MEP). (2012). Technical Regulation on Ambient Air Quality Index (on trial) JH 633-2012. Retrieved from http://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/jcffbz/201203/W020120410332725219541. pdf on January 16, 2017.

There are three important limitations, however, in the use of the air monitoring data in China. First, air quality data before 2013 is not publicly available because these data are stored in individual monitoring stations and have not been centralized and published. Second, ground air sensors for local monitoring stations are usually placed either within or close to highly polluted areas, such as a city, while haze conditions in rural areas are largely ignored— even though air pollutants migrate from central cities to surrounding rural areas. Third, in-situ measurements are limited to point data by which buffers may be drawn around to measure local air quality. Statistical interpolation methods may be used to obtain estimated air quality levels between monitoring stations, although substantial error may occur in the interpolation modeling process.

An alternative to using air monitoring data in China is to use satellite imagery, which is available before 2013 and covers both urban and rural areas on the same temporal scale. Although there is no single satellite sensor that can detect all of the criteria air pollutants at the same time, Aerosol Optical Thickness (AOT) also referred to as Aerosol Optical Depth (AOD) and the Ultraviolet Aerosol Index (UVAI) are popular tools by which to measure haze (Li et al., 2005; Zheng et al., 2014; Higurashi and Nakajima, 2002). AOT is the magnitude of light transmission that is absorbed or scattered by ambient aerosols (tiny particles or dust), passing through the vertical column of the atmosphere from the ground to the satellite's sensor (Duncan et al., 2014). It is a dimensionless number that is used by scientists to indicate the amount of aerosol in the atmosphere. However, during haze days with lots of clouds or water vapor, the accuracy of AOT measurements using visible bands can be greatly compromised. On the contrary, another satellite product, UVAI also collected on the OMI satellite, is not influenced by cloud cover. The Aerosol Index (AI) is also known as Aerosol Absorbing Index and Aerosol Absorbing Indicator, a dimensionless and qualitative index that indicates the presence of ultraviolet absorbing aerosols, such as the dust and soot emitted from dust storm, volcano eruption, and biomass burning (Setin-Zweers and Veefkind, 2012). The calculation of UVAI is based on the spectral contrast method by utilizing measured spectral radiance and calculated radiance in Rayleigh scattering in the UV spectral region where ozone absorption is minimal. For example, for a given pair of wavelengths (e.g., 360 nanometers (nm) and 331 nm are used in Total Ozone Mapping Spectrometer (TOMS) and Ozone Measuring Instrument (OMI)), the ratios of measured top of atmosphere reflectance and calculated theoretical reflectance in a Rayleigh scattering-only atmosphere are calculated first. Log 10 transformation is, thereafter, performed and the difference of these two ratios is calculated and then is magnified 100 times (Setin-Zweers and Veefkind, 2012). The final result is a residual value, which can be used to differentiate the types of aerosols (Torres et al, 2007; Kim et al, 2007). The negative UVAI represents non-absorbing aerosols, such as sulfate and sea salt, while the positive UVAI indicates absorbing aerosols, such as carbonaceous aerosols and mineral aerosols. The near-zero UVAI means the atmosphere is free of aerosols (Torres et al, 2007).

In the United States, two instruments equipped within "A-train" satellites launched by the U.S. National Aeronautics and Space Administration (NASA) are used to measure air quality: The Moderate Resolution Imaging Spectroradiometer (MODIS) that is carried by the Aqua satellite and the Ozone Monitoring Instrument (OMI) carried by the Aura satellite. For this study, after a closer check on the availability and quality of OMI and MODIS data for Xianyang over time, it was decided that using OMI data was best in this haze measurement for the following reasons: 1) MODIS only covered eastern China and was not available for the extent of Xianyang, nor was daily data available; 2) MODIS level 2 daily images were raw data and have not been rectified for temporal overlay, which made image stacking and average calculations difficult; and 3) MODIS level 3 daily data, which is an aggregation of level 2 data has too low of resolution (1 degree by 1 degree) limiting the spatial variation within the study area and it also exhibits many missing values. To the contrary, the OMI Level 3 data product (0.25 degree by 0.25 degree) not only had an appropriate resolution for the study area, but the data itself exhibited clear variation with fewer missing values. This study therefore utilized the OMI Level 3 data to measure haze in the Xianyang study area of China.

4.2. Haze Assessment Objectives

The objectives of this study are: To demonstrate the use of satellite products as a substitute for ground monitoring data to measure the haze compound and show the changes in haze in Xianyang Area. Ozone Monitoring Instrument (OMI) products -i.e., the AOT and UVAI are evaluated and validated with monthly ground monitoring AQI and particulate matters ($PM_{10,}$ $PM_{2.5}$) during the 2014~2016 time period (period-2) within Xianyang Municipality. Using the best OMI product, to measure the monthly, seasonal, and annual trends in haze across Xianyang Area and Xianyang Municipality during the 2008~2016 time period (period 1).

4.3. Haze Data

This study utilizes two sources of data to conduct the haze assessment (a) satellite imagery Level-3 OMI/Aura Multi-wavelength Aerosol Optical Thickness (AOT) and Ultraviolet Aerosol Index (UVAI) products (Setin-Zweers and Veefkind, 2012); (b) Air Quality Index (AQI) as well as its major components ($PM_{10,}$ $PM_{2.5}$) collected from air monitoring stations (Zhenqi Wang, 2018). The in-situ monitoring data (AQI and particulate matters) was analyzed for the more recent years (2014-2016). The OMI data was analyzed across the study time period-1 (2008-2016).

4.3.a. Satellite Imagery

The Aura satellite is the third satellite in Earth Observing System (EOS), which is launched by NASA on July 15, 2004 (NASA, 2020). Unlike its predecessors, Terra and Aqua, that were designed to study the surface of earth (land and ocean), the Aura spacecraft was exclusively designed to collect data about the Earth's upper and lower atmosphere. Its major mission is to assist in the study of ozone, air quality, and climate trends (NASA, 2009). It carries four instruments: Microwave Limb Sounder (MLS), High Resolution Dynamics Limb Sounder (HIRDLS), Tropospheric Emission Spectrometer (TES), and the Ozone Monitoring Instrument (OMI) (NASA, 2020).

OMI is the evolutionary descendant of NASA's Total Ozone Mapping Spectrometer (TOMS) instrument and the European Space Agency (ESA) Global Ozone Monitoring Experiment (GOME) instrument. The OMI is a highly synergistic instrument carried by the Aura satellite to promote the identification and the measurement of criteria air pollutants (NASA, 2020). It detects tropospheric pollutants by observing backscattered solar radiance in two visible (350~500 nm) and ultraviolet (270~380 nm) bands.

Both AOT and UVAI were retrieved as the subsets of OMI/Aura Multi-wavelength Aerosol Optical Depth and Single Scattering Albedo L3 1day best pixel size 0.25 degree by 0.25 degree (Stein-Zweers and Veefkind, 2012). This OMI level 3 data is compiled on the basis of the aerosol value from the OMI Level 2 good quality data by using a multi-wavelength algorithm with up to 20 wavelength bands between 331nm and 500nm (NASA Aura, 2019). AOT measures the magnitude of solar beam prevented from reaching the ground due to ambient aerosols, while the UVAI can also indicate types of pollutants by using positive or negative numbers. In this study, haze was conceptualized as a compound of polluting aerosols, therefore, the final UVAI variable will be the absolute value of raw satellite UVAI data. Based on the coordinates of Xianyang Area (W: 107.648°, N:35.547°, E:109.167°, S:34.194°), which will also represent the extent of the imagery, a total of 7*7 grid cells will comprise the entire study area as further described below.

The daily OMI data was downloaded from the EOS website in NetCDF format and further processed in RStudio (RStudio, Incorporated, Boston, MA, 2015).

4.3.b. Ground Monitoring Data

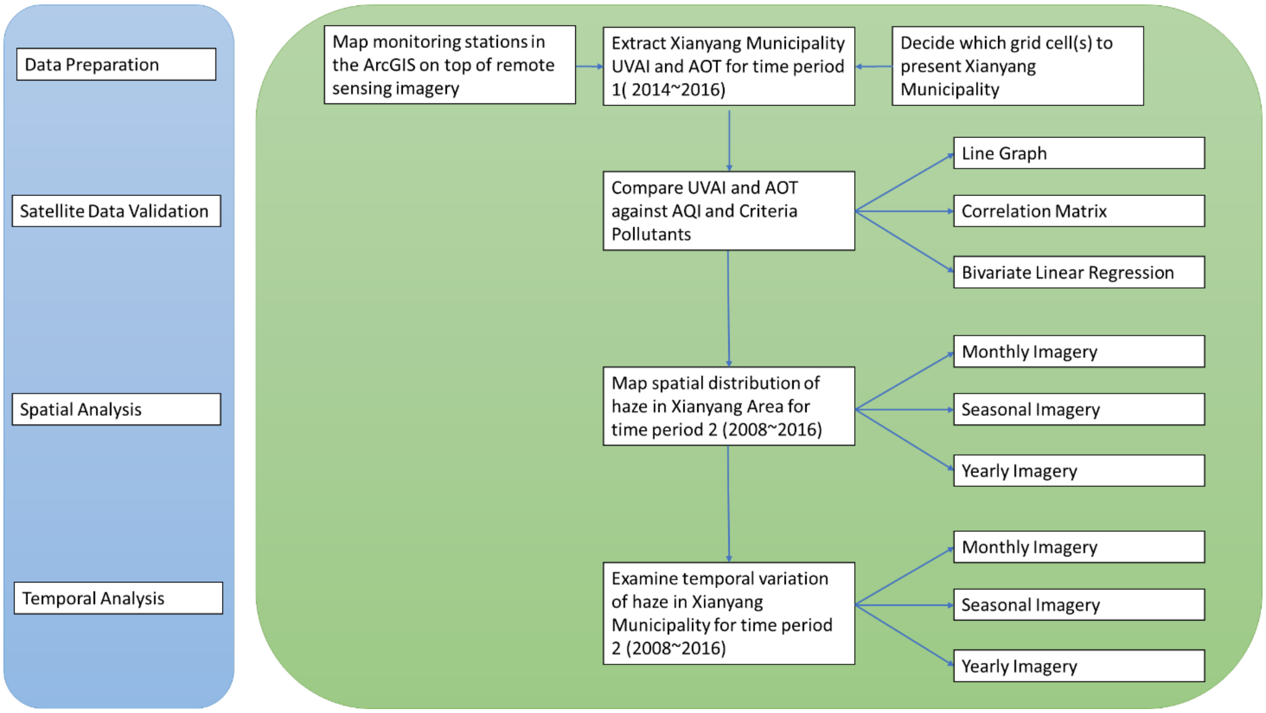
The daily air quality of the study area was measured by four air monitoring stations within and proximate to Xianyang Municipality. The final published data were averaged across the entire municipality. More details about these four monitoring stations are discussed below. These in-situ monitoring data were obtained from Zhenqi Wang (2018), a public website that had permission from the China MEP to download real-time data from CNEMC. This platform was established by $PM_{2.5}$ Prevention and Treatment Special Group, a professional group of researchers and scholars who belong to the Recruitment Program of Global Experts (Zhenqi Wang, 2018). This program is an elite recruiting strategy developed by the Chinese government, to attract Chinese scientists and scholars with international training from top universities and research institutes back to China.

4.4. Methodology

A prerequisite for health study was to calculate haze exposure based on each mother's pregnancy length and trimester dates beginning at conception. Since the investigator collected nine years of obstetric records (2008~2016) from a collaborating hospital (further described in Chapter 4), it was important that the haze data could be traced back as early as 2007. However, the ground monitoring data that was published by the Chinese MEP started only in 2014. Therefore, validating the feasibility of using satellite data to measure haze was an important first purpose of this haze study. Two satellite products, UVAI and AOT were extracted from OMI imageries and compared with ground monitoring data in Xianyang Municipality, including AQI, PM_{10}, and $PM_{2.5}$. After being validated, one satellite product was then utilized to investigate the spatial patterns of haze in

Xianyang Area as well as the temporal pattern of haze in Xianyang Municipality, 2008 to 2016. Figure 4.1 illustrates the analytical processes that was carried out for this haze assessment.

Figure 4.1. Analytical Flowchart by Which Haze Measurements were Constructed.



The latitude and longitude and satellite products were imported into RStudio (RStudio, Incorporated, Boston, MA, 2015) to assess the quality and spatial and temporal structures of the AOT and UVAI data. A correlation matrix was then used to assess the correlation between each satellite product and the ground monitoring data. To further validate the accuracy of satellite imagery, bivariate linear regression analyses were conducted to assess the magnitude of change in AQI (dependent variable) that could be explained by each satellite product (independent variable).

The spatial and temporal trends of the best-fit satellite product for Xianyang Area was visualized using ArcGIS presenting each month, season, and year of imagery across time period-1 (2008~2016). Then the temporal trends of same best-fit satellite product for Xianyang Municipality were plotted in a line-graph. Moreover, the descriptive statistics for Xianyang

Municipality–e.g., min, max, range, mean, median and standard deviation of haze were evaluated for each year and across years to examine monthly, seasonal, and yearly patterns.

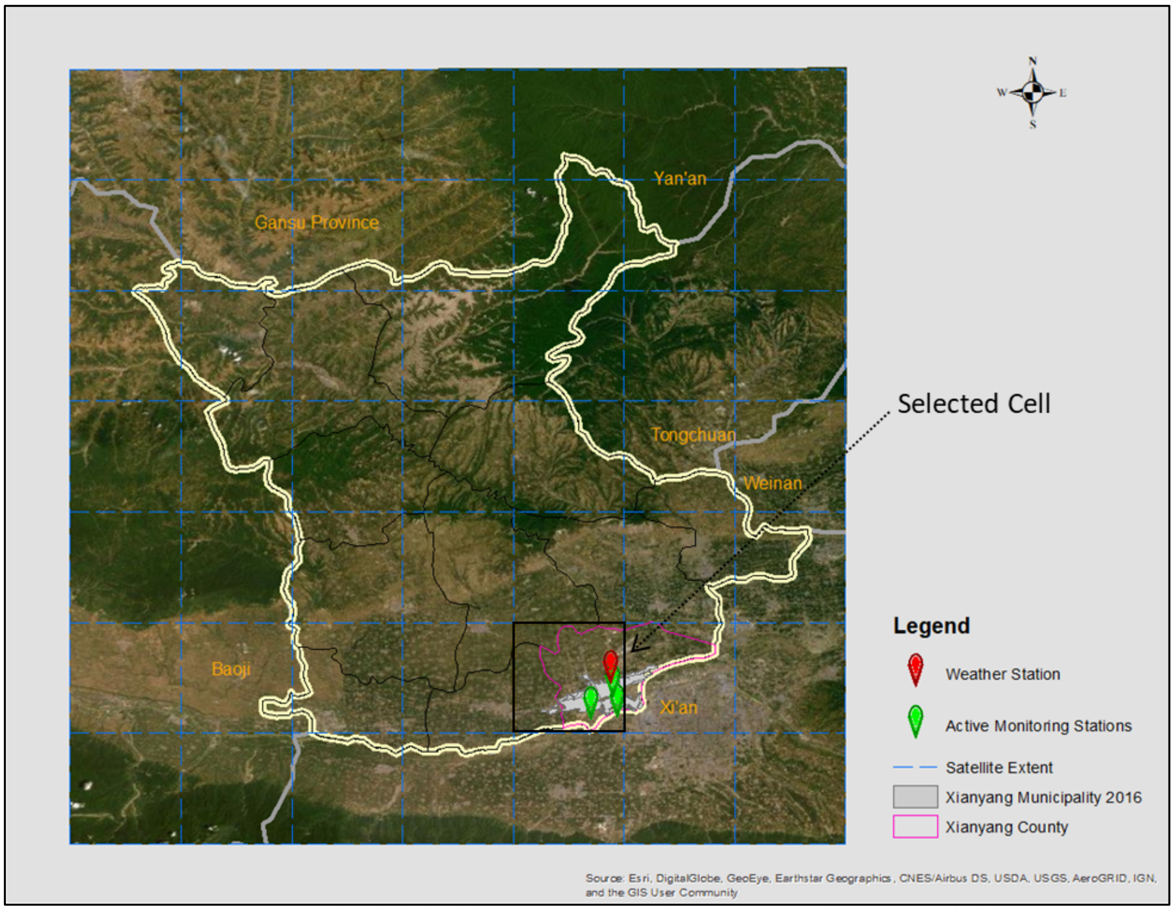
4.5. Results

4.5.a. Satellite Data Preparation (UVAI and AOT) for Xianyang Municipality

In Shannxi Province the Air Quality Realtime Publishing System (http://113.140.66.226:8024/sxAQIWeb/help.aspx) had four monitoring stations in Xianyang Municipality. This publishing system was created by Shannxi Environmental Monitoring Central Station, the technical headquarter of Shannxi Ecology and Environment Bureau, which is responsible for the daily operation of all 144 air quality monitoring stations, 181 water quality monitoring stations, and 1,036 soil quality monitoring stations across Shannxi Province (China MEE, 2019). Of the four monitoring stations, three were selected as active monitoring locations: Xianyang Municipal Experimental Middle School (34.313871, 108.677277), Shannxi University of Chinese Medicine (34.316513, 108.741208), and Xianyang Normal University (34.364829, 108.727069). There also was one Weather Station (34.394310, 108.723571 (Figure 4.2).

The Xianyang Municipal Experimental Middle School is located in the west side of the municipality, representing the old town and the newly developed business area of Xianyang Municipality. The Shannxi University of Chinese Medicine monitoring station is the only station located on the south side of the Wei He River, measuring the air quality in newly constructed residential areas bridging Xianyang and Xi’an areas. The Xianyang Normal University lies in the northern edge of the municipality, representing traditionally highly populated residential areas. The Weather Station lies further north of Xianyang Normal University, a more rural place on the periphery of the Municipality. This location mainly focused on collecting suburban local weather data to serve the needs of the Xian-Xianyang International Airport. As the control group, the air quality data collected in this location was not included in the final calculation of AQI for Xianyang Municipality. Unfortunately, the east side of Xianyang Municipality where most industries and power stations were located had no monitoring station. After mapping the point locations of the three monitoring and one climate stations and overlying these data onto the UVAI and AOT images in ArcGIS, it showed that all active stations were located within the same grid cell (Figure 4.2.). Therefore, the value of such grid cell was used as the satellite data for comparison with the ground monitoring data collected from Zhenqi Wang (2018).

Figure 4.2. Extent of Ozone Monitoring Instrument (OMI) Data Coverage and Location of Air Monitoring and Climate Stations for Xianyang Area and Xianyang Municipality, China.



Source: Base map source: Esri. DigitalGlobe. GEoEye, Earthstar Geographics. CNES/Airbus Ds. USDA. USGS. AeroGrid.IGN, and the GIS User Community; The shapefiles source: National Catalogue Service for Geographic Information (www.webmap.cn).

The monthly average UVAI and AOT imageries for Xianyang Area between 2014 and 2016 were calculated by adding within cell values from the daily images. Then the UVAI and AOT were extracted from the same grid cell for the Xianyang Municipality. Table 4.2 summarizes the descriptive statistics of UVAI and AOT as well as seven ground monitoring variables (AQI, PM_{10}, and $PM_{2.5}$) during time period-2 (2014~2016) in Xianyang Municipality. The results show that PM_{10} has highest starting point (minimum value), AOT has highest ending point (maximum value) and largest dispersions (Std. Dev), and UVAI has the smallest dispersion. Comparing to AOT, UVAI's mean, and median is closer to the AQI's mean and median. There was no missing data.

Table 4.2. Descriptive Statistics of Satellite Data and Ground Monitoring Data (2014 ~ 2016).

	Min	Max	Range	Mean	Median	Std.Dev	N.Valid
UVAI	0.416	1.595	1.179	0.974	0.942	0.298	36
AOT	0.509	2.902	2.393	1.369	1.327	0.620	36
AQI	**0.592**	**2.017**	**1.425**	**1.087**	**0.984**	**0.409**	**36**
PM_{10}	0.703	2.457	1.754	1.324	1.254	0.515	36
$PM_{2.5}$	0.294	1.609	1.315	0.710	0.611	0.383	36

The unite for particulate matters is microgram/m3. Ultra-Violet Aerosol Index (UVAI), Aerosol Optimal Thickness (AOT), and Air Quality Index (AQI) are unitless.

4.5.b. Satellite Data Validation

To validate the reliability of using satellite imagery data to present local air quality, the temporal relationship between satellite products and ground monitoring data were examined visually and mathematically. First, the monthly UVAI and AOT values were plotted against each ground monitoring factor to visually examine their similarity (Figure 4.3.). The standard deviation of each ground monitoring variable was also calculated to indicate the upper and lower bounds of dispersion. Second, a correlation matrix was produced to further validate the association by checking the correlation coefficients and significances (Table 4.3.). Third, bivariate linear regression analyses were estimated to assess the magnitude of change in AQI (dependent variable) explained by each satellite product (independent variables) (Table 4.4.).

In Figures 4.3., the comparison between OMI products (UVAI and AOT) and AQI shows that UVAI had better performance than AOT in temporal consistency under all circumstances. When comparing with AQI, 30 out of 36 UVAI values lied within the variance range of AQI (lower limit: AQI-standard deviation ~ upper limit: AQI + standard deviation), while for AOT only 12 out of 36 lied within the same variance range. Also, all UVAI values lied below the upper limit shadow. Since AQI is a comprehensive indicator of air quality, the similar temporal trend of UVAI indicated that the satellite product UVAI could be used as the measurement of haze even before 2014, the time without ground monitoring data. Their correlations with UVAI and AOT were further tested in a correlation matrix. For PM_{10}, and $PM_{2.5}$, all UVAI plot line presented better spatial consistency than the AOT plot lines. For PM_{10}, the UVAI values were lower than the estimated upper limit, while for $PM_{2.5}$ the UVAI plot line lied above the estimated lower limit.

Figure 4.3. Comparison of Temporal Trends in UVAI, AOT and AQI ground monitoring data.

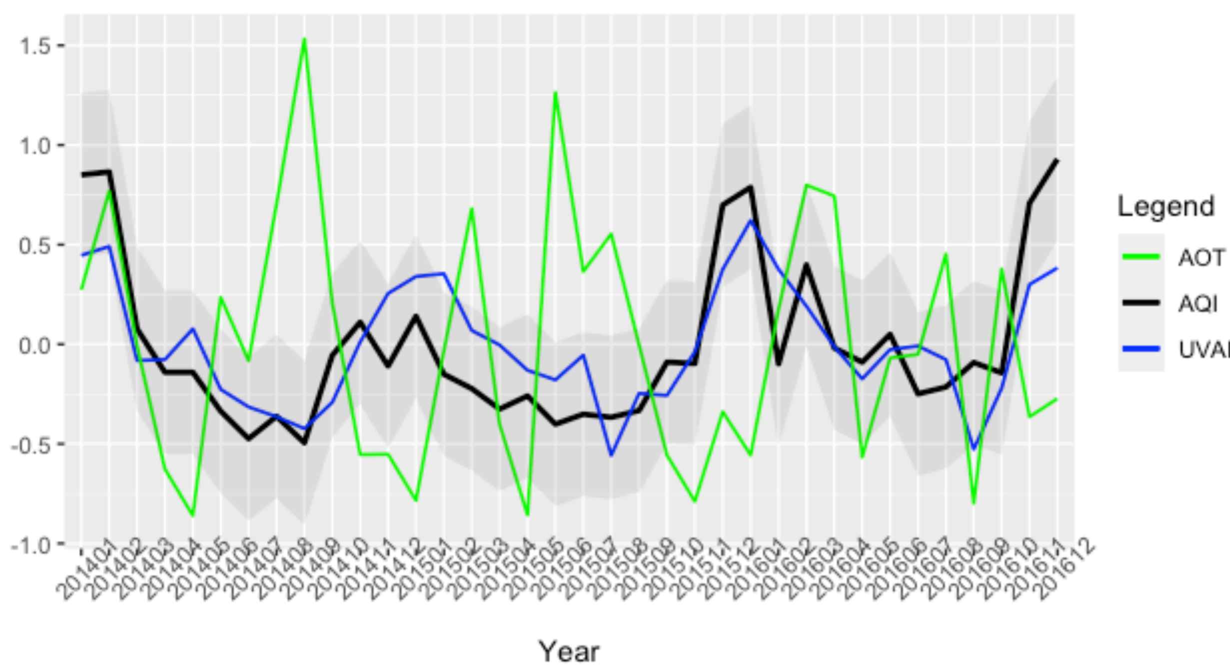


Figure 4.4. Comparison of Temporal Trends in UVAI, AOT and PM_{10} ground monitoring data.

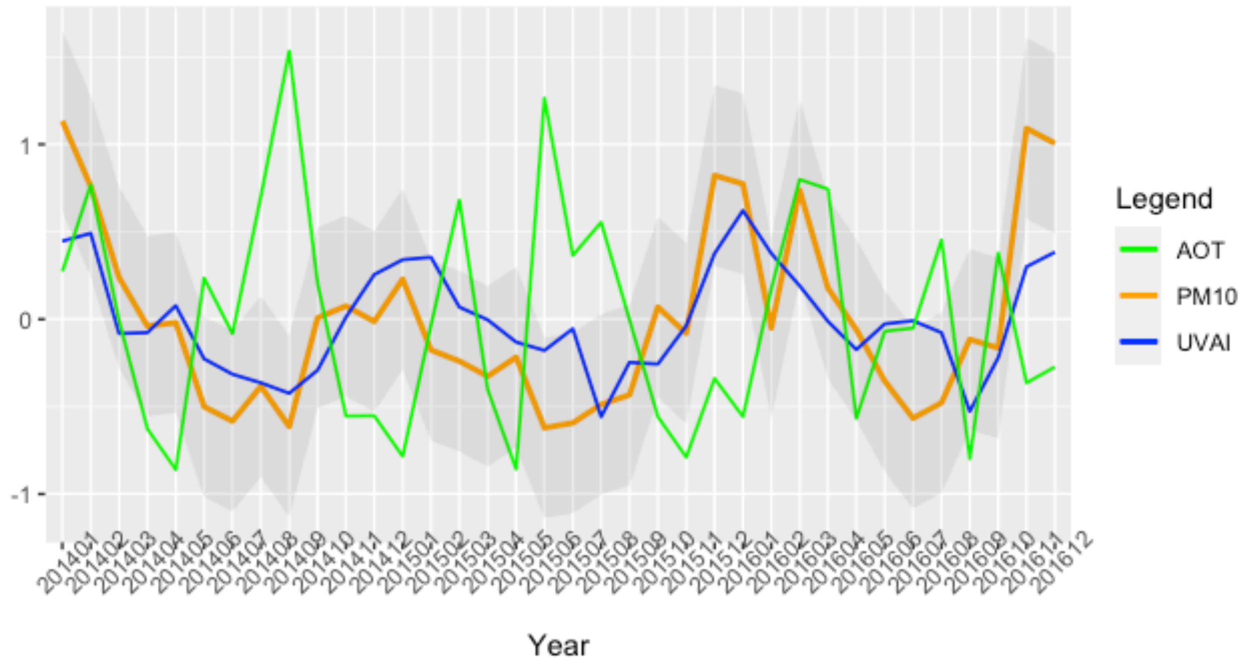


Figure 4.5. Comparison of Temporal Trends in UVAI, AOT and $PM_{2.5}$ ground monitoring data.

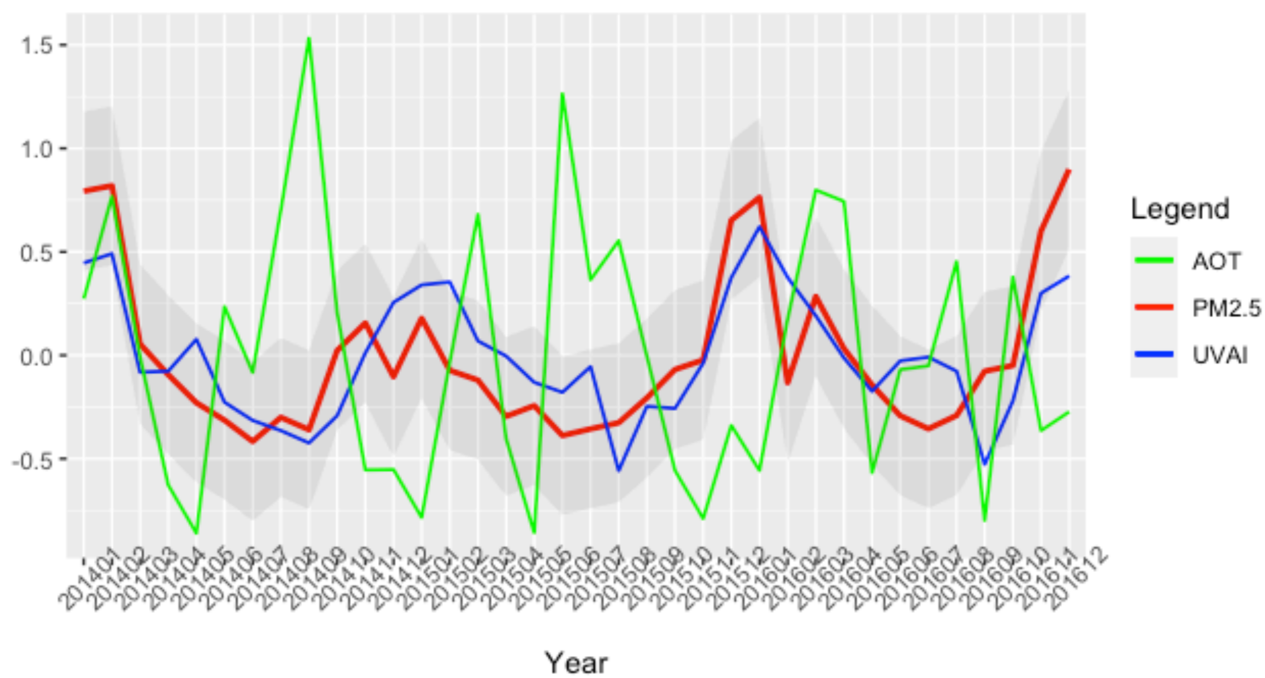


Table 4.3. contains both the table of correlation coefficients and correlation significance among paired variables in the dataset. It indicates that UVAI was significantly associated with AQI and $PM_{2.5}$ and PM_{10}, while AOT showed no significance.

Table 4.3. Correlation Coefficient Significance Matrix of UVAI and AOT and AQI and Particulate Matters.

	UVAI	AOT	AQI	PM2.5	PM10
UVAI	1.00 (NA)	-0.19 (0.27)	0.76 (**0.00**)	0.73 (**0.00**)	0.72 (**0.00**)
AOT	-0.19 (0.27)	1.00 (NA)	-0.17 (0.33)	-0.15 (0.40)	-0.22 (0.21)
AQI	0.76 (0.00)	-0.17 (0.33)	1.00 (NA)	0.98 (0.00)	0.96 (0.00)
PM2.5	0.73 (0.00)	-0.15 (0.40)	0.98 (0.00)	1.00 (NA)	0.96 (0.00)
PM10	0.72 (0.00)	-0.22 (0.40)	0.96 (0.00)	0.96 (NA)	1.00 (0.00)

Finally, to further demonstrate the feasibility of using UVAI to represent haze air quality, the bivariate regression estimates were used to compare the association between AOT/UVAI with AQI. The results showed that UVAI was positively and significantly explained AQI (p-value: 0.0000000767) and 56.49% change in AQI can be explained by UVAI (Table 4.4). On the contrary, AQI and AOT did not have a statistically significant relationship.

Table 4.4. Unadjusted Bivariate Linear Regression Results Estimating AQI in Response to UVAI and AOT.

<table>
<tr><td>Call: lm(formula = AQI ~ UVAI, data = data, na.action = na.exclude)</td><td>Call: lm(formula = AQI ~ AOT, data = data, na.action = na.exclude)</td></tr>
<tr><td>Residuals:
Min 1Q Median 3Q Max
-0.51963 -0.21435 -0.02932 0.18325 0.53013</td><td>Residuals:
Min 1Q Median 3Q Max
-0.48347 -0.26714 -0.15351 0.05619 0.95037</td></tr>
<tr><td>Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.07213 0.15558 0.464 0.646
UVAI 1.04238 0.15294 6.815 7.67e-08 ***</td><td>Coefficients:
Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.2388 0.1672 7.408 1.37e-08 ***
AOT -0.1107 0.1115 -0.993 0.328</td></tr>
<tr><td>Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1</td><td>Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1</td></tr>
<tr><td>Residual standard error: 0.2699 on 34 degrees of freedom
Multiple R-squared: 0.5774, Adjusted R-squared: 0.5649
F-statistic: 46.45 on 1 and 34 DF, p-value: 7.674e-08</td><td>Residual standard error: 0.4093 on 34 degrees of freedom
Multiple R-squared: 0.02818, Adjusted R-squared: -0.0004027
F-statistic: 0.9859 on 1 and 34 DF, p-value: 0.3278</td></tr>
</table>

4.5.c. Spatio-Temporal Distribution of Haze in Xianyang Area, 2008~2016

The spatial distribution of haze in Xianyang Area during the time period-1 (2008~2016) ware calculated, displayed, and examined by month, season, and year. To calculate the trimester average UVAI value for mother who were pregnant during 2007 but gave the birth in 2008, the 2007 UVAI daily data were also collected. However, since the year 2007 lies outside of the study period, it was not included in the examination of the spatial distribution of haze here. However, 2007 December monthly UVAI was used to calculate winter UVAI for 2008.

Figure 4.6. to Figure 4.14. listed the monthly UVAI values for Xianyang Area, which were produced based on the daily satellite imageries. Since it was possible that the missing data in daily

values may have varied spatially from day to day, the numerator and denominator to calculate monthly averages for each grid cell were dependent upon the number of days with valid data. The monthly UVAI data ranged from 0.345 to 1.89 and were subdivided into 9 classes with a first breaking point of 4.0 and equal interval of 0.2.

In most of 2008, the air quality was acceptable with UVAI below 1.0. The beginning and ending months (January, February, and December) show higher density of haze in the central and southern parts of the Xianyang Area, especially around Xinayang County in January. However, the entire situation changed dramatically in 2009 when most months show a slightly higher concentration of haze in the south and east sides. The duration of massive outbreak of haze apparently became longer. The end-of-year outbreak of haze in 2009 first emerged in the right-bottom corner of Xianyang Area and was higher than in surrounding areas, including Xianyang County, Xinpin, Liquan, Jingyang, and Sanyuan, which lasted 5 months until the next spring (April, 2010). This outbreak event started from the south end of the Xianyang Area and gradually spread into the central and north parts. Meanwhile, the density of haze in southern Xianyang Area remained higher than regions. In the rest of 2010, the air quality in the entire Xianyang Area seemed acceptable until rising again in December around Xianyang County. It quickly developed into a severe outbreak of haze covering the whole Xianyang Area in January 2011. The massive distribution shows four rings of degree. The most polluted ring centered in Xianyang County and surrounded by Xingping and Liquan. The slightly less polluted ring was consisted of Wugong, Jingyang, and Sanyuan, the next polluted ring was consisted of most rural counties in Xianyang Area, including Qian, Yongshou, Bin, Xunyi, Chunhua, the least polluted ring included three counties, including Changwu, Gansu Province, Yan'an, and Baoji. After reached the peak, the haze gradually dissipated during February and March. As promised, the end-of-year haze in 2011 came back again in November but with larger coverage than before, including most counties in the Xianyang Area. The good news was that this time the outbreak was not as severe as the previous year and lasted a shorter period till March 2012. The same cycle happened throughout the entire 2012 with better air quality in most time and the massive haze outbreak emerged in south part of Xianyang Area again in November 2012. The difference was the peak of this end-of-year haze outbreak in 2012 shifted from winter (December or January) to the early spring in following year. In 2013, the most severe haze pollution emerged in March with similar four geographical rings of degree. But only during this time the degree of pollution for each ring was higher than previous time. In addition, the end-of-year haze outbreak in 2013 returned in October, one month earlier than in previous years. Moreover, the high concentration of haze (UVAI>1.2) lasted entire winter from December to February 2014 in most counties of the Xianyang Area. The condition of air quality in the first two-thirds of 2014 was less acceptable than in previous years. Only two months, September and October, had UVAI smaller than 0.8 throughout entire Xianyang Area. This status in 2015 apparently became worse. For example, the haze outbreak that was initiated at the end of 2014 lasted much longer than ever (10 months from November 2014~Augst 2015). Furthermore, the concentration of haze kept a relatively high level (UVAI>1.0) throughout the entire year. It was the first time that the middle year's months (May, June, July, and August) had higher level of haze (UVAI>1.0). This high-level haze appeared in west side counties of Xianyang Area, such as Changwu, Bin, Yongshou, Qian, and Wugong. The same situation also happened in 2016. The only difference was that in 2016. June, July, and August had more severe and massive haze in the west wing of Xianyang Area than May.

Figure 4.15. to Figure 4.17. contained all seasonal UVAI imageries that were produced based on monthly imageries. The sequence of season as Winter (December, January, February),

Spring (March, April, May), Summer (June, July, August), and Fall (September, October, November). The seasonal UVAI ranged from 0.479 to 1.44. The seasonal average smoothed the variation among each grid cells. Therefore, in order to understanding the differences, the whole range (0~1.5) was classified into 11 categories with a first breaking point of 0.5 and equal interval of 0.1. Table 4.5. shows the month of the imagery data in relation to season and year used.

Table 4.5. Seasonal Ultraviolet Aerosol Index (UVAI) Calculation Scheme.

Imagery	Season	Year
Dec-2007, Jan-2008, Feb-2008	Winter	2008
Mar-2008, Apr-2008, May-2008	Spring	2008
Jun-2008. July-2008, Aug-2008	Summer	2008
Sep-2008, Oct-2008, Nov-2008	Fall	2008
--	--	--
--	--	--
Sep-2016, Oct-2016, Nov-2016	Fall	2016

The winter of 2008 had very distinctive feature of haze than other three seasons. All the counties in Xianyang area showed certain level of haze pollution (UVAI>0.9). Particularly, the southern counties, including Wugong, Qian, Liquan, Xinping, Jingyang, and Xianyang, appeared to be the hotspot areas (UVAI>1.2). This seasonal distinction was seen again in the next year. In 2009, the severity of haze alleviated somewhat, but the duration and coverage of affected areas became longer and larger with a very clearly spatial variation. For example, in winter 2009, the haze emerged in southern counties again with a hotspot around Xianyang county, while in spring and summer the haze was blown to the east side, including Xunyi, Chunhua, Jingyang, Sanyuan, and Xianyang. In 2010, the severe haze outbreak (UVAI>1.2) lasted during both the winter and spring seasons with three concentration rings. In winter 2010, similarly geographic haze rings that were discussed above in monthly images also appeared here too. The highest concentration ring (UVAI>1.2) consisted of southeastern counties, such as Xingping, Liquan, Jingyang, Xianyang, and Sanyuan. The neighboring counties, including Wugong, Qian, Yongshou, and Chunhua, formed the next high concentration ring(UVAI>1.0), while the rest counties, including Changwu, Bin, and Xunyi, belonged to the least high concentration ring (UVAI>0,9). In the spring, the constituents of these three rings have some geographic change. The degree of severity decreased successively from the southeast to the northwest. Similar winter and spring concentration rings also appeared in winter and spring 2011. However, the change of haze density was contradictory between the two years. For example, in winter ring 2011 the counties in each level had one degree (one degree=0.5) higher UVAI values than the same counties in winter ring 2010, while in spring ring 2011 the counties in each level had two degrees lower UVAI values than in spring ring 2010. The situation of haze pollution in winter and spring became better in 2012 with lower density in each county. However, the condition quickly became worse again in 2013 with a high level of haze pollution in both winter and spring. Only this time the peak shifted from winter to spring. The southeastern counties again remained the hotspot areas (UVAI >1.2). Moreover, it was the first time that the haze pollution appeared in the fall season in Xianyang and neighboring counties. In 2014, the similar winter ring returned as scheduled. However, the dissipation of this ring took three seasons, much longer time than previous years. In last two years, 2015 and 2016, the winter haze pollution rings came back as usual, while the air quality in the northwestern counties was better than previous years. In other words, the gap of difference in air quality between the southeastern corner where more urbanized counties located and northwestern corner where more ruralized counties resided became larger. Moreover, for the first time, the high-level haze pollution (UVAI>1.0) also appeared in the west side of Xianyang Area in the summer season.

Figure 4.18. display the annual UVAI imageries from 2008 to 2016 for Xianyang Area. The yearly UVAI ranged from 0.58 to 1.059. It further smooths the variation within Xianyang

Area. Therefore, in order to present the variance, the range of yearly UVAI (0~1.1) is divided further clearly into 11 categories with a first breaking point of 0.6 and equal interval of 0.05. Comparing to monthly and seasonal haze images, the yearly data clearly indicated an outstandingly and steadily increasing trend in both coverage and severity of the haze pollution within Xianyang Area from 2008 to 2016. For example, in 2008, the light haze pollution (UVA>0.8) appeared only in the lower half of the Xianyang Area, including Wugong, Qian, Liquan, Xinping, Xianyang, Jingyang, and Sanyuan. Then the polluted area rapidly expanded to the entire area in 2009 except the northwestern corner, including county of Chagwu, Bin, Yongshou, and Xunyi. Meanwhile, the air quality in Xianyang County as well as its surrounding counties (Xinping, Liquan, Jingyang, and Sanyuan) greatly deteriorated because UVAI jumped 4 levels from 0.8~0.85 to 1.0~1.05. Then in the following year, 2010, the severity of haze in the southeastern counties had small a degree of alleviation but the degree of air pollution in rest the counties became exacerbated. The coverage of haze pollution developed into the entire Xianyang area with no county had UVAI<0.8. The situation became worse by having more counties' UVAI increased at least on degree. For example, the UVAI for Yongshou increased from the level of 0.8~-0.85 to 0.85 to 0.9, while Qian and Wugong increased from 0.85~0.9 to 0.9~0.95. The good news was that the air quality for Xunyi became better. While after entering 2012, the air quality in the entire Xianyang Area showed some improvement by having UVAI decrease 1 degree. However, this temporary mitigation did not last longer in 2013. On the contrary, for the first time, a massive outbreak of server haze pollution struck the entire Xianyang Area. Most counties in the Xianyang Area had UVAI larger than 0.85. Noticeably, the UVAI value for the southeastern 4 counties, including Xinping, Liquan, Jingyang, and Xianyang, have reached another peak (1.0~1.05). Then in 2014 the degree of pollution in these four counties had a slight decrease. However, the entire Xianyang area still maintained a haze polluted status by keeping UVAI larger than 0.85. After a small break, the haze pollution started showing a raising trend again in 2015, especially in the west side of Xianyang Area. For example, the UVAI for Changwu, Bin, and Yongshou jumped from 0.8 to 0.9 level and Qian and Wugong jumped from 0.9 to 1.0 level. Meanwhile, the situation became further exacerbated in 2016 by having UVAI for each county increased one more degree. For example, the UVAI for the southeaster four counties increased from 0.9 level to 1.0 level and Xunyi and Chunhua increased from 0.8 to 0.9 level.

Figure 4.6. Monthly Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2008.

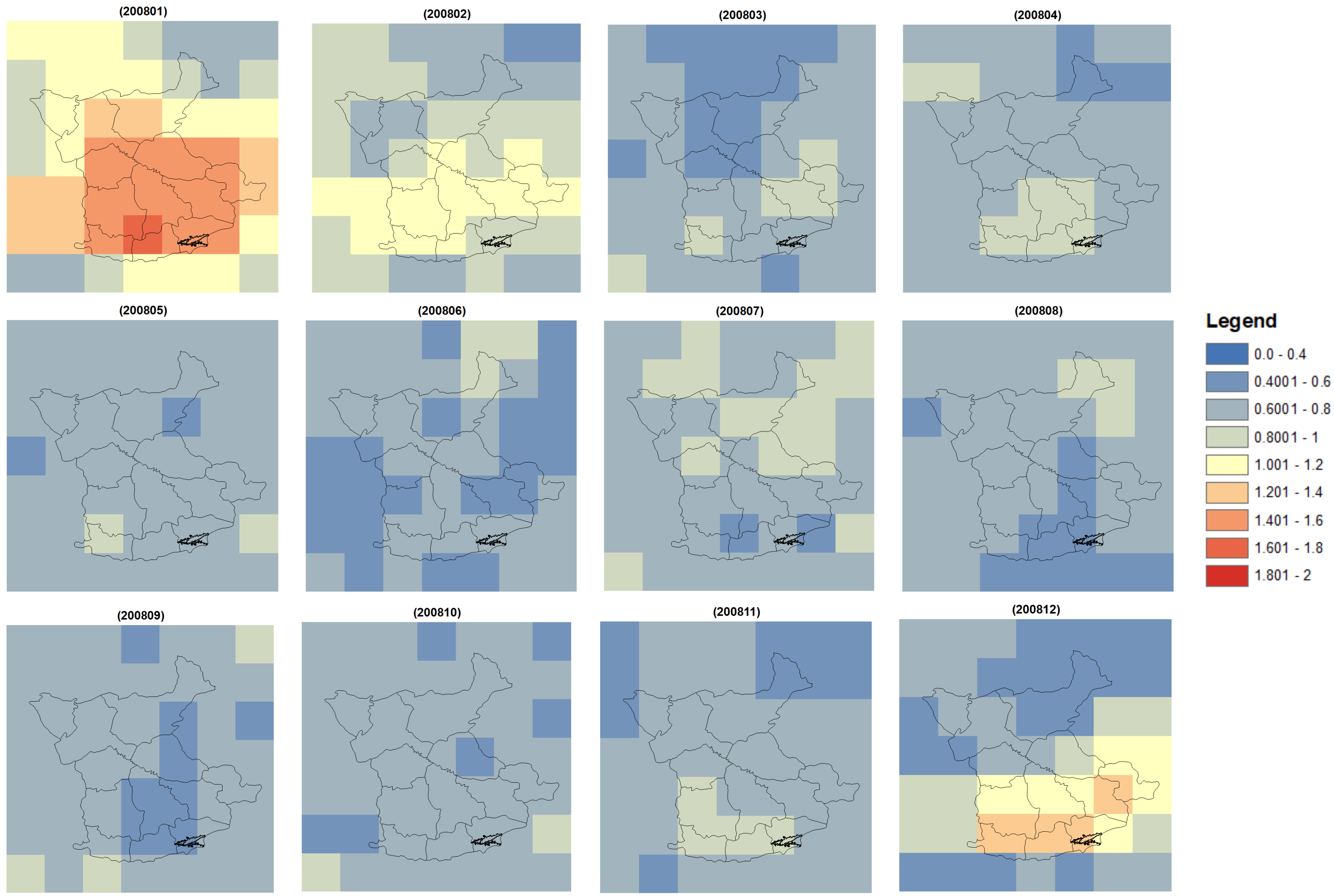


Figure 4.7. Monthly Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2009.

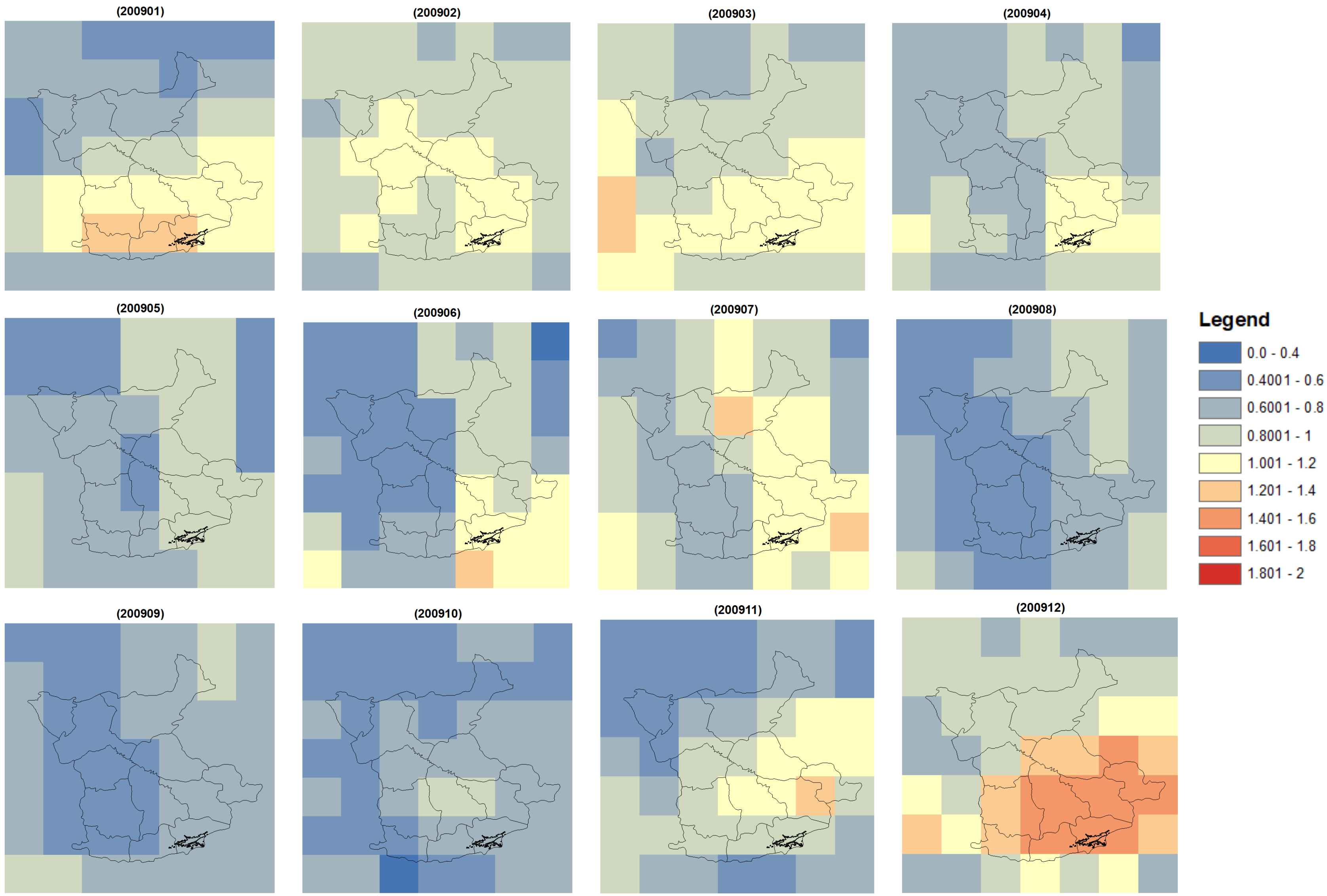


Figure 4.8. Monthly Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2010.

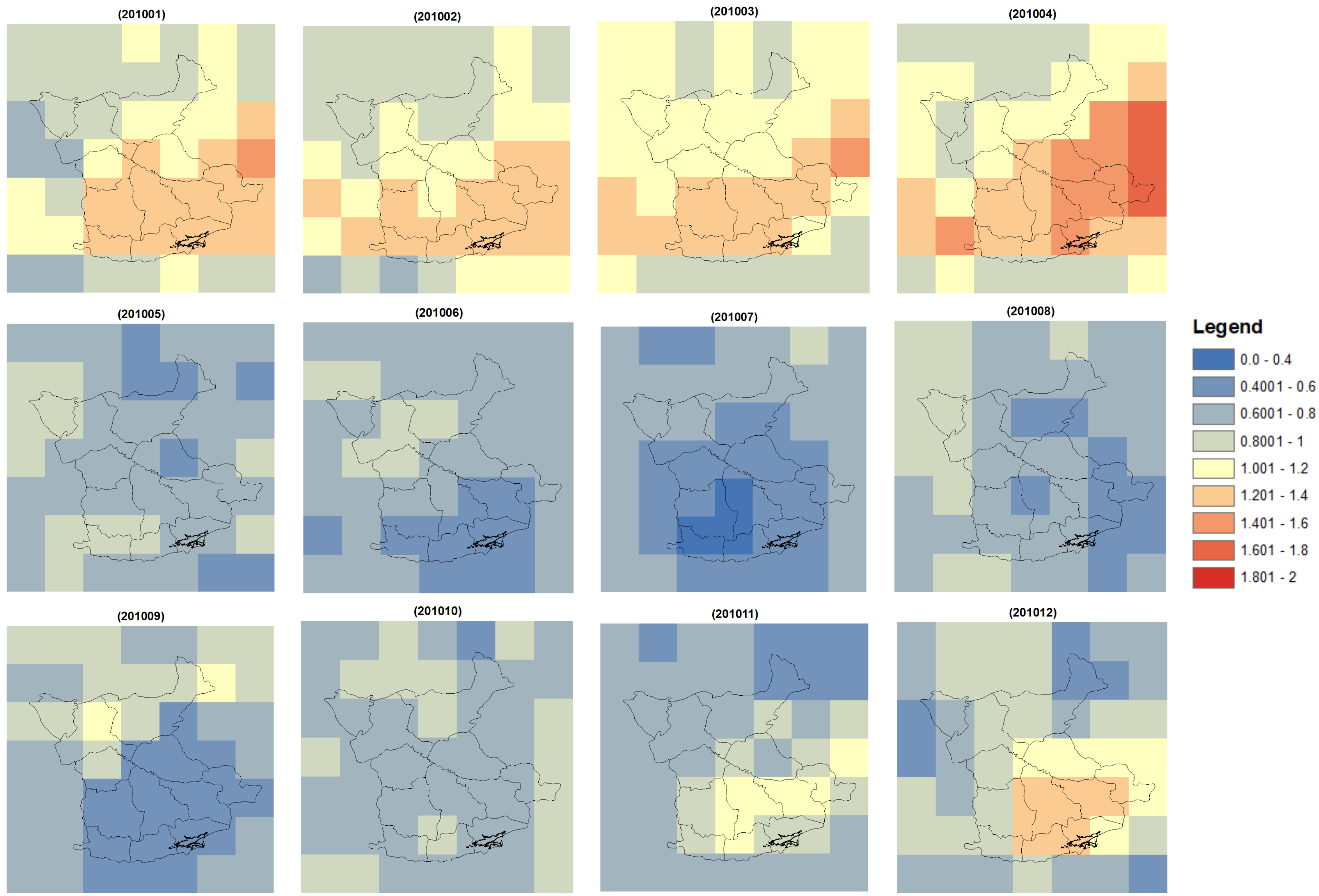


Figure 4.9. Monthly Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2011.

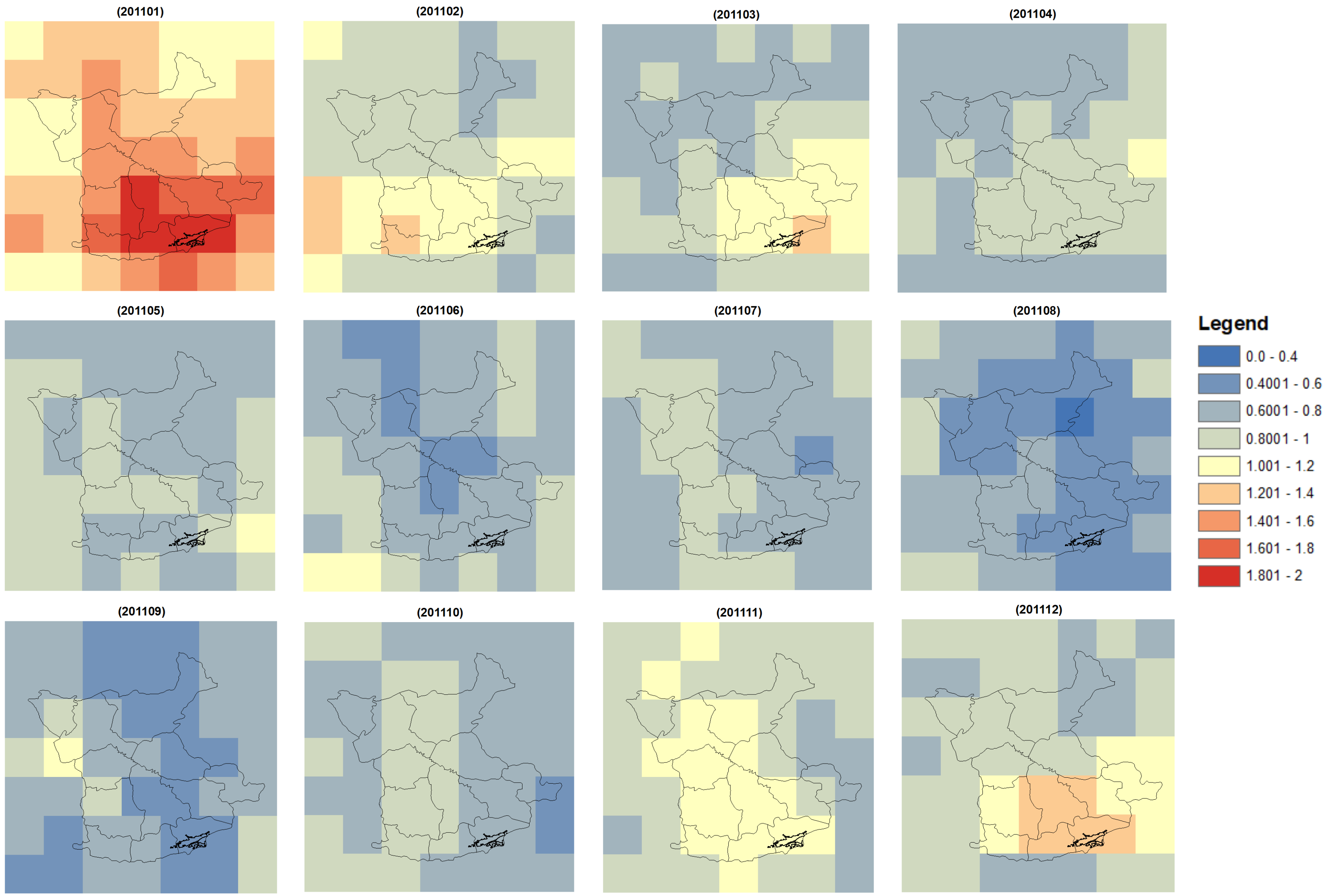


Figure 4.10. Monthly Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2012.

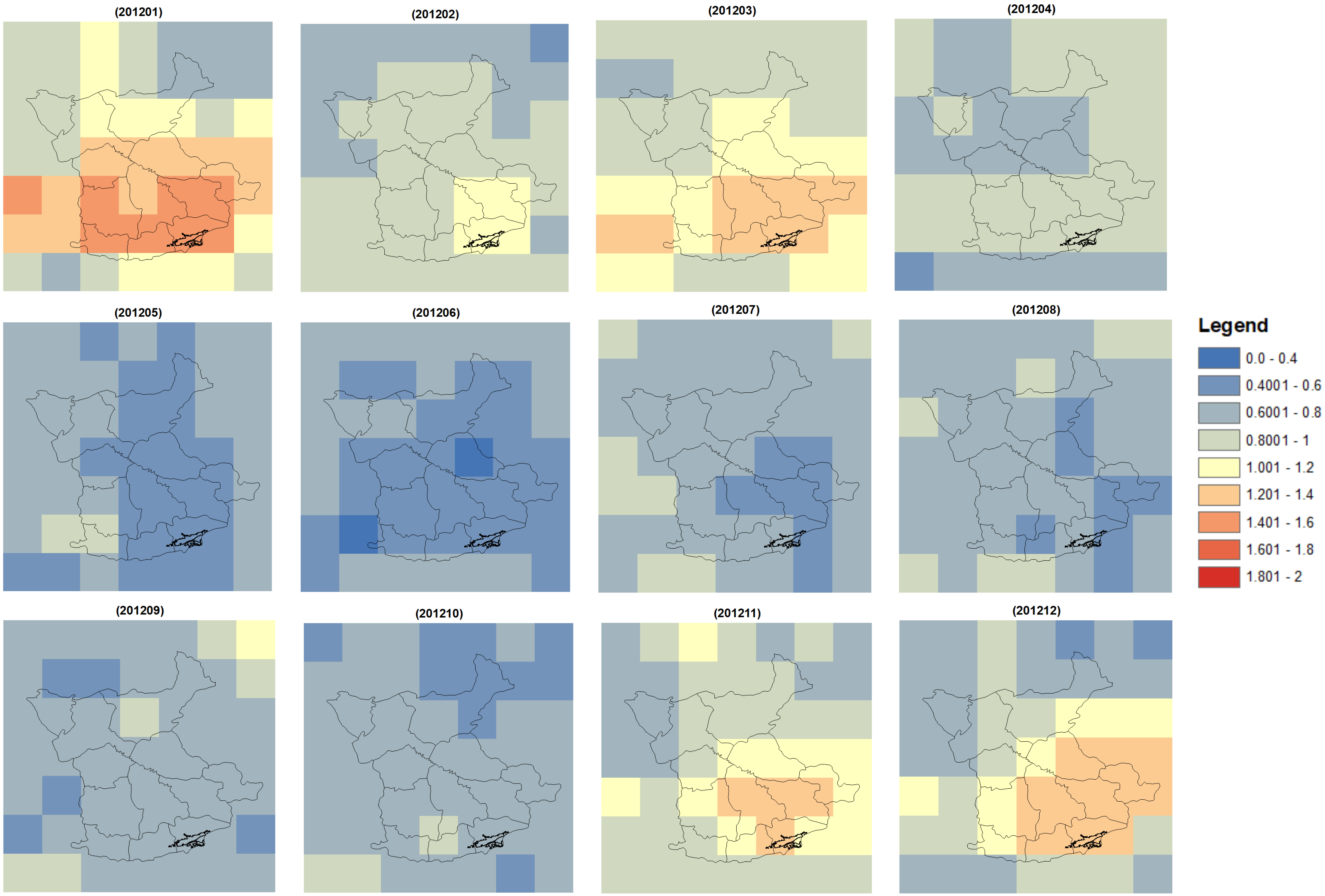


Figure 4.11. Monthly Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2013.

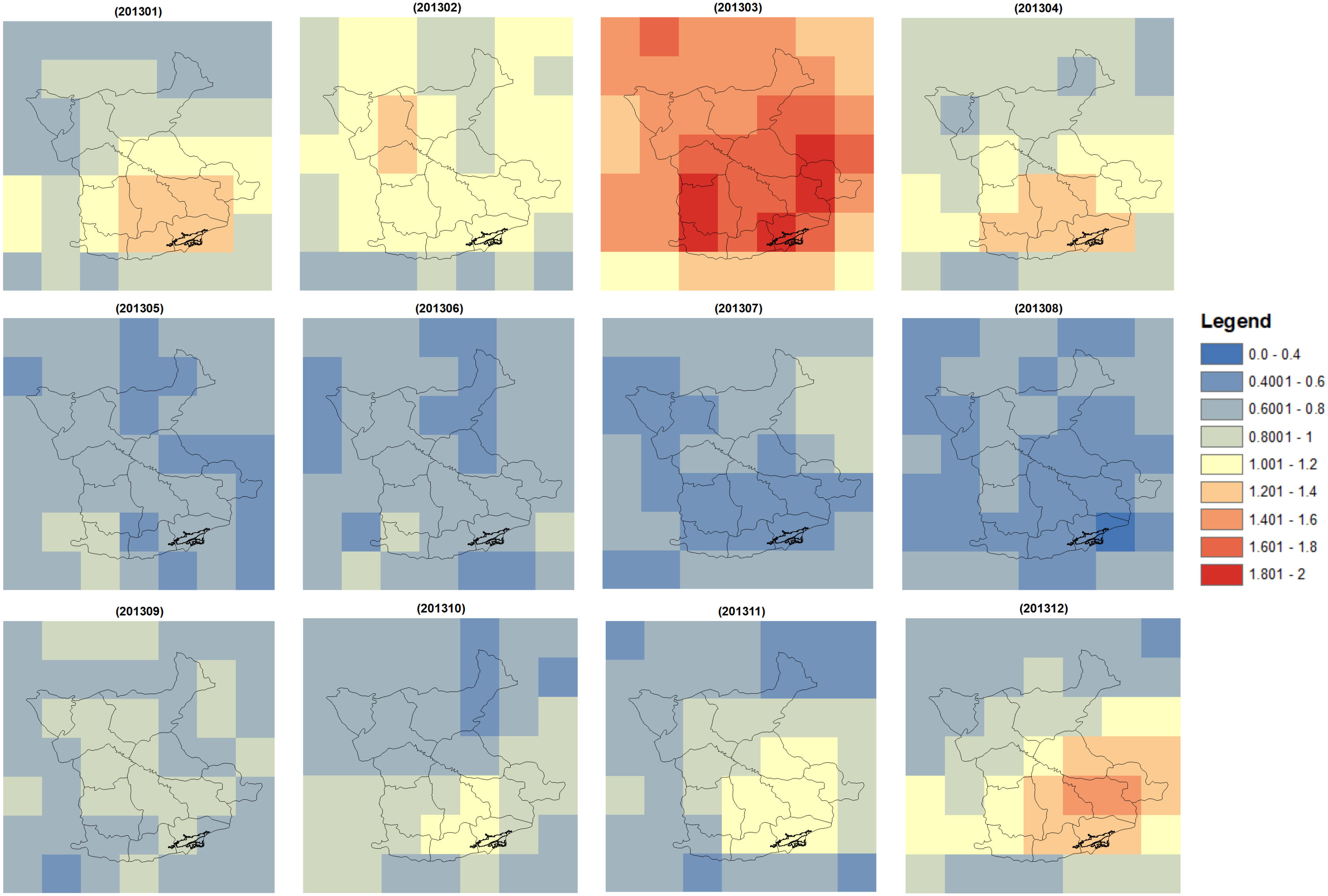


Figure 4.12. Monthly Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2014.

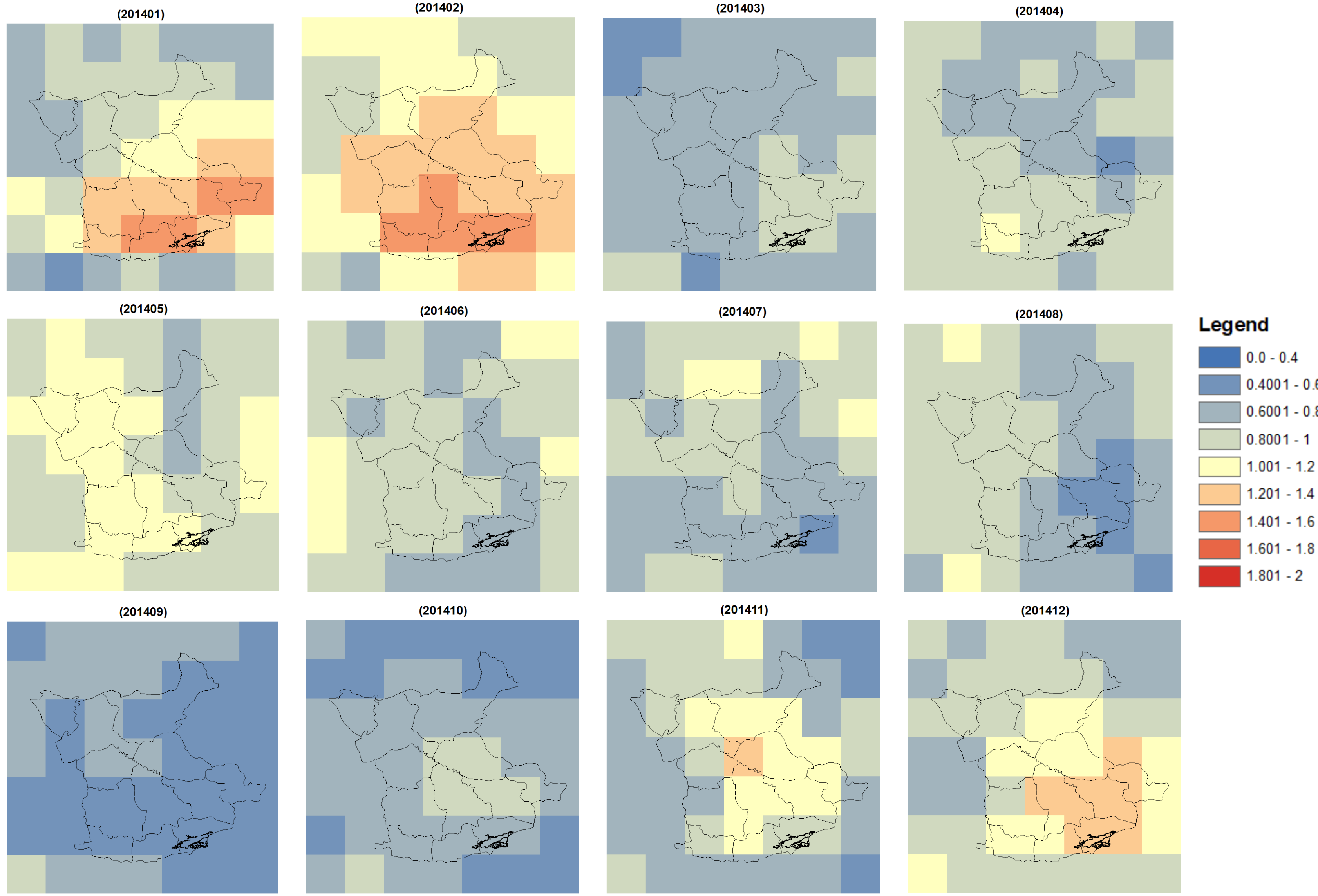


Figure 4.13. Monthly Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2015.

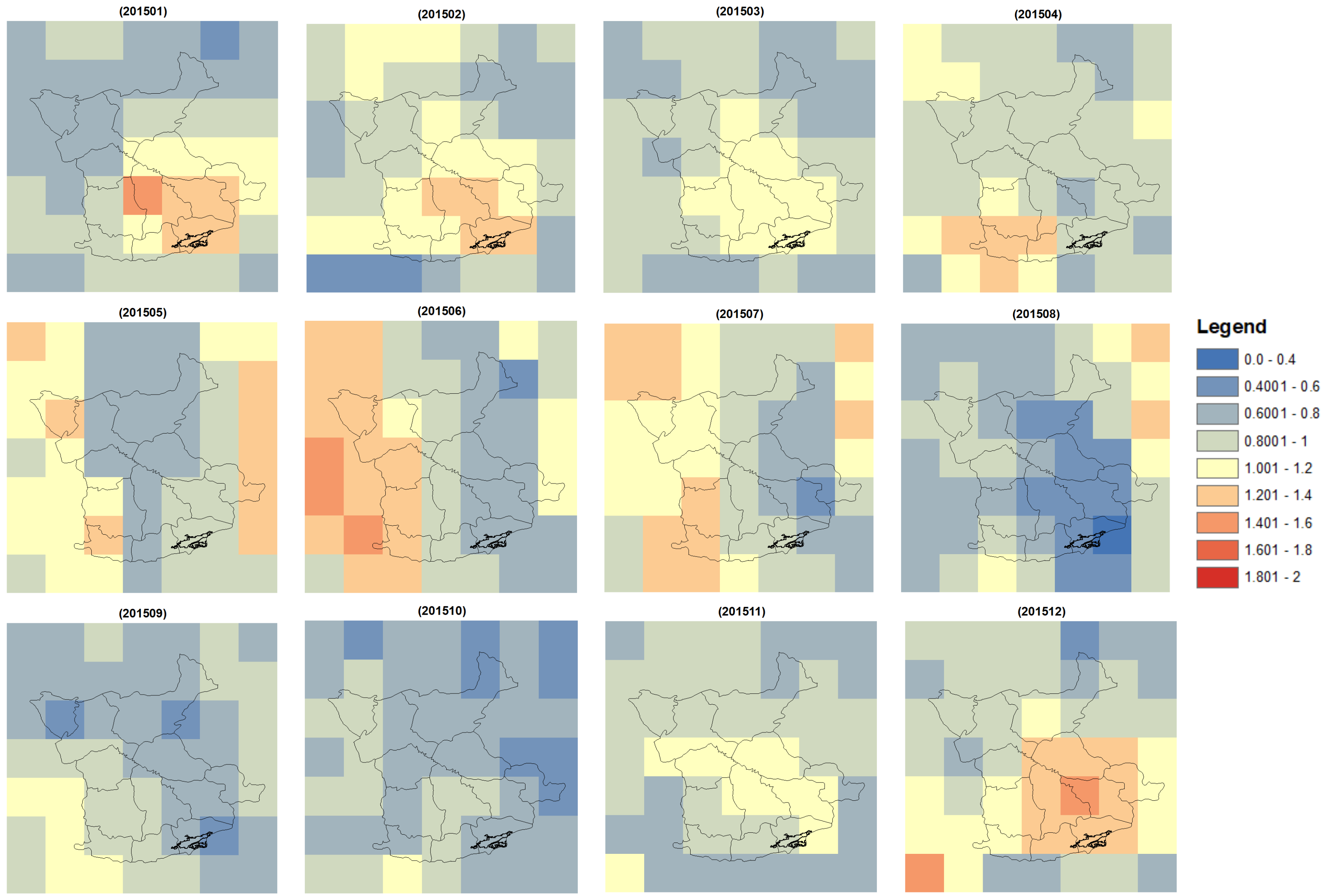


Figure 4.14. Monthly Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2016.

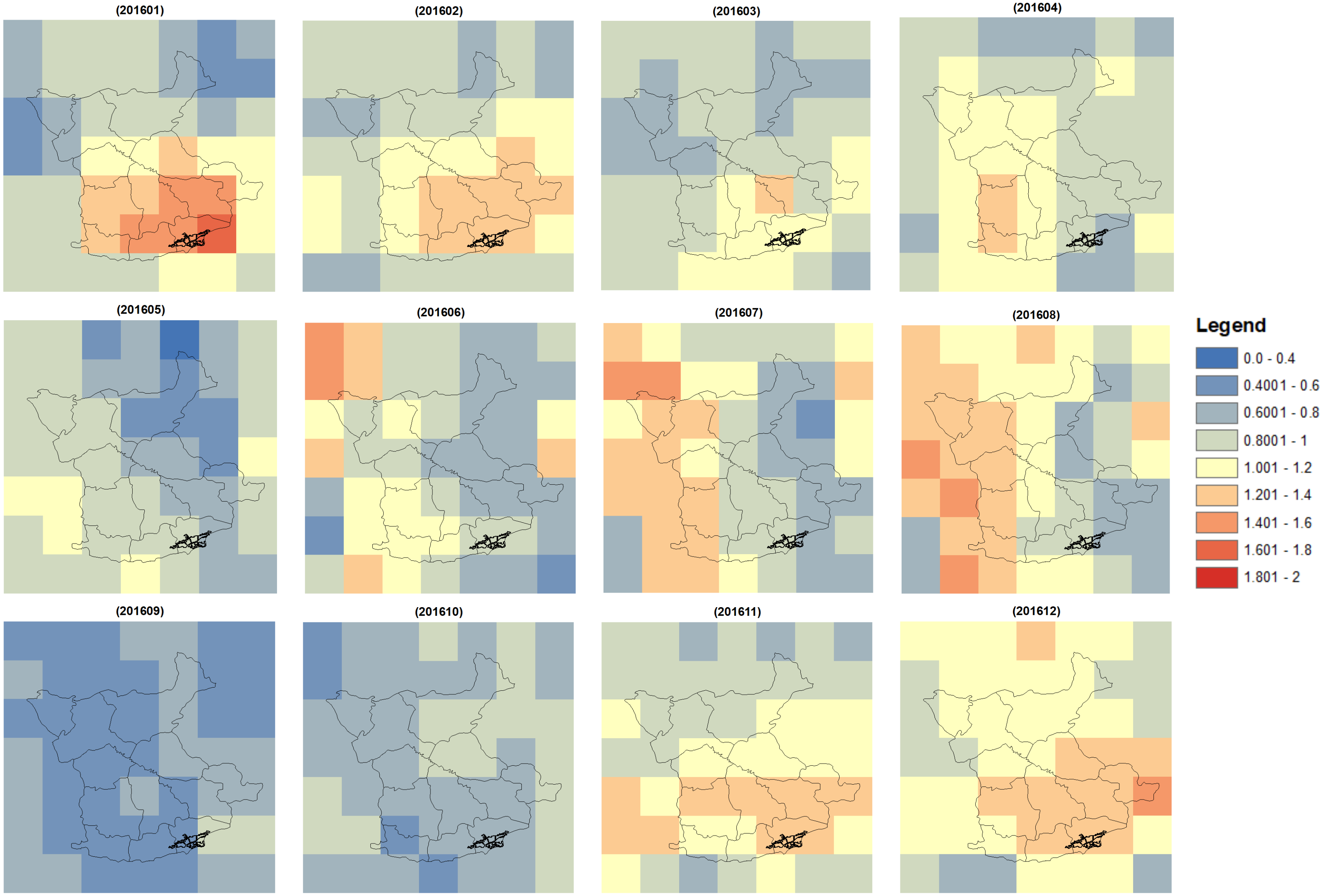


Figure 4.15. Seasonal Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2008 to 2010.

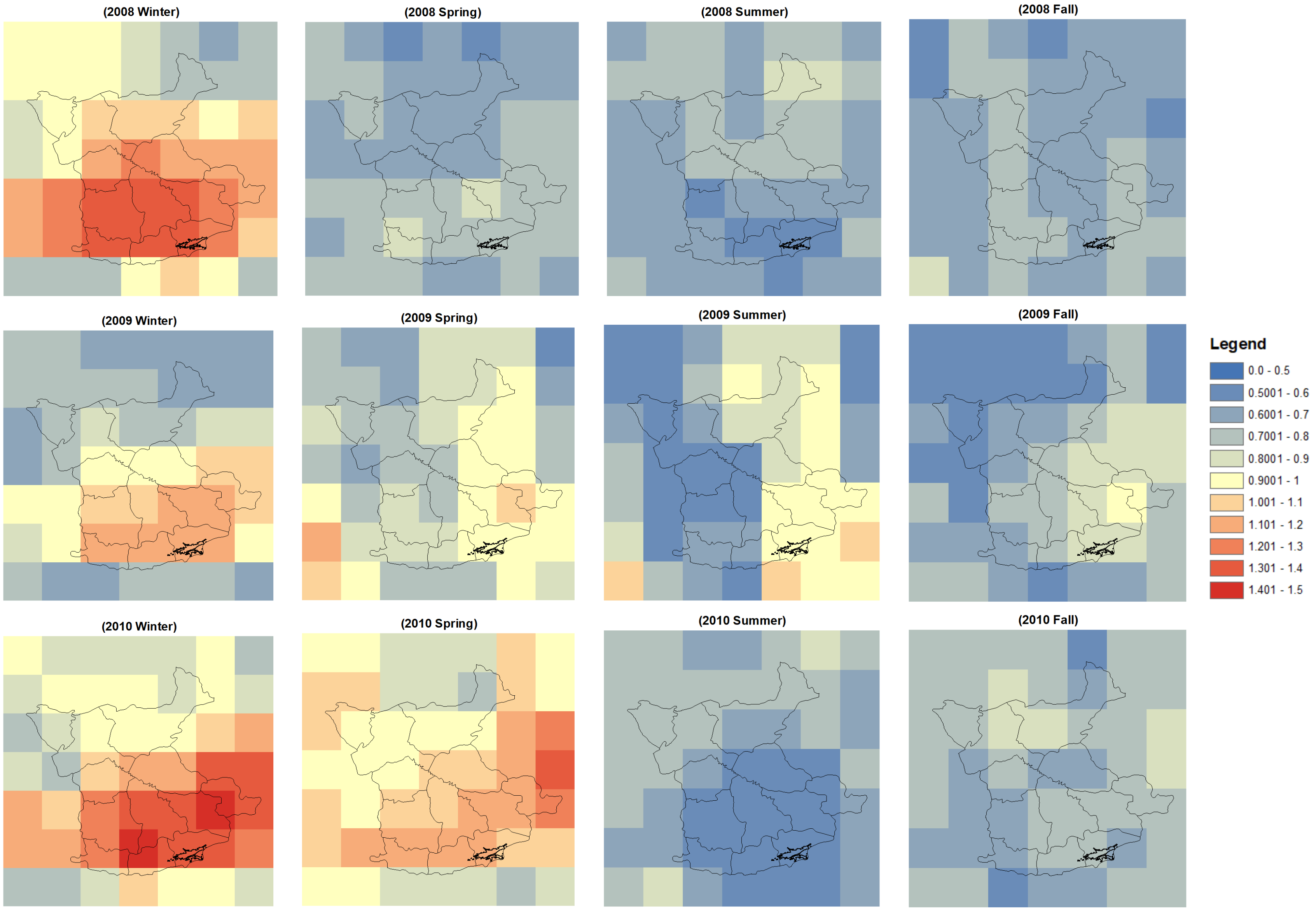


Figure 4.16. Seasonal Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2011 to 2013.

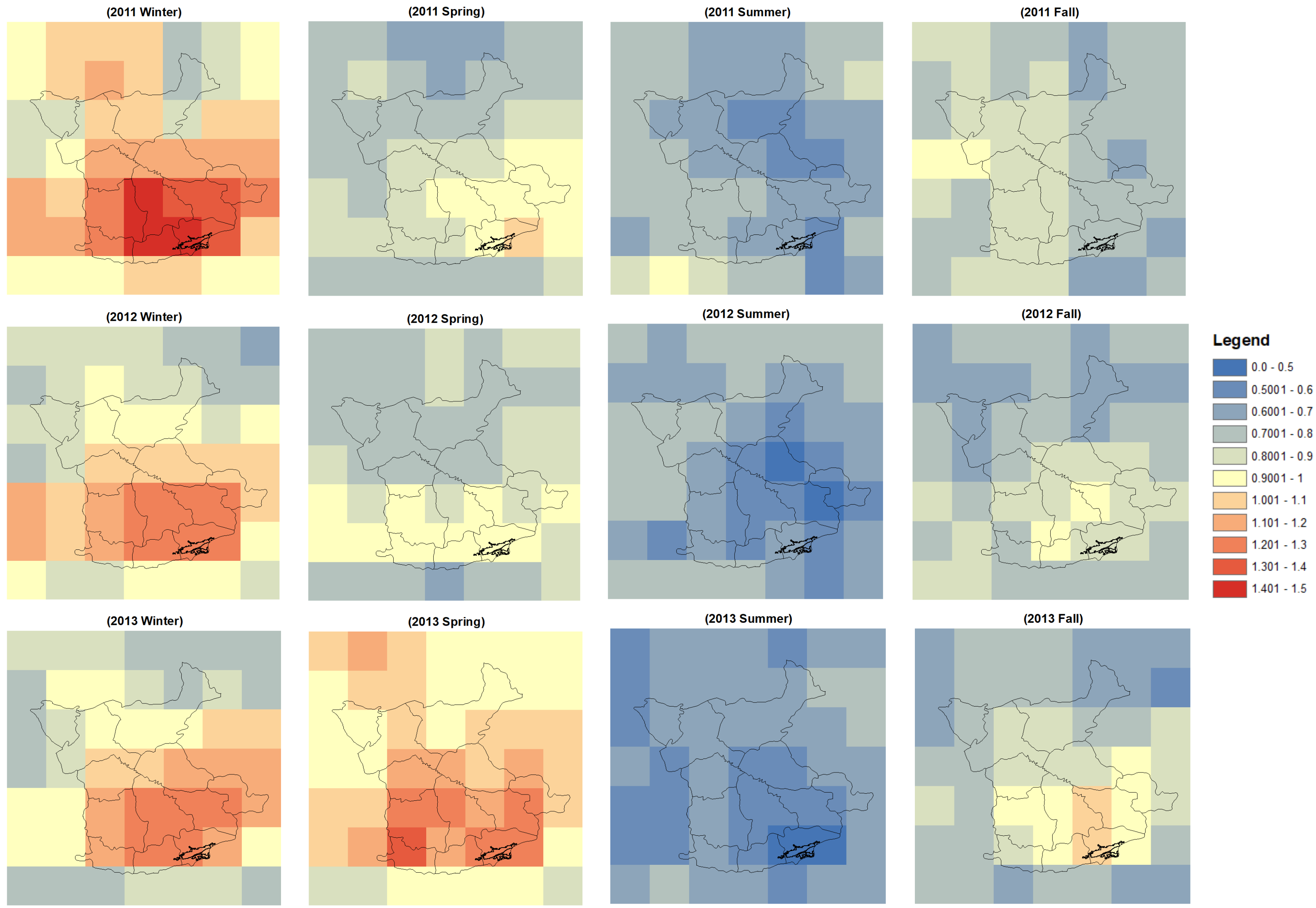


Figure 4.17. Seasonal Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2014 to 2016.

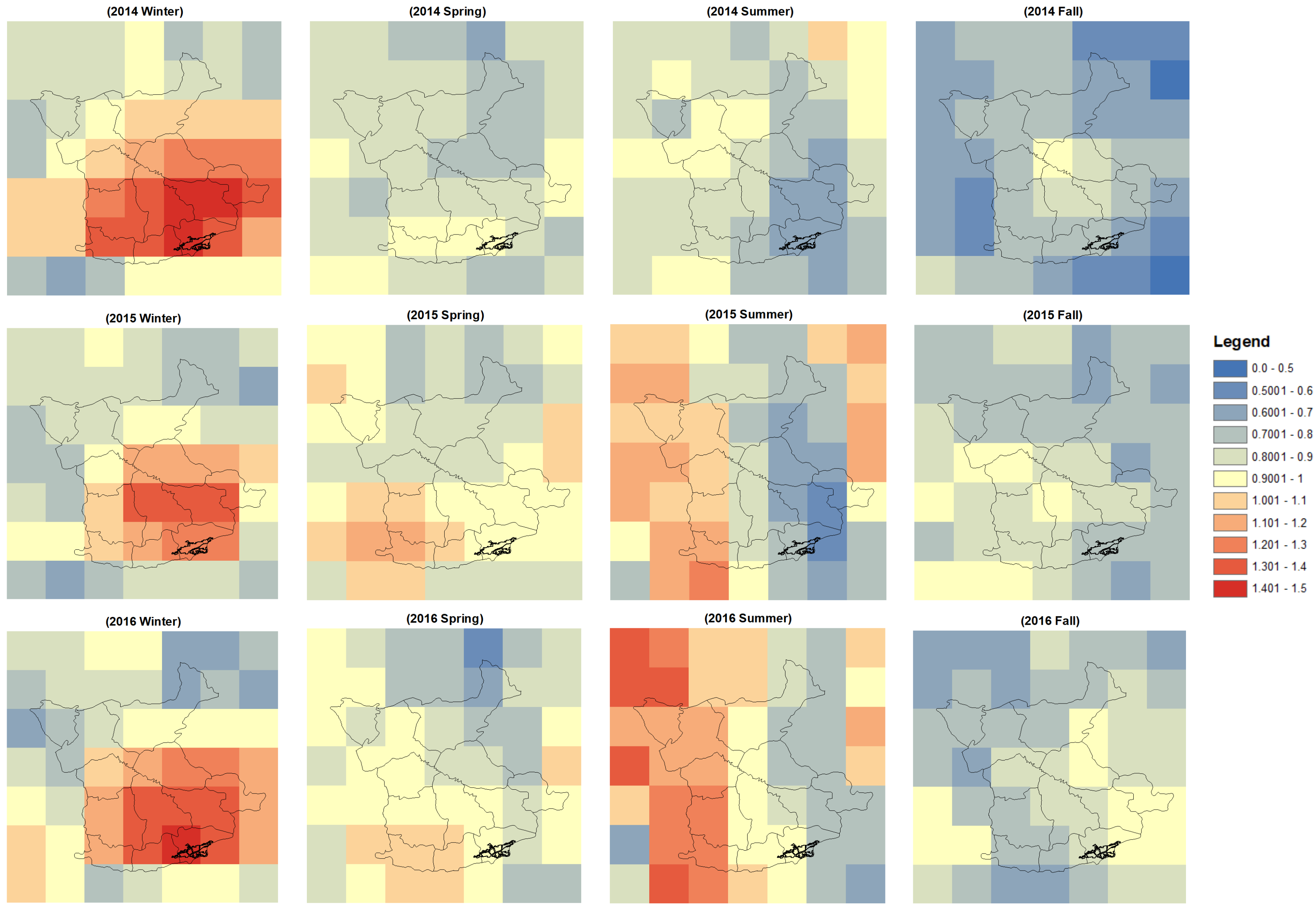


Figure 4.18. Annual Ultraviolet Aerosol Index (UVAI) Values for Xianyang Area, China, 2008 to 2016.

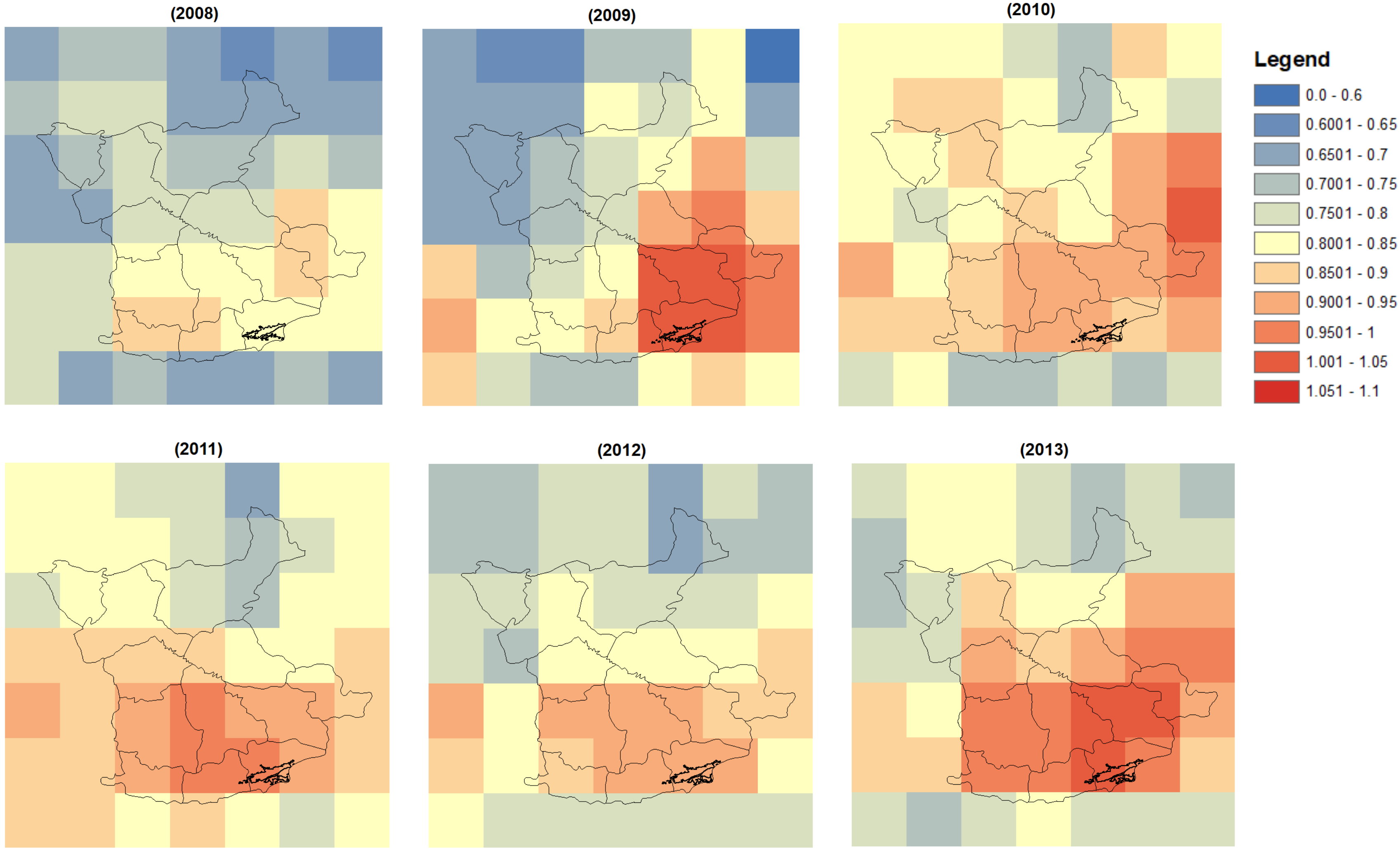
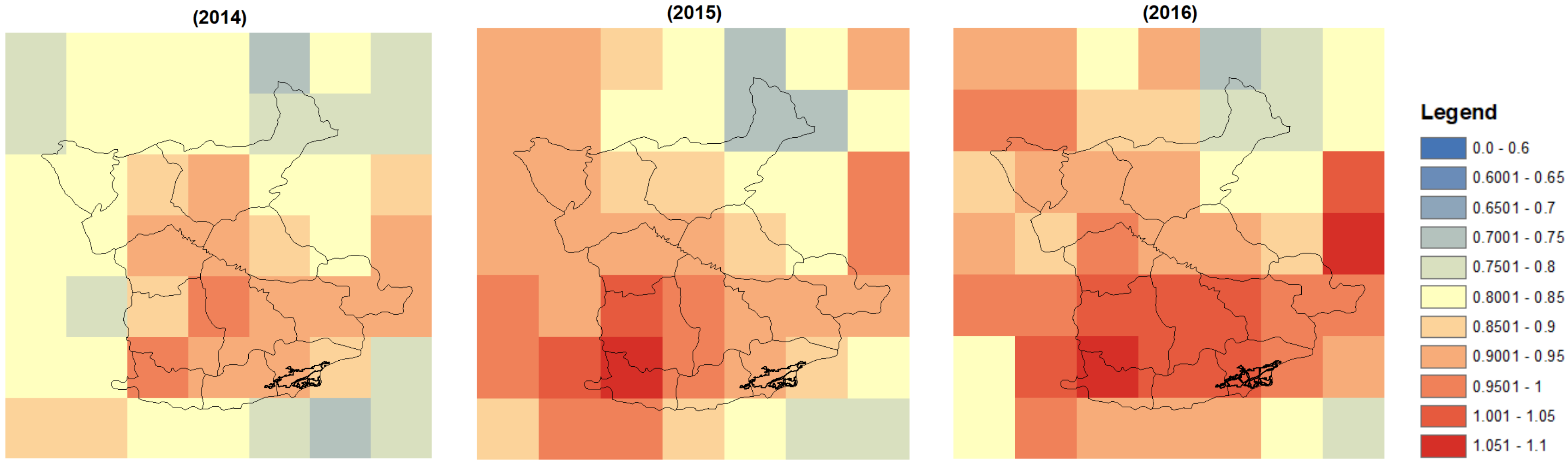


Figure 4.18. (cont'd).



4.5.d. Temporal Variation of Haze in Xianyang Municipality

In this section, the focus zooms into Xianyang Municipality to study the temporal variation of haze within an urbanized area. The monthly, seasonal, and yearly UVAI values for Xianyang Municipality are extracted from the imageries above and plotted in line graphs.

Table 4.6. summarizes the descriptive statistics for all monthly UVAI data between 2008 and 2016. The year 2009 has the highest starting point (Min=0.683) and maintained a high level of haze throughout the whole year (Mean=1.011 and Median=1.027). The year of 2013 has the highest ending point (Max=1.89), following by year of 2011 (Max=1.873), Even though the year 2013 had the largest monthly difference (Range=1.482) and dispersion (Std.Dev.=0.434), most months still maintained a relatively higher level of haze (Mean=1.002 and Median=1.069). Figure 4.19. shows the monthly pattern of haze. The graph clearly demonstrates a slightly right-skewed U shape with high values in both ends of the year and low values around August and September. The most severe haze can be detected either in December or January. The haze decreased slowly in first half year (7 or 8 months) and then quickly rose again in the second half of the year (3 or 4 months). Before hitting the turning point, most lines detected a small rise peaking around June and July.

Table 4.6. Annual Ultraviolet Aerosol Index (UVAI) Descriptive Statistics for Xianyang Municipality, China, 2008~2016.

	Min	Max	Range	Mean	Median	Std.Dev	N.Valid
2008	0.485	1.514	1.029	0.813	0.739	0.305	12
2009	0.683	1.502	0.819	1.011	1.027	0.232	12
2010	0.441	1.407	0.966	0.934	0.865	0.377	12
2011	0.483	1.873	1.390	0.955	0.868	0.393	12
2012	0.556	1.509	0.953	0.942	0.862	0.346	12
2013	0.408	1.890	1.482	1.002	1.069	0.434	12
2014	0.550	1.465	0.915	0.932	0.895	0.309	12
2015	0.416	1.350	0.934	0.947	0.928	0.281	12
2016	0.447	1.595	1.148	1.043	0.963	0.317	12

Figure 4.19. Monthly Ultraviolet Aerosol Index (UVAI) for Xianyang Municipality, China, 2008~2016.

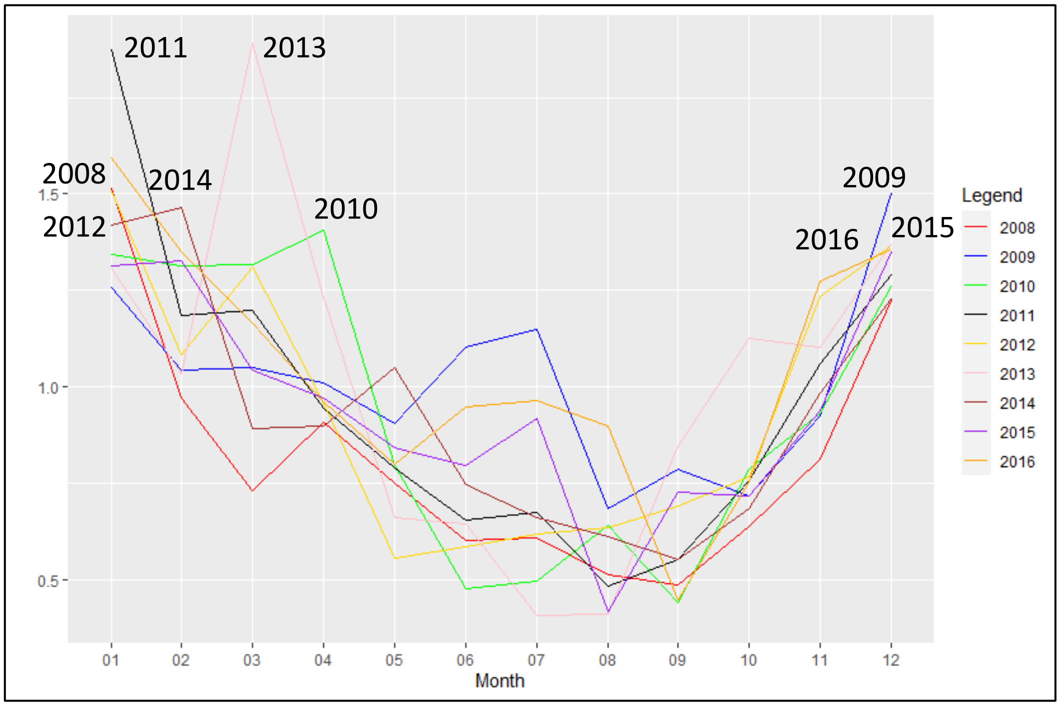


Table 4.7. summarizes the descriptive statistics for all seasonal UVAI data from 2008 to 2016 and Figure 4.20. illustrates the temporal change of these seasons. In China, the winter always is the high-incidence season of haze due the increasing consumption of coal for heating, the burning of straw after the fall harvest, the traditional holiday celebration with large amount of firework, and more stagnant atmosphere conditions. The results in Table 4.7 shows that summer had the best air condition (Min=0.487 and Max=0.978) throughout all the years (Mean=0.707 and Median=0.642) but had the largest difference (range=0.491) and dispersion (Std.Dev.=0.164). On the contrary, Winter had the worst air condition (Min=0.977 and Max=1.44) in all the years (Mean=1.296 and Median=1.304). In addition, the air quality in Fall is more consistent than other seasons (Std.Dev.=0.103). From Figure 4.20, it is also clear that Winter is the season with the most severe haze by lying on top of other seasons. Only in 2013 was spring the worst season. The next

severe season is Spring followed by Fall. Summer was the most stable season with 6 out of 9 smaller than Fall.

Table 4.7. Seasonal Ultraviolet Aerosol Index (UVAI) Descriptive Statistics for Xianyang Municipality, China, 2008~2016.

	Min	Max	Range	Mean	Median	Std.Dev	N.Valid
Fall	0.646	1.025	0.379	0.801	0.791	0.103	10
Spring	0.795	1.261	0.466	0.986	0.964	0.138	10
Summer	0.487	0.978	0.491	0.707	0.642	0.164	10
Winter	0.977	1.440	0.463	1.296	1.304	0.143	10

Figure 4.20. Seasonal Ultraviolet Aerosol Index (UVAI) for Xianyang Municipality, China, 2008~2016.

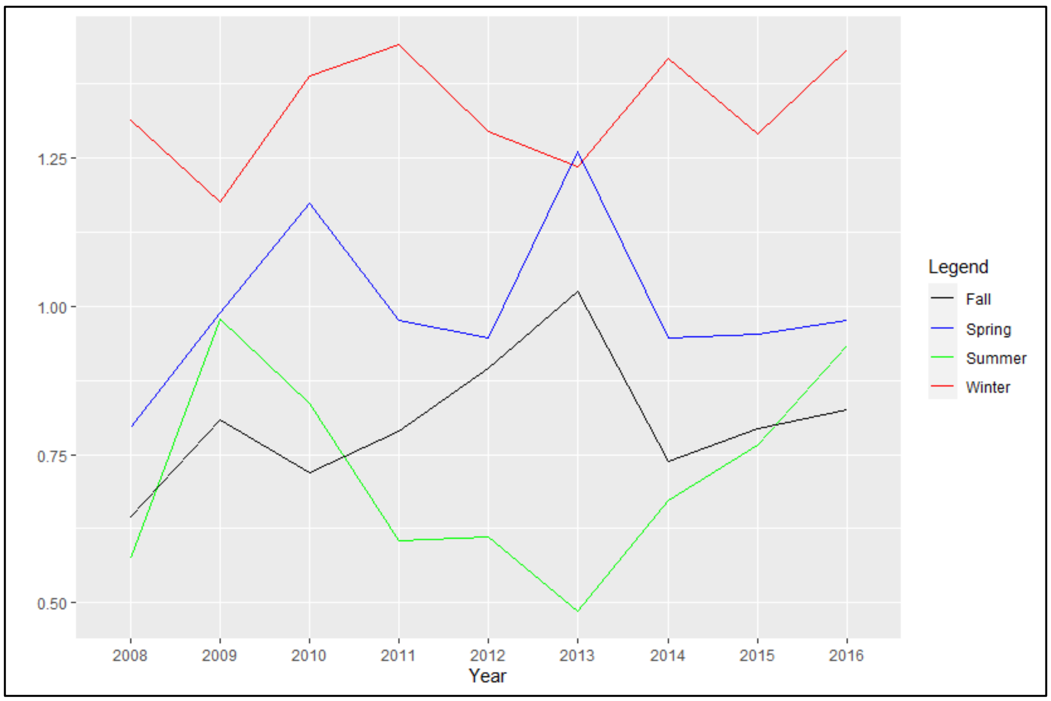
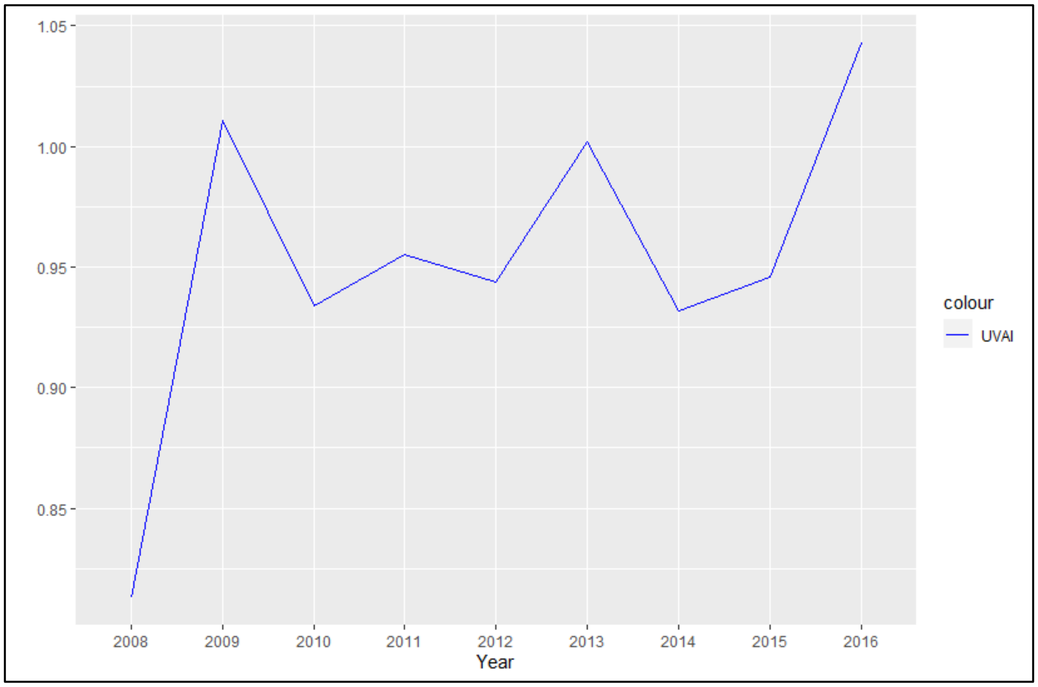


Figure 4.21. shows yearly change of UVAI between 2008 to 2016. The line graph shows that haze in 2008 was still low. However, the effect of years of accumulation in air pollutants started exhibiting and reached the first peak in 2009. After a small buffer period (2010~2012), it reached to the second peak in the year of 2013, the milestone year in the history of Chinese air

quality. After the massive outbreak in 2013, the air quality became a little bit better in 2014. Since then, the haze kept deteriorating and now reaching to a unprecedently higher level.

Figure 4.21. Annual Ultraviolet Aerosol Index (UVAI) for Xianyang Municipality, China, 2008~2016.



4.6. Discussion

As the first longitudinal study in this dissertational human ecological research, this project completed the assessment of physical environment by evaluating the spatio-temporal distribution of haze with satellite imagery. Two analytical projects were designed and implemented: 1) To compare the monthly average ground monitoring AQI data as well as PM_{10} and $PM_{2.5}$ during the time period-2 (2014~2016) in Xianyang Municipality with Aerosol Optical Thickness (AOT) and Ultraviolet Aerosol Index (UVAI) obtained from OMI; and 2) To measure the average monthly, seasonal, and annual trends in haze across Xianyang Area and Xianyang Municipality during the time period-1 (2008~2016) using better fitted satellite product obtained from OMI imagery.

From the satellite validating project, the visually and mathematically checking results proved that **the UVAI could be used as a substitute for ground monitoring AQI to present the severity of haze in Xianyang**. In this study, two satellite products, AOT and UVAI, were obtained from Aura satellite's OMI, an instrument specialized in the identification and the measurement of criteria pollutants. By plotting the AOT and UVAI against AQI and particulate matters, the graphs demonstrated that most UVAI distribution lines lay within the dispersion range of AQI, PM10, and $PM_{2.5}$. Moreover, the results of correlation matrix also proved that UVAI was highly correlated with AQI and all particulate matters from mathematical perspective, while AOT showed no significance. Furthermore, the bivariate regression results proved that only UVAI was statistically significant to AQI (P-value: 0.0000000767, R-square: 0.5649).

The AOT uses visible bands to detect aerosol, which is heavily examined in the study of PM, such as $PM_{10,}$ and/or $PM_{2.5}$. On the contrary, the UVAI detects the backscatter or the absorption of radiance of absorbing and non-absorbing aerosols in both visible and ultraviolet bands (270~500nm), which is greatly free from the influence of cloud or water vapors. Within all criteria pollutants, $PM_{10,}$ and $PM_{2.5}$ are Black Carbon (BC) material that can absorb significant amount of radiation, especially at UV and blue wavelengths (Kim et al., 2007). They are considered as the important benchmarks in determining air quality and are usually produced from the incomplete combustion of biomass and fossil fuels (Bond et al., 2013; Buseck et al., 2014).

From the spatial and temporal analysis of haze in Xianyang Area, **the generally increasing trends of haze in both severity and coverage has been detected in all yearly, seasonal, and monthly imageries**. In addition, the southeastern counties, including Xianyang, Jingyang, Xingping, and Liquan, became a clear and regular haze hotspot by having the highest UVAI values in Xianyang Area. That is because geographically these four counites are located in the southern basin area within Xianyang Area while economically they are more urbanized/developed counties too.

The yearly imagery clearly shows an increasing trend of haze in severity spreading to more and more areas (Figure 4.6). The haze was found in all years. It first appeared only in southern counties located in the basin area of the WeiShui River and then quickly spread into the entire Xianyang area. Meanwhile, the development of severe haze area also followed similar geographic path but starting from southeast corner to south and central area and then to entire Xianyang area. Moreover, before 2013, because the Qinling Mountain is south of the Xianyang Area and the north Xianyang Area is highland topography, the condition of air quality in the bottom and the top of the imagery is relatively better than in the rest of the areas. However, due to the continuous accumulation of air pollutants nationally and locally, the air quality in these areas has become worse too since 2014.

The seasonal imagery clearly demonstrates the regularity of winter peak, the appearance of spring peak, and the addition of summer peak (Figure 4.5). Although the concentration of haze is generally high throughout the year, two peaks can be found in winter and spring. The winter peak is the most regular peak that kept coming back every year. This finding is consistent with a previous study finding that the winter peak is generally seen in northern China from November to March due to the heating season and low mixing layer height (Zhang et al, 2015). On the other hand, although the severity is not as worse as the winter peak, the spring peak still can be detected clearly after 2009. In 2010 and 2013, the spring break and the winter break became even equally bad. Theoretically the spring peak is more easily found in southern cities of China as the result of the high concentration of carbonaceous aerosols (Zhang et al., 2008). However, it is obvious that with the increasing number of emitted pollutants every year the spring peak can overcome the general climate limitation and appear in northern China too. Moreover, besides winter and spring peaks, another peak, summer peak, also emerged in 2015 and 2016. In the past, the summer haze appeared only once in 2009. It also showed an obvious spatial concentration in urbanized area by having highest level's UVAI in Xianyang county and its surrounding counties.

The monthly imagery further shows three unique features about the seasonal outbreak of haze in Xianyang area (Figure 4.4). First, the rising of winter haze became earlier and earlier, while the dissipation of winter haze became later and later. Before 2010, the winter haze only started to appear in December, while in 2011 it began to raise in November and in 2013 it started even earlier in October. Before 2014, except for the outbreak of haze in 2010 and 2013, the winter haze usually shows the tendency of dissipation in February or March. While after 2014, the dissipation of haze postposed to April or May and immediate transited into spring peak or summer peak. Second, the emerging area of winter haze and severe winter haze became larger and larger. The first appearing area of winter haze grew from southeastern counties only (Xinayang, Jingyang, Xingping, and Liquan) in 2008 to more and more counties in central and southern Xianyang Area. Meanwhile, since they are also more urbanized counties, the severity of haze in these southeastern counties kept deteriorating and then became a regular hotspot core. Third, after 2014, with the increasing number of pollutants emitted into the air, the transition among three peaks, from winter peak to spring peak to summer peak, became less evident. In other words, haze was maintained at a relatively high level throughout the most months in 2015 and 2016.

Additionally, this study zoomed the focus into the Xianyang Municipality, examining the temporal change of haze in this most urbanized area. The monthly data demonstrates a clear and consistent U shape feature of haze variation for all 9 years too. The seasonal data compares the severity of haze among four seasons and found the ranking of haze severity is

Winter>Spring>Fall/Summer. The yearly data shows the temporal fluctuation of haze between 2008 to 2016.

By comparing monthly data (Figure 4.7.), there is no single year outstandingly above or below the majorities. In other words, no single year had noticeably high or low haze in every month than other years. However, the graph still shows two distinctive features. First, the most evident feature is the slightly right skewed U shape with higher value in both ends and lower value around August and September. The longer decreasing left curve indicates that the large number of pollutants newly emitted and produced in spring and summer exceeds the consuming capability and rate of atmosphere by slowing the speed of dissipation of winter haze. Meanwhile, the shorter increasing right curve is caused by the biomass burning in agriculture and heating season. Second, the small fluctuations before hitting the bottom of U shape shows that the appearance of spring and/or summer peak become more and more clearly and frequently. In addition, the national 2013 haze outbreak can be easily identified by showing an outstanding spring peak in March.

From seasonal data (Figure 4.8.), the ranking of four season is Winter > Spring > Fall/Summer. First, it is not surprised to see that winter haze has the highest level of haze due to the biomass burning for heating season and the stagnant atmospheric conditions. Second, because the high cumulation of haze during the winter dissipated more and more slowly, the increasing amount of air pollutants stayed longer in the air and transmitted into the spring season. The only one time that spring haze exceeded winter haze appeared in 2013. The year 2013 was a special year in the Chinese environmental protection because it was the first time that haze massively and severely struck most mainland provinces. It was the same year that the Chinese central government had to admit the existence of haze and promise more efforts in air clean actions. Third, because of connecting to the winter haze, the density of haze in fall is higher than in summer in most years (6 out of 9). However, in 2010 the local haze outbreak in Xianyang Area as discussed above, was one of the hotspot haze area and the most urbanized and developed area, the density of haze in Xianyang Municipality maintained at a relatively high level in both spring and summer seasons. Moreover, after the 2013 national haze outbreak, the summer haze in Xianyang Municipality begin deteriorating dramatically in the following years and even exceed the fall haze again in 2016.

From yearly data (Figure 4.9.), the peak of 2013 haze outbreak can be easily identified, which is consistent with the performance of satellite imagery in 2013 for entire Xianyang area, while the 2009 peak is one year earlier than the satellite imagery peak showed in 2010. It is because the 2013 haze outbreak is a national intensive outbreak which is happened massively and simultaneously in the mainland, while the 2010 haze outbreak in Xianyang Area is a more localized event which is developed from the 2009 haze peak in Xianyang Municipality, a highly polluted urbanized area. After 2014, due to the exponentially accumulation of air pollutants emitted by massive civil construction and transportation both in Xianyang Municipality and Xianyang Area, the density of haze in entire area kept increasing continuously and reached a unprecedently high level.

There are some limitations of this study. The ground monitoring data used in this study was the average of three monitors' data. The locations of these monitors were discussed above. According to the selecting standard of ground monitoring stations, the location should have following five features: Representativeness, Comparability, Integrity, Perspective, and Stability (Chen and Zhao, 2014). For the integrity, the standard requires that the selection of location should be the result of holistic consideration covering physical geography, climatology, city planning, industrial layout, demographic distribution, economic development, etc. However, as discussed, Xianyang Municipality has no monitoring stations in the east side, where most industrial factories and municipal facilities (like power stations and a sewage treatment plant) are concentrated. Moreover, as the area that is closer to the network of national, provincial, and inter-city highways, the east side of Xianyang Municipality was under heavy urban construction. Therefore, the lack of ground monitoring data in this area will not allow for the validation of haze measurements using satellite products in this area of Xianyang Municipality. Another limitation is unavailability of individual pollutants for measurement. Thus, to measure the influence of haze on maternal and infant health, this study adopted the same definition used in the public by generalizing the term of haze as the compound of air pollutants. The quantification of haze severity is the holistic measurement of air quality. Therefore, this study took the absolute value of UVAI as the final satellite data. On one hand, the UVAI used in this study has been proved to be beneficial in the measurement of long-term haze. On the other hand, another advantage of UVAI, distinguishing aerosols with positive or negative values, was intentionally omitted. In future study, more efforts can be dedicated to the use of UVAI to distinguish the absorbing and non-absorbing aerosols and to examine their effects on maternal and infant health. The last limitation is the missing study about the relationship between haze and urban sprawling in Xianyang Municipality. As discussed before, the Xianyang Municipality has been through dramatic development in urban construction and sprawling. However, as a socioeconomic area, there was no clear or consistent or official definition of the coverage of Xianyang Municipality. The shape of Xianyang Municipality was manually drawing on the top of Google Earth images by the investigator. Moreover, in order to obtain the clearest image to draw Xianyang Municipality, the snapshot of Xianyang Municipality with the best view at different time was selected for each year. In future study, more efforts can be invested on the landcover classification with shorter temporal interval by using remote sensing skills and high-resolution satellite imagery to further study the association between urban sprawling and haze density.

4.7. Conclusions

In conclusion, after proved that UVAI can be used to measure the variation of haze in long term, this study also highlights the growing tendency of haze in both severity and coverage by examining the spatial and temporal variation of UVAI in Xianyang Area and Xianyang Municipality. In satellite data validating project, the UVAI was selected to present the haze condition in Xianyang from 2008 to 2016 by showing better consistency with AQI and particulate matters visually and mathematically. As an important prerequisite study for later health assessment, this project was designed to provide feasibility of assigning daily haze exposure during pregnancy to each mother. Then, by using monthly, seasonal, and yearly average of UVAI, this study also examined the spatio-temporal distribution of haze in the Xianyang Area from 2008 to 2016 and the temporal variation of haze in Xianyang Municipality during same study period. The findings not only demonstrate the increasing trends of haze in both severity and coverage but also revealed the formation of severe haze hotspot in southeastern Xianyang Area. The purpose of these examinations is to understand the distribution, severity, and development of haze in the study area, which further raise the interest of audience wondering how the residents' health, especially the maternal and infant health, is affected by living in such highly polluted atmosphere and inhaling large number of pollutants every day for a long period.

CHAPTER V

Haze Air Pollution Impacts on Maternal and Infant Health in Xianyang

Abstract

Air pollution has been recognized by the World Health Organization (WHO) as an important environmental health risk factor that can lead to premature death. However, as one of the countries now experiencing a consistently high density of haze, little has been done to explore the spatio-temporal impacts of haze on both maternal and infant health in China. This study investigated the haze impacts on maternal and infant health in Xianyang utilizing the satellite product OMI UVAI and a primary dataset of a sample of infants born at Shaanxi University of Chinese Medicine First Affiliated Hospital in Xianyang City from January 2008 to December 2016. The results showed that the maternal haze exposure in first and third trimester had negative impact on infant birth weight in different sub-population of mothers, controlling for mother age, gender, and birth time. This relationship was mediated by maternal co-morbidities including cardiopathy, hypertension, digestive, and diabetes. This study concluded that the haze level in Xianyang Municipality has reached to a dangerously high level with evidently severe negative impact on maternal and infant health. Therefore, it is important to decrease the haze density and prove maternal health to ensure a healthy growing environment for every infant.

Keywords: Haze Pollution, Ultraviolet Aerosol Index, Maternal and Infant Health, Birth Outcomes, Mediating Maternal Medical Conditions, China

5.1. Introduction

The World Health Organization (WHO) recognizes air pollution as a critical environmental health risk, annually causing 7 million premature deaths worldwide as a result of stroke, heart disease, lung cancer, chronic obstructive pulmonary disease and respiratory infections (WHO, 2018). The latest data reveals that 9 out of 10 people are currently breathing highly polluted air (WHO, 2018). Importantly, people living in low- and middle-income countries, particularly in the Eastern Mediterranean Region and Southeast Asian regions are at highest risk of air pollution exposure (WHO, 2018).

The porous structure and surface area of particulate matter can make particles the perfect carrier of an array of toxic chemicals (Zhuang et al., 2014). When inhaled, the larger particles (PM_{10}) may lodge in the upper airways, with smaller particles $PM_{2.5}$ transporting deeper into the alveoli of the lungs. Inhaled ultra-fine particles release from the lungs into the bloodstream where they are circulated into other organs (Ritz et al., 2007).

Studies in pregnant mice have found trace PM in the placenta, chorion, and amniotic fluid (Ritz et al., 2007). The first trimester of pregnancy is the time in which the placenta nourishes the fetus and fetal organs begin to develop. There have not been studies to our knowledge that have assessed the statistical relationships between maternal haze exposure (measured using the UVAI) and first trimester pregnancy outcomes. There is, however, evidence that in the first trimester, elevated levels of CO in the blood will compete with oxygen causing oxidative stress (Salam et al., 2015; Bell et al., 2007) and endothelial and placental dysfunction (Stevenson et al., 2003; Backes et al., 2016). Furthermore, exposure to elevated SO_2 levels has been shown to increase the incidence of stillbirth (Hwang et al., 2011). NO_x (NO and NO_2) suppresses antioxidant defense systems, disturbs postnatal development, and leads to lung inflammation and preterm birth

(Tabacova et al., 1995, 1998). Some studies have shown that short-term exposure to $PM_{2.5}$ during the first trimester is strongly associated with preterm birth (infants born < 37 weeks gestation) and increased risk of morbidity and infant mortality (Brook et al., 2004; Sun et al., 2010; Pui et al., 2014). Loomis et al. (1999) found that a 10ug/m^3 increase in $PM_{2.5}$ would lead to a 6.9% increase in infant mortality. Maternal exposure to haze in early pregnancy may also compromise fetal organ development (Ritz et al., 2007). Some studies have shown a significant relationship between high concentrations of $PM_{2.5}$ and congenital anomalies, especially heart defects (Ritz et al., 2007), specifically ventricular septal defects –per a 10 ug/m^3 increase in $PM_{2.5}$, OR = 1.17 (95% CI, 1.02-1.26).

Evaluating exposures in the third trimester is also important because this is the time window in which the fetus is growing (maturing) most rapidly. Studies have shown a strong statistical association between maternal exposure to $PM_{2.5}$ in the third trimester and low-birth weight (LBW, infants born <2,500 grams, or 5.5 pounds) and intrauterine growth restriction (IUGR, birth weight falls below the 10^{th} percentile for gestational age) believed to be due to poor oxygenation and nutrient delivery across the placenta (Choi et al., 2012; Parker et al., 2005; Bell et al., 2010). In Poland, Jedrchowski et al. (2004) showed that a 40ug/m^3 increase in $PM_{2.5}$ density would lead to a 140.3 gram decrease in birth weight (BW).

Wu et al. (2009) examined the effects of local traffic-generated air pollution (NOx and $PM_{2.5}$) during the entire pregnancy on very preterm birth (gestational age< 30 weeks) and found a 128% increase, OR = 2.28 (95% CI 2.15-2.42) and an 81% increase, OR = 1.81 (95% CI 1.71-1.92) in the odds of very preterm birth with exposure to high quartile NOx and $PM_{2.5}$. Long-term exposure to particulate air pollution has also been associated with increased inflammation (Hertel et al, 2010). Finally, developmental delays in utero may predispose a neonate to a higher risk of developing brain, respiratory, and digestive problems in early life and cardiovascular diseases into adulthood (Sun et al., 2005; Ritz et al., 2007; Rocha et al., 2008; Bolton et al. 2012). Due to the immaturity of lungs, the brain, and immunological system at birth, these infants are also more susceptible to later environmental insults (Ritz et al., 2007).

Importantly, previous studies have shown that a large proportion of the variation in adverse birth outcomes can be explained by maternal risk factors recorded on the birth certificate (Simpson 2002; Backes et al., 2013; Lavigne et al., 2016; Laurent et al., 2014). Lavigne et al. (2016) reported an increased risk of preterm birth with increasing levels of air pollutants among women with pre-existing diabetes mellitus, $PM_{2.5}$: Relative Risk (RR) = 10.6% (95% CI 0.2-2.1%) and NO_2: RR=23.8% (95% CI 5.5-44.8%), preeclampsia, $PM_{2.5}$: RR=8.3% (95% CI 0.8-16.4%) and asthma O_3 : RR=12% (95% CI 3.5-21.1%). Laurent et al. (2014) also found a strong association between maternal air pollution exposure and the odds of LBW among women with chronic hypertension, $PM_{2.5}$: OR=1.19 (95% CI 0.99-1.43); O_3: OR=1.09 (95% CI 0.94-1.27); NO_2: OR=1.3 (95% CI 1.1-1.54) and obesity, $PM_{2.5}$: OR=1.24 (95% CI 1.04-1.47) and NO_2 : OR=1.069 (95% CI 0.96-1.2), controlling for maternal age, parity, race/ethnicity, education, neighborhood income, gestational age, and infant sex.

Despite this growing body of literature about the harmful effects of maternal exposure to PM, there have been no studies investigating the spatial, temporal or spatio-temporal impacts of haze on adverse birth outcomes in China. There are approximately 50,000 births each year in Xianyang City (crude birth rate = 10.13 births per 1,000 population) (Xianyang Bureau of Statistics, 2013). There is an immediate need therefore, to understand the relationships between maternal exposure to varying levels of haze and infant birth outcome and maternal medical conditions in this study area.

5.2. Health Assessment Objectives

This study will estimate the direct impacts of maternal exposure to haze during different trimesters of pregnancy and overall pregnancy on birth outcomes (birth weight), controlling for maternal and infant level confounding. This objective will also examine indirect pathways –i.e., mediating maternal medical risks in the maternal haze exposure and birth outcomes relationships, controlling for maternal and infant level confounding. It is hypothesized that haze exposure will increase the likelihood of pre-pregnancy and pregnancy-related medical conditions, which will in part contribute to poor infant outcomes—in this study lower birth weight.

5.3. Study Design

This study utilized a retrospective cross-sectional cohort study design. A sample of infants born at Shaanxi University of Chinese Medicine First Affiliated Hospital in Xianyang City from January 2008 to December 2016 was the focus of this study. The population of infants was selected from a retrospective cross-section of births (January 1, 2008 to December 31, 2016). The cohort of mother's exposures to haze at susceptible periods of time (conception to trimester-1 (T-1), trimester-2 (T-2), trimester-3 (T-3)) to birth were measured from January 1, 2008 to approximately April 1, 2016 to capture the full gestation for infants born through December 31, 2016. The cohort of infants born from approximately September 1, 2008 to December 31, 2016 was studied to capture the full gestation for mothers who conceived in January 2008.

5.4. Maternal and Infant Data

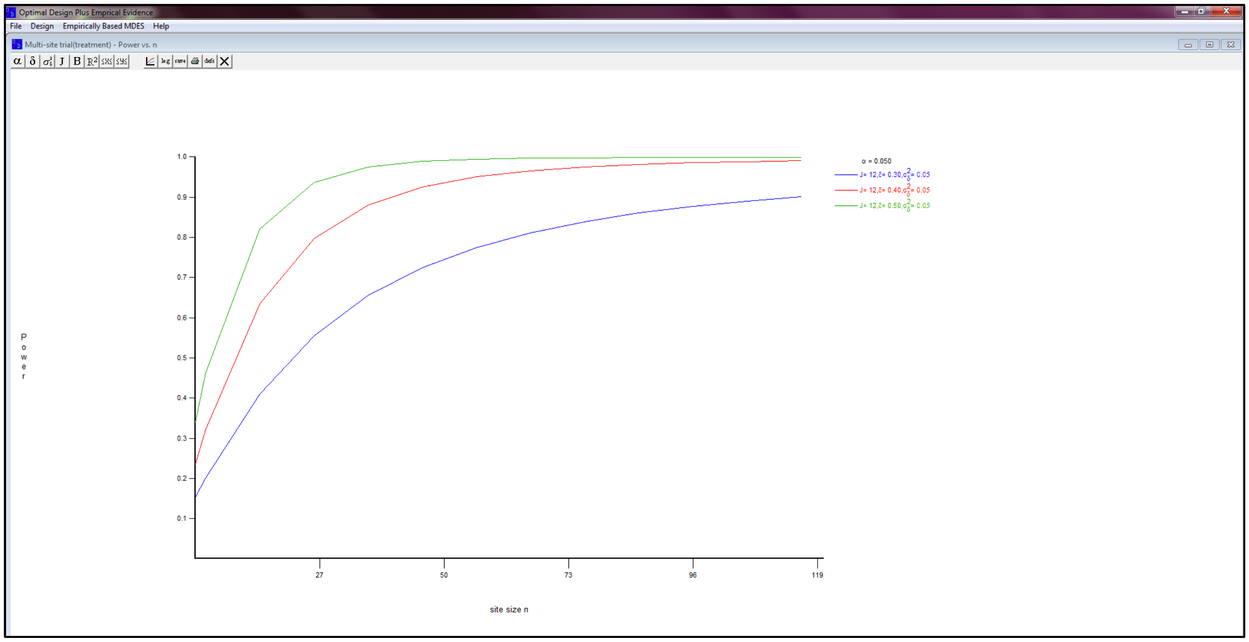
The maternal and infant health data were collected during the summer of 2017 at Shaanxi University of Chinese Medicine First Affiliated Hospital in Xianyang City. Two datasets were obtained via photocopying (a) a list of obstetric records from 2008 to 2016 (also referred to as annual catalog lists) and (b) a sample of mothers who gave birth from the obstetric records. These two datasets were joined using a common ID for mothers.

The catalogs between 2008 to 2016 contain information on all women admitted to the Obstetric Department (total N= 14,712) including the Patient ID and information on the date of admission, admission diagnosis, mother age and residential address, the number of stay days in the hospital and the results of treatment. For those women who gave birth in the catalog database there is information on the infant's health at time of birth as well as additional information on the mother pertaining to her pregnancy and deliver. A systematic stratified and random sample of mothers who gave birth was generated from the catalog using the following sample size and power calculations.

5.4.a. Sample Size Calculations and Data Collection

To obtain the number of obstetric records for this study, sample size and power calculations were conducted in Optimal Design software (Spybrook et al., 2011) (Figure 5.1.). For a 12-month time period (J) and power=0.8 and alpha = 0.05 the sample size for each month = approximately 27 births with a change in effect of 0.4 (red); and 20-30 births for a change in effect of 0.5 (green). In this study data on n=30 births were collected each month to ensure an adequate sample size.

Figure 5.1. Sample Size and Power Calculation.



Within each year, the catalog lists were organized chronologically (systematically) by month (stratified). However, within each month, the obstetric records were listed randomly. Therefore, for each month, the first 30 mothers-birth' obstetric records were selected. Based on the Patient ID, these obstetric records were manually retrieved from different shelves in the archive room, photocopied and returned immediately. In order to protect the mother-infant's privacy, no record was allowed to leave the archive room, which also had to be locked at all times and only one key could be used by permitted staff.

At the end of data collection process at least 30 obstetric (mother-birth) records were photocopied per month (12 months) x 10 years for a total N=3,465 obstetric records containing mother's and infant's information. For this study multiple births were removed (n= 28) to reduce bias associated with low birth weight due to multiple born infants reducing the dataset to N=3,437. Furthermore, mothers who gave birth in the hospital but did not live in Xianyang City were also removed from the dataset (n=115). Infant who was born at home, abortion, still birth (death in utero) and infant mortality (infant suffocate to death right after birth) are removed due to the missing of data, thereby reducing the dataset to 3,226. At last, a total of 3,226 obstetric records were kept for the final statistical analysis.

Table 5.1. demonstrated the increasing trend of patients in obstetric department from 2008 to 2016, while Table 5.2. further broke down this data into each month and showed that March (Spring) and June (Summer) are the months with highest number patients. Also, because the reorganization movement within the hospital in 2012, the data in December 2012 were missing.

Table 5.1. Obstetric Department Patient Distribution (per Year) 2008~2016.

Year	Number	Change Rate
2008	1231	--
2009	1247	0.013
2010	1428	0.127
2011	1574	0.093
2012	1659	0.051
2013	1697	0.022
2014	1925	0.118
2015	1573	**-0.224**
2016	2378	0.339

Table 5.2. Obstetric Department Patient Distribution (per Month) 2008~2016.

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016
Jan	97	113	113	133	129	136	**198**	146	157
Feb	91	85	103	129	144	104	132	116	158
Mar	103	100	111	**154**	169	156	150	129	**240**
Apr	90	108	**155**	125	133	147	162	106	187
May	87	113	93	120	126	137	153	120	180
Jun	89	103	107	123	**192**	132	152	**147**	194
July	109	89	125	152	149	158	172	117	218
Aug	111	**123**	125	131	134	158	161	143	217
Sep	**119**	92	107	127	145	133	180	135	205
Oct	111	95	116	125	158	170	169	132	212
Nov	115	122	132	138	180	**173**	144	136	189
Dec	109	104	141	117		93	152	146	221

5.4.b. Maternal and Infant Variables

The catalog database was limited to including the information about Patient ID, date of admission, admission diagnosis codes, mother age and residential address, the number of stay days in the hospital and the results of treatment. These data were joined to the obstetric records using the mother's Patient ID.

There were 15 variables pertaining to the mother's condition in the obstetric record, including demographic and socioeconomic characteristics (age, marital status, place of birth, occupation), pre-pregnancy and pregnancy-related diseases and conditions (diseases and conditions are written in admission diagnosis codes) and method of delivery and obstetric complications (Table 5.3.).

Table 5.3. Mother Variables Obtained from the Obstetric Record.

Mother Variables	Variable Type	Coding Strategy
Patient ID	Link Variable	Link to infant
Residence	Dichotomous	1= urban, 0= rural
Age	Continuous	MM/DD/YY
Marriage	Categorical	1=Single;2=Married;3=Divorce;4=Widow;5= Others
Occupation	Dichotomous	1= indoor worker, 2= outdoor worker
Amniotic Fluid	Dichotomous	1= good, 2= others
Hospital Days	Continuous	Hospital Days= Admission & Discharge
Gestation	Continuous	Unit = day
Diagnosis 1,2,3,4	Nominal	Text
First Prenatal Care	Continuous	Unit = week
Total number of Prenatal Care	Continuous	Unit = time
Pregnancy History	Continuous	How many times pregnant
Parity	Continuous	How many births delivered before
Blood Pressure	Continuous	BPHigh VS BPlow
Mother Weight	Continuous	Unit=kg
Nutrition	Categorical	1=Good;2=Normal;3=Bad

There were also 14 variables pertaining to the infant, including the sex, gestational age, birth weight and a checkbox list of observable deformities (Table 5.4.). These independent variables will be coded as dichotomous or ordinal variables and used as predictors or control variables to estimate the effect of haze on birth outcomes in subsequent models.

Table 5.4. Infant Variables Obtained from the Obstetric Record.

Child Variables	Variable Type	Coding Strategy
Patient ID	Link Variable	Link to mother
Date of Birth	Date	MM/DD/YY
Method of deliver	Categorical	1=natural; 2=C-section; 3=middle; 4=low; 5=forceps; 6=Cesarean;7-Zeng
Gender	Categorical	1=male, 2=female
Term of Birth	Categorical	1=preterm;2=full term;3=post term
Birth Weight	Continuous	Unit=grams
Deformity	Dichotomous	1=no; 2=yes
Complication 1,2,3,4,5	Nominal	Text
Accident 1,2,3,4,5	Nominal	Text
Apgar Scoring	Categorical	1,5 minutes
Appearance (skin color)	Categorical	0=purple or white;1=red and purple;3=red
Pulse	Categorical	0=no;1<100;2>100
Grimace (reflex irritability)	Categorical	0=no;1=minal;2=strong
Activity (muscle tone)	Categorical	0=no;1=minal;2=strong
Respiration	Categorical	0=no;1=low;2=strong

5.5. Methods

5.5.a. Maternal Exposure Assessment

The spatial character of mothers' residency was determined in ArcGIS. First, the mothers' locations were obtained from the living addresses filled in the obstetric records. Due to the absence of street shapefile, the mother's addresses were manually geocoded in ArcGIS to obtain the maximum accuracy. Second, considering the high speed of urban sprawling in Xianyang Municipality during the past decade, the satellite images of Xianyang Municipality from Google Earth Pro were downloaded from 2008 to 2016 and the changes in boundaries were manually drawn on top of each rectified base map in ArcMap. Following the placement of mother's residency each record was assigned a rural vs. urban code (inside or outside of Xianyang municipality).

Sample Time Span Calculations: Since the hospital only maintained the most recent 10 years' records, the sampling of birth data will start from January 2008 till December 2016. In other words, the first infant that entered our database was born in January 2008. The corresponding haze data was traced back to February 2007, the beginning of first trimester. The last infant that entered our database was born in December 2016, the end of third trimester. Therefore, the last haze data was collected in December 2016. Table 5.5. shows the years of the imagery and monitoring data in relation to the birth data that was collected and the extent of the study area.

Table 5.5. Years of Haze Assessment Datasets and Birth Cohort.

Satellite Imagery	Birth Cohort
March-2007	Jan-2008
--	--
--	--
Dec-2013	Dec-2013
Dec-2014	Dec-2014
Dec-2015	Dec-2015
Dec-2016	Dec-2016

The UVAI value was the primary independent variable of interest in the birth outcome models described in following health assessment section. In these models UVAI was assessed over two sensitive windows of pregnancy the first (T-1) and third (T-3) trimesters. They were calculated by taking the birth date minus the gestational age (days) = estimated date of conception. From the estimated date of conception months 1, 2 and 3 of pregnancy (approximately 97 days) are added to = T-1, D98 to D195 are added to =T-2, and Day 196 forward to birth (months 7, 8 and 9) are added to = T-3.

The UVAIT1Mean, UVAIT2Mean, and UVAIT3Mean were the average haze exposure in first, second, and third trimesters for each mother. The UVAIT1Mean was the average of UVAI exposure for mother X from conceptional date(D1) to Day 97. Similarly, the UVAIT2Mean measured the average exposure between Day98 to Day 195, while the UVAIT3Mean from Day 196 to the birthday. The UVAITriMin and UVAITriMax are each mother's smallest and largest trimester exposure values by comparing UVAIT1mean, UVAIT2Mean, and UVAIT3Mean. The UVAI is the averaged haze exposure during whole pregnancy by taking the mean of UVAIT1mean, UVAIT2Mean, and UVAIT3Mean. The calculation code by which mother's trimester of pregnancy was assigned an UVAI exposure can be found in Appendix 1. Descriptive statistics to learn of the structure of maternal exposure were calculated in RStudio (RStudio, Incorporated, Boston, MA, 2015).

5.5.b. Descriptive Analyses

The continuous variables will be examined for their descriptive statistics, such as min, max, median, mean, range, standard deviation, and skewness. The boxplots will be created too as assisting tool to understand the distribution within variable. For the categorical variables, the frequency and percentage for each group will be presented. Their bivariate correlations will also be tested as the pre-requisite for the analytical analysis by using Pearson Correlation Matrix, Pearson's Chi-square, and ANOVA.

5.5.c. Analytical Analyses

Objective 1. To estimate the direct impacts of maternal exposure to haze during the pregnancy on birth weight(gram), controlling for maternal and infant level confounding.

This study will use multiple linear regression to quantify the magnitude of change in birth weight (grams) with each unit change in maternal trimester haze exposure unit. For the haze variables, we decided to use first trimester and third trimester maternal average exposure (UVAIT1mean & UVAIT3Mean) since they are most critical pregnancy stage during which the infant more growth and weight.

Besides being used as a DV in multiple regression models, the birth weight is also measured at each gestational age in weeks to evaluate infant's physiological growth and development. Dai et al. (2014) developed a gender-gestational age-specific birth weight percentile table for Chinese infants based on N=1,105,214 healthy live singleton births (2006-2010) collected from the China National Population-based Birth Defects Surveillance System. In the table, the birth weight at gestational age can be grouped into three categories, Small for Gestational Age (SGA), Normal for Gestational Age (NGA), and Large for Gestational Age (LGA). SGA will be birth weight that falls below the 10^{th} percentile for gestational age. NGA will be the birth weight that lies between the10^{th} and 90^{th} percentile for gestational age. LGA will be birth weight that exceeds above the 90^{th} percentile for gestational age. This study will adopt the birth weight reference percentile table for Chinese male and female newborns created by Dai et al. (2014). Each infant's birth weight will be compared with the reference birth weight by gestational age in the table and coded as SGA, NGA, or LGA.

Objective 2. To examine indirect pathways –i.e., mediating maternal medical risks in the maternal haze exposure and birth outcomes relationships, controlling for infant level confounding.

Even though it is possible that more mediators may exist to influence the relationship between maternal haze exposure and maternal medical conditions as well as between maternal medical conditions and birth outcomes, in this study we will focus on the mediating effect of first-level variable, maternal medical conditions. The Barron and Kenny's (1986) model were adopted as the basic mediation model. To be defined as a mediator, the following three steps much demonstrate statistical significance. The first step aims to estimate the direct effect of haze on birth outcomes. The second step aims to estimate the effect of haze on maternal medical condition(s)—pre-pregnancy or pregnancy-related conditions. The third step aims to estimate the effect of maternal medical conditions on birth outcomes. The final step will be to estimate the change in effect of haze on birth outcomes after adding the maternal medical condition(s) as a mediator using tests such as Sobel (1982). If the effect of haze on birth weight is significantly minimized it can be concluded that maternal medical conditions in part explains the haze and birth weight relationship.

The goal of mediating tests was to find out whether the increase of haze density would cause the increase of possibility of mothers' medical conditions, which in turn negatively affect the birth outcomes. In this study, instead of investigating the mediating effect of individual maternal health condition, we expanded into the group effect of similar clinical risks. A total of 12 clinical classes that were composed of diagnosis codes in Pre-pregnancy, Pregnancy-related, Pre-pregnancy and Pregnancy-related were tested for their mediating effects on haze in different geographic units. In IVs, besides clinical classes, three haze measurements were tested, including UVAI, UVAITriMax, and UVAITriMin. As to the DVs, the continuous DVs we selected centered Birth Weight (BWCenter) and centered Gestation (GestCenter), while the dichotomous DVs we selected LBW, LGA, Preterm, and SGA. For the controlling variable, we kept the variable that had no collinearity with haze variables and at the same time significant to all DVs in bivariate regression models—Female Infant (Female). Additionally, in order to prevent the significant loss of sample size, we performed mediating tests on all mother group in Xianyang Area. All mediating tests were conducted in R by using mediate function in mediating package (Tingley et al., 2014).

The Nonparametric Bootstrap method was used to test the mediating effects here because the models in this study were compose of both categorical and continuous IVs and this method did not require the prerequisite knowledge of the distributional form, such as Normal, Gamma, etc. The nonparametric method assumes that the data comes from an unknown distribution with unknown parameters, while the bootstrapping is a method of sample use. This simulation method estimates the parameters from the data provided and then create new sample with same size by replicating some samples in original data.

In this study, three key results of mediate function were reported for each diagnosis code: Average Causal Mediating Effects (ACME), Average Direct Effects (ADE), and Total Effect. The ACME described the indirect effect of IVs on the DV that goes through the mediator, which was also the focus of the mediating test. The ADE described the direct effect of IVs on the DV after taking into account the presence of mediator, while the Total Effect described the total effect of IVs on the DV without the presence of mediator. Since ACME equals Total Effect minus ADE, when Total Effect > ADE, the ACME will be positive, which means the including of mediator reduces the effect of IVs on DV. In other words, the reduced effect of IVs works on mediator instead of DV. However, when Total Effect<ADE, the ACME will be negative, which means the inclusion of this variable increases the effect of IVs on DV. According to Zimmermann et al. (2017), this variable is called suppressor variable. In other words, this variable increases the predictive validity of IVs on DV.

5.6. Results

5.6.a. Descriptive Results

<u>Urban</u>: Table 5.6. shows the number of observations in urban and rural from 2008 to 2016. Even though the total number of mothers in each year is quite similar (around 10~12%), the numbers of

urban mothers (Total=1853/57.4%) were generally higher than rural mothers (Total=1,373/42.6%) except the year of 2015 (Difference=-1).

Table 5.6. Urban and Rural Mothers from 2008 to 2016.

	Urban		Rural		Total		Difference	
Year	No.	(%)	No.	(%)	No.	(%)	No.	(%)
2008	226	59.318	155	40.682	381	11.810	71	18.635
2009	216	57.143	162	42.857	378	11.717	54	14.286
2010	198	58.235	142	41.765	340	10.539	56	16.471
2011	195	52.279	178	47.721	373	11.562	17	4.558
2012	184	56.269	143	43.731	327	10.136	41	12.538
2013	199	60.671	129	39.329	328	10.167	70	21.341
2014	228	61.290	144	38.710	372	11.531	84	22.581
2015	179	49.861	180	50.139	359	11.128	**-1**	**-0.279**
2016	228	61.957	140	38.043	368	11.407	88	23.913
Total	1853	57.440	1373	42.560	3226	100.000	480	14.879

Age: A total of 3,224 (system missing=2) had valid age data, ranging from 17 to 45 years old. The average maternal age is 27.9 years old. The boxplot (Figure 5.4) indicated that the most popular maternal age range was 25 to 27, followed by 27 to 30 years old. The positive skewness indicated that Age variable is right skewed with more days above mean value (=27.9). It also had negative kurtosis, indicating the distribution has longer tail than the normal distribution. The boxplot (Figure 5.4) also demonstrated more extreme outliers. The age variable was also recoded as a binominal variable and multinomial variable. The dichotomous variable had category 1 (25~34) indicating appropriate maternal age and category 0 (<25 &>34) indicating inappropriate (too young or too old) for the pregnancy. The results indicate that most mothers (n=2,178/67.5%) gave the birth during appropriate maternal age. Also, a multinomial variable was constructed with category 1 indicating mothers younger than 25 years old, category 2 indicating between 25 and 34, and category 3 including mothers older than 34. The results showed that most mothers (n=2,178/67.5%) gave the birth during appropriate maternal age and there were more younger mothers (n=735/22.8%) than elder mother (n=311/9.6%). Also, considering mother age started from age 17, a new variable, AgeCenter, was created for regression analysis by centering mother ages around mean value.

Mother Weight: A total of 2,404 mothers had valid entries for this variable (system missing =822). The average mother weight was 70.65 kilogram. The variable ranged from 40 kg to 130 kg. The boxplot showed that most mothers weighted between 65 kg to 75 kg (Figure 5.4). From absolute value of Mother Weight variable, it seemed that some mothers were underweighted while some were overweighed. However, without any information on mother's heights, it was impossible to calculate mother's Body Mass Index (BMI). Therefore, it was inappropriate to test whether mother's weight was associated with birth outcomes and this variable was not included in the regression analysis.

Mother's Occupation: The occupation is a self-identifiable variable that was text-filled by the mothers. A total of 3,214 mothers had valid data (system missing =12). In the obstetric records, the mothers usually identified themselves as 6 major occupations, including Farmer (category 1, n=1,511/46.8%), Industrial worker (category 2, n=370/11.5%), Civil officer (category 3, n=275/8.5%), Teacher (category 4, n=141/4.4%), Medical supplier (category 5, n=76/2.4%), and Others (category 6, n=841/26.1%). The other category included mother unemployed, self-employed, engaged in commercial business, etc. According to the condition of mothers' working environment, this variable is recoded as dichotomous variables with 1 representing outdoor workers (farmers) and 0 indoor workers (industrial worker, civil officer, teacher, medical supplier, and others).

Marital Status: A total of 3,197 mothers had valid data (system missing =29) in the variable of marital status. The results indicated that most mothers (category 2, n=3065/95.9%) were married.

In other words, it is highly possible that the mothers could receive certain physical and financial support from the families. The other categories included all other non-marital-legitimate cohabitation states. Category 1 was single mothers (n=7/0.2%), 3 was widowed mother (n=1/0.0%), and 9 was others (n=124/3.9%). In multiple regression, it coded as dichotomous variable with 1 presented married mother, while 0 indicated unmarried mother.

Nutrition: The nutrition factor was a self-identifiable variable. A total of 2974 mothers had valid data (missing=252). Most mothers reported either having medium nutrition (n=1,506/50.6%) or good nutrition (n=1466/49%), while only 2 mothers reported having bad nutrition.

5.6.b. Maternal Health Variable Results

In this section, the detailed description of results will be provided for mothers' health variables, such as Hospital Days, First Prenatal Care, Total Prenatal Care, Blood Pressure, Pregnancy History, Parity, Method of Delivery, and Amniotic Fluid, as well as infants' variables, including Fetus Position, Gender, Type of Delivery, Deformity, Birth Weight, Gestation, and Apgar Score.

Hospital Days: The average length of mothers staying in hospital was 6.75 days (range, 1-36 days). It was also positive skewed and had longer tail right to the mean. The boxplot indicated that more outliers were above 11 days (Figure 5.4). A closer look at the data revealed that most mothers (n=1,837/56.9%) stayed 5 to 8 days in the hospital.

First Prenatal Care: A total of 2,710 (84%) mothers had complete data in this variable. The average week for mother's first prenatal care was week 12.34 and the median was week 12. However, the data varied from week 1 to week 48, which did not consistent with common sense and reality. After having closer look at the obstetric records, the author suspected that the unit of this variable may be mistakenly viewed as day instead of week or last prenatal natal care by certain medical suppliers.

Total Prenatal Care: A total of 2,773 (86%) mothers had valid data in this variable. The average times of prenatal care received by the mothers were 6.73, while most mothers have 5~8 prenatal exams (n=1,837/56.9%). Comparing to previous variable, First Prenatal Care, this variable had better quality with only one outlier (Figure 5.4). After moving this outlier, the maximum times of total prenatal care decreased to 16 times, which is more acceptable considering the mothers with some medical conditions may need more frequent prenatal care to monitor the health of the fetus. The positive skewness indicated that more mothers had more than 6.73 times of prenatal care. A maternal care guidebook, "Mother and infant health handbook" that was issued by the National Health Commission of the People's Republic of China, recommended that every mother should at least have 5 times of prenatal care and one prenatal care before week 13 of pregnancy, two times of exam among week 16 and 24, two times after week 28 (Xianyang Maternal and Infant Health Hospital, 2019). By viewing this variable as ordinal variable, the author found 14.8% mothers (n=413) had less than 5 times of prenatal care.

Blood Pressure: The blood pressure variable recorded the measurements when mother admitted into the hospital, which was one of the most important factors to maternal and infant health. A total of 3216 mothers had valid values (missing=10). The original blood pressure were numerical variables, including BPHigh and BPLow. The systolic (high) blood ranges from 80 to 190, while the diastolic (low) blood pressure ranges from 30 to 120. The average systolic blood pressure was 115.188, while the mean diastolic blood pressure was 74.573 (Figure 5.4). Both variables had positive skewness and kurtosis, indicating more mothers above mean values.

According to the standards in American Heart Association (AHA), the hypotension is defined when systolic pressure lower than 90 or diastolic pressure lower than 60, while the hypertension happens when systolic larger than 120 or diastolic pressure higher than 80. Based on new, the numerical blood pressure measurements were recoded as nominal variables (see BPHigh1 and BPLow1. The hypotension (systolic pressure <90 OR diastolic pressure <60) as category 1 and hypertension (systolic pressure >120 OR diastolic pressure >80) as category 3, while other normal ones as category 2. The descriptive results showed that the BPHigh1 had more hypertension mothers (n=569/17.7%) than hypotension mothers (n=7/0.2%) in systolic pressure. The BPLow1 also had more (n=442/13.7%) hypertension mothers than hypotension mothers (n=12/0.4%) in diastolic pressure. After merged BPHigh1 and BPLow1, the number of mothers with hypotension (BPHypo) was n=16/0.5%, while the hypertension mother (BPHyper) was n=669/20.8%. Both BPHypo and BPHyper were dichotomous variables.

Pregnancy History: There were two variables in obstetric record related to mother's pregnancy history, Pregnancy History and Parity. Pregnancy History indicated how many times the mother was pregnant including current pregnancy. A total of 3224 mothers had valid data for this variable, ranging from first time pregnancy to 8 times. The results showed that 47% (n=1,515) mothers were first time pregnancy while most mothers (n=1,709/53%) were pregnant at least once before current pregnancy. In regression analysis, this variable was recoded as dichotomous variable, PregH, with mothers had no prior pregnancy =1, while mothers had prior pregnancy =0.

Parity: The parity indicated how many live birth(s) were given by the mother before current pregnancy. The results showed that most mothers (category 0, n=2,344/72.7%) were giving the birth to their first baby. In addition, considering Chinese government became more and more lenient about One-child-policy in past decade, 25.5% mothers (n=822) were giving the birth to her second child. Due to the economic burden and family planning policy, only 57 (1.8%) mothers gave live birth to more than 2 babies. In addition, by combining pregnancy history and parity table, we will have a brief estimation of mothers who had at least one abortion/miscarriage. For example, for the first-time pregnant mothers (n=1,515), the parity should be 0. While in Parity table, there were 2,344 mothers with 0 parity. Therefore, it means 829 mothers had at least one abortion/miscarriage. Similarly, for the second-time pregnant mothers (n=904), theoretically there should be 904 mothers within 1 parity if none of them have abortion/miscarriage experience. However, there were 822 mothers with 1 parity. It means 82 (=904-822) mothers had at least one abortion/miscarriage. Based on this principle, we found that a total of 1,659 (51.4%) mothers in this database had at least one abortion/miscarriage.

Type of Delivery: The majority of baby was born around due day (n=3,039/94.2%). The number of preterm baby (n=167/5.2%) is higher than the overdue baby (n=20/0.6%). Unlike preterm and post term births that were calculated based on gestation; this variable was filled by the medical suppliers.

Method of Delivery: As to the method of delivery, the Caesarean section(category 3) were performed on most mother (n=1,998/61.9%), followed by the spontaneous delivery (category 1) took 36.5% (n=1176). In addition, a total of 52 mothers used vacuum extractor delivery (category 2). Based on this variable, two new dichotomous variables are generated for regression analysis, C-section and Spontaneous.

Amniotic Fluid: This variable describes the condition of amniotic fluid. A total of 3,218 mothers had valid data in this variable (missing = 8). The results indicated that most mothers (71.8%) had good amniotic fluid at medical level (n=2309, category 1). It also showed that 28.2%(n=909) mothers had certain problem, such as polluted water(n=558/17.3%, category 2, 3, 4), oligohydramnios(n=333/10.3%, category 5), or polyhydramnios(n=18/0.6%, category 6). In regression analysis, this variable was recoded as dichotomous variable with 1= good amniotic fluid while 0= others.

Fetus Position**:** When approaching the end of pregnancy, the position of fetus became more critical in determining the risk of delivery. Generally, there are two types of position, cephalic position (head down) and breech position (feet down). In this study, a total of 3,210 mothers had valid data for this variable (system missing=16). The descriptive results showed that the cephalic position (LOA, LOP, LOT, ROA, ROP, ROT: sum=3,034/94.5%) was much common seen than breech position (LAS, RSA: sum= 176/5.5%). Moreover, in clinic, the cephalic position is more ideal than breech position, which also having Occiput Anterior (OA) position, Occiput Posterior (OP) position, and Occiput Transverse (OT) position. Occiput Anterior(OA) position means the baby's head back(occiput) facing the front (anterior), which is the easiest position for the fetal head to traverse the maternal pelvis. It included two sub-positions, Left Occiput Anterior (LOA) and Right Occiput Anterior (ROA). The descriptive statistics showed that OA was the most common seen position in this study, including LOA (n=2131/66.4%) and ROA (n=841/ 26.2%). Since Fetus Position was more associated with method of delivery instead of birth weight or birth weight by gestation, this variable was not included in the regression model.

5.6.c. Infant Health Variable Results

Gender: The proportion of male baby (51.9%) was still slightly higher than the female baby (48.1%). After Chinese government forbidden doctors disclosing the gender information of fetus to the parents, the incidence of intentional abortion due to unwanted sex greatly decreased. A new dichotomous variable, Female, was created based on this variable because the son preference in Chinese traditional culture suggested that female infant was taken less seriously than male infant.

Deformity: By reading the descriptive text in the obstetric record, the researcher found that during the prenatal exam the parents were able to know the physical condition of baby and were allowed to abort the pregnancy when the baby was found having deformity. Due to this prenatal screen, only 6 babies (0.2%) were born with deformity. Therefore, this variable was removed from the regression model due to its extremely low observations.

Birthweight: A total of 3,222 infants had valid measurement of birthweight, ranging from 800 grams to 5250 grams (Table 5.7.). The descriptive statistic showed that the average birthweight was 3283.633 grams. The negative skewness indicate that more infants had birthweight less than mean value. The boxplot also showed that more outliers could be found in lower end than the higher end (Figure 5.2.). Since birth weight started from 800, a new continuous variable, BWCenter, was created by centering each observation with mean value. According to CDC's definition, the birth weight can be classified as extremely low birth weight (ELEB, <1,000 g), very low birth weight (VLBW, <1,500 g), low birth weight (LBW, <2,500 g), normal birth weight (NBW, <4,000 g), and high birth weight (HBW, >4,000 g) (Martin et al., 2019). In this study, there were 1 ELBW, 9 VLBW, 147 LBW, and 159 HBW. Due to the low number in ELBW and VLBW, the research combined them with LBW (n=1+8+147) and created a new dichotomous variable called LowBW. Another new dichotomous variable, called ExcessiveBW, was also created based on HBW.

Table 5.7. Descriptive Summary of Birth Weight Across the Sample of Mothers (n=3,226) in Rural and Urban Areas, Xianyang, 2008~2016.

	Birth Weight (Study Area)				Birth Weight (Urban)				Birth Weight (Rural)			
Year	Min	Median	Mean	Max	Min	Median	Mean	Max	Min	Median	Mean	Max
2008	1100	3300	3273	4800	1500	3400	3355	4800	1100	3200	3155	4500
2009	1200	3100	3162	4700	1500	3200	3262	4700	1200	3050	3029	4400
2010	1700	3250	3255	5000	2100	3300	3366	5000	1700	3100	3099	4250
2011	1600	3250	3257	4600	1900	3300	3341	4600	1600	3200	3166	4450
2012	1000	3400	3343	4500	1000	3400	3401	4500	1800	3300	3267	4500
2013	1000	3300	3299	4300	1400	3400	3368	4200	1000	3200	3193	4300
2014	800	3400	3385	5250	1000	3400	3429	5250	800	3400	3316	4400
2015	1500	3300	3308	5000	1600	3300	3355	5000	1500	3300	3263	4400
2016	1250	3300	3286	5100	1950	3300	3307	5100	1250	3250	3250	5100

Figure 5.2. Histogram of Birth Weight Across the Sample of Mothers (n=3,226) in Xianyang Area, 2008~2016.

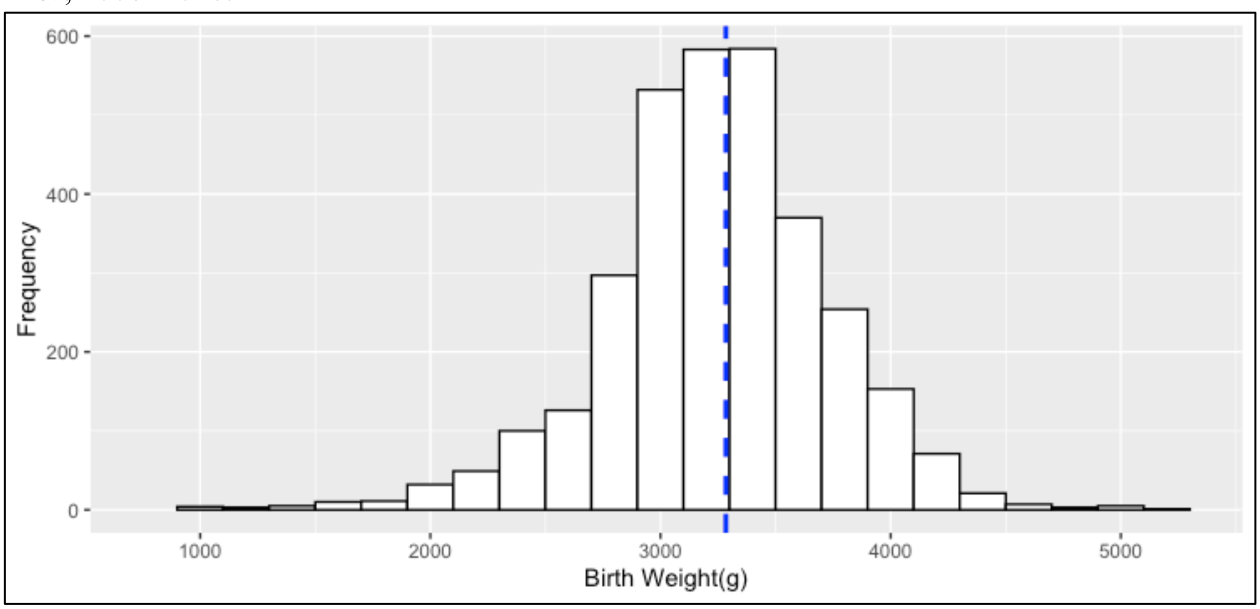
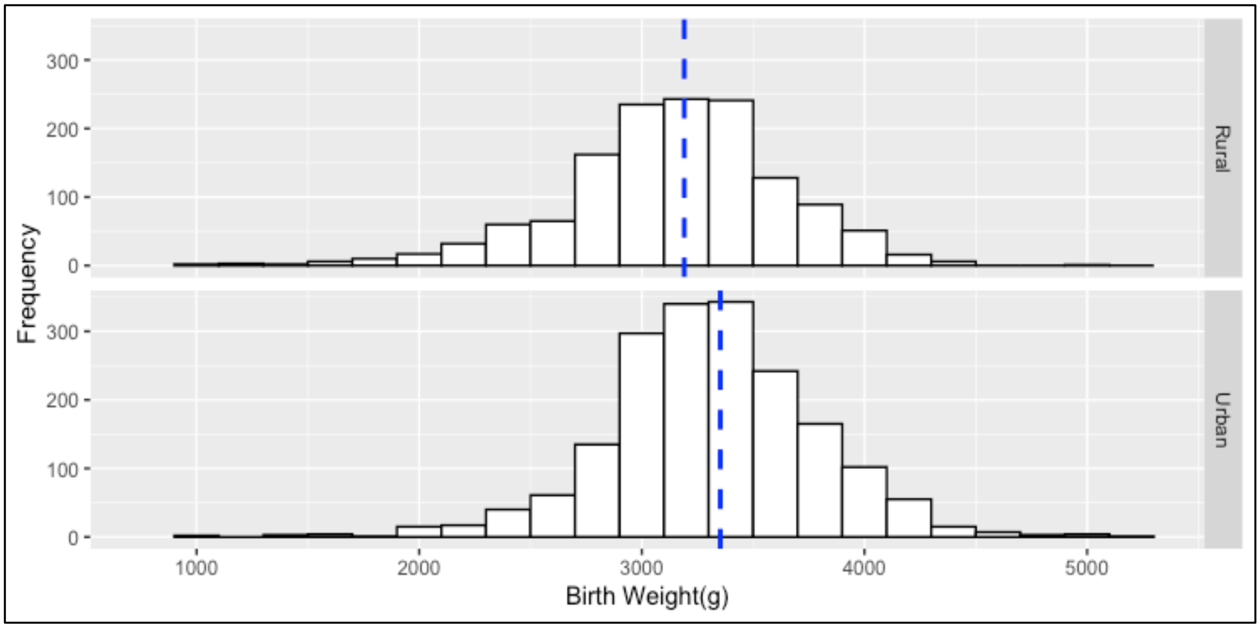


Figure 5.3. Histogram of Birth Weight Across the Sample of Mothers (n=3,226) in Rural and Urban Aras, Xianyang, 2008~2016.



Gestation: The original gestation variable is recorded by weeks, which is calculated by mother's self-reported last menstruation date. In this study, in order to calculate the cumulative haze exposure during different trimester periods, the variable is recoded by days. A total of 3, 226 mothers had valid data in this variable, ranging from 168 days (=24 weeks) to 308 days (=44 weeks) (Table 5.8.). The negative skewness (=-2.19) indicates that there are more mothers had less gestation days than the mean days (=274.443), while the high kurtosis value (=10.413) indicates a sharper peak and a longer tail. The boxplot shows that there are more outliers in lower end than in higher end (Figure 5.4.). A closer look at the gestation revealed that more mothers(n=167) had preterm birth (gestation< 259 days or 37 weeks) than postterm birth (n=14, gestation>=294 days or 42 weeks).

Table 5.8. Descriptive Summary of Gestation Across the Sample of Mothers (n=3,226) in Rural and Urban Areas, Xianyang, 2008~2016.

	Gestation (Study Area)				Gestation (Urban)				Gestation (Rural)			
Year	Min	Median	Mean	Max	Min	Median	Mean	Max	Min	Median	Mean	Max
2008	30	40	39	44	30	40	39	42	30	40	39	44
2009	29	40	39	43	31	40	39	43	29	39	39	43
2010	24	39	39	43	33	40	39	43	24	39	39	43
2011	31	40	39	43	33	40	39	42	31	40	39	43
2012	30	39	39	43	33	40	39	43	30	39	39	41
2013	30	40	40	43	32	40	40	43	30	40	39	43
2014	29	40	40	43	30	40	40	42	29	40	40	43
2015	28	40	40	42	31	40	40	42	28	40	40	42
2016	28	40	40	43	31	40	40	42	28	40	40	43

Figure 5.4. Histogram of Gestation Across the Sample of Mothers (n=3,226) in Xianyang Area, 2008~2016.

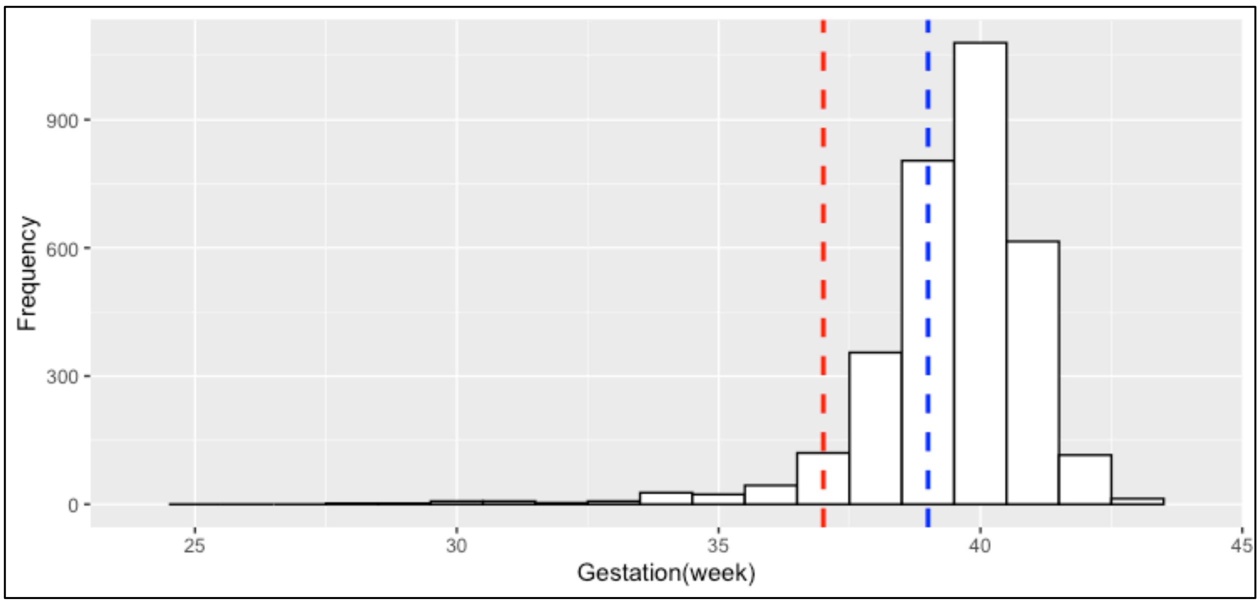
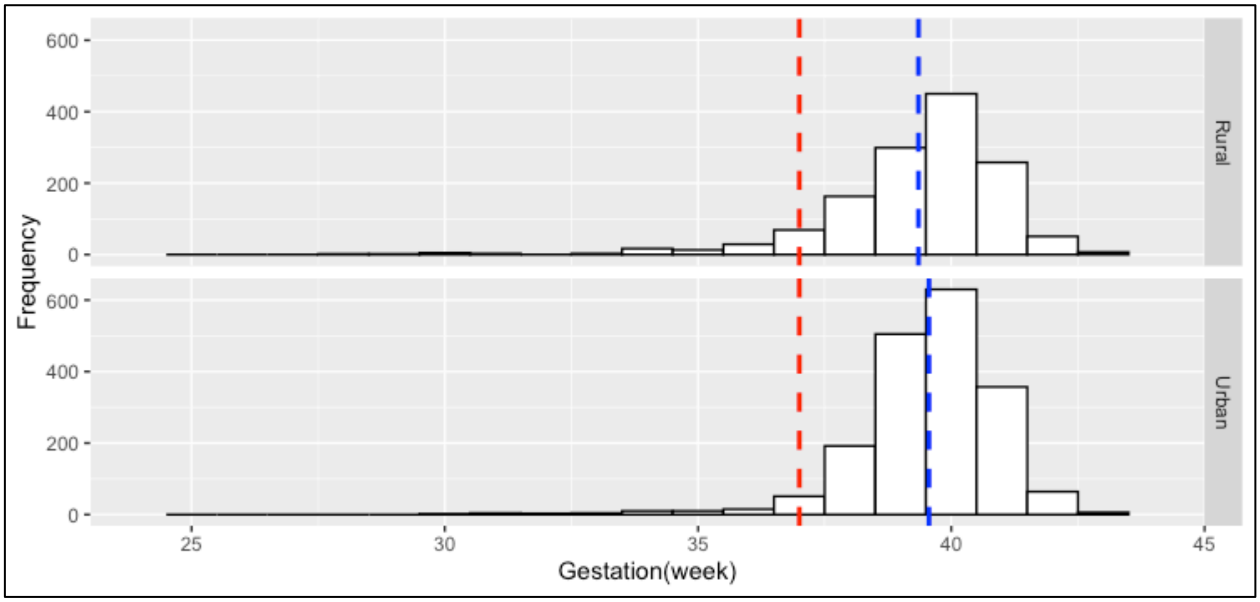


Figure 5.5. Histogram of Gestation Across the Sample of Mothers (n=3,226) in Rural and Urban Aras, Xianyang, 2008~2016.



Birthweight by Gestation: Dai et al. (2014) developed a gender-gestational age-specific birth weight percentile table for Chinese infants based on N=1,105,214 healthy live singleton births (2006-2010) collected from the China National Population-based Birth Defects Surveillance System. In his study, the birth weight at gestational age can be grouped into three categories, Small for Gestational Age (SGA), Normal for Gestational Age (NGA), and Large for Gestational Age (LGA). SGA will be birth weight that falls below the 10^{th} percentile for gestational age. NGA will be the birth weight that lies between the10^{th} and 90^{th} percentile for gestational age. LGA will be birth weight that exceeds above the 90^{th} percentile for gestational age. This study adopted the same birth weight reference percentile table for Chinese male and female newborns to create a nominal variable based on these percentiles (Table 5.9.). Each infant's birth weight was compared with the reference birth weight by gestational age in the table and coded as SGA, NGA, or LGA (gestational weight). The descriptive statistics showed that 77.2% (n=2,491) infants were NGA, 7.8% (n=251) SGA, and 15% (n=484) LGA.

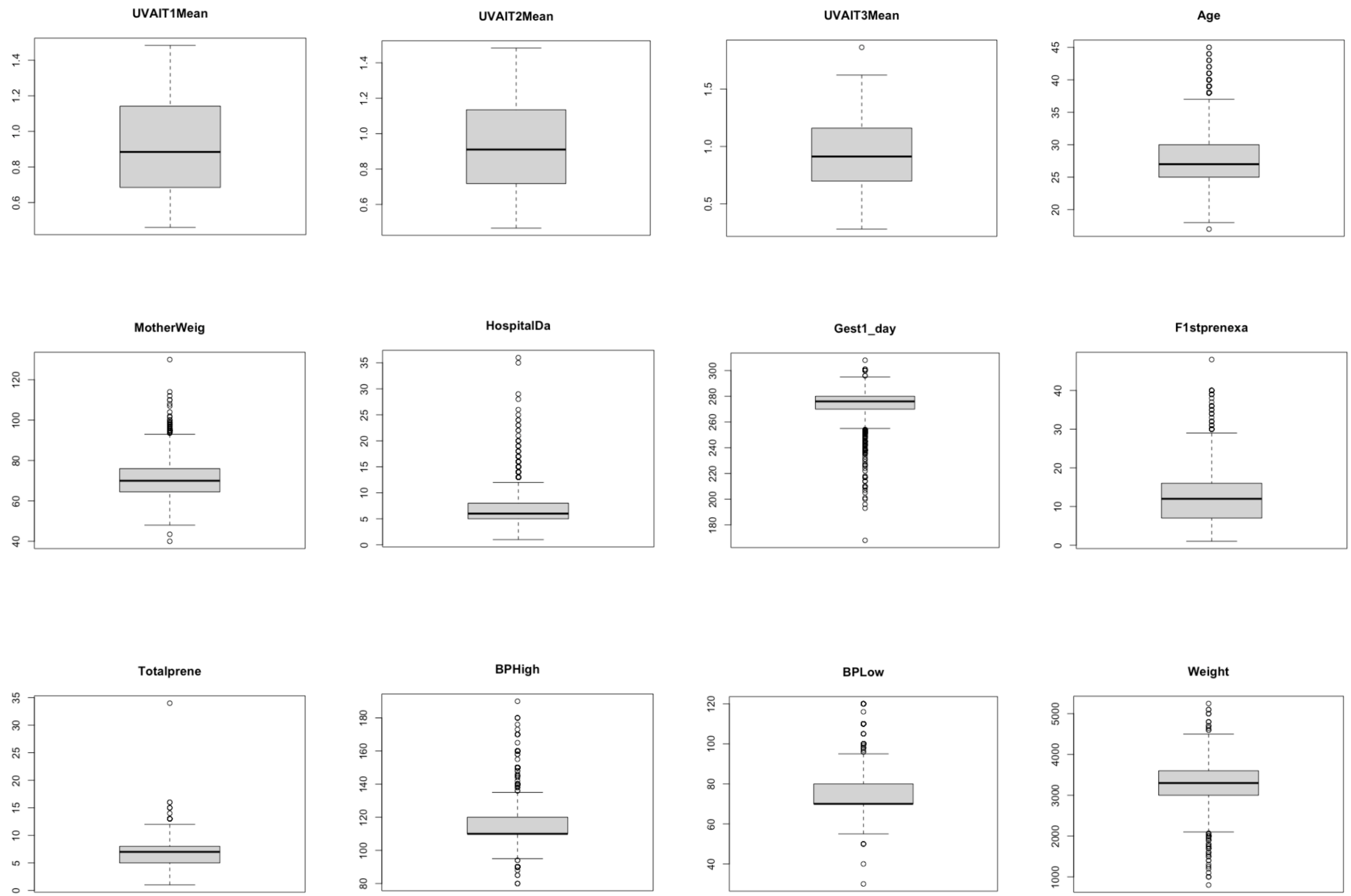
Table 5.9. Referential Birthweight by Gestation.

Week	P10_M	P90_M	P10_F	P90_F
29	895	1458	830	1432
30	1056	1707	992	1692
31	1220	1957	1157	1950
32	1388	2208	1325	2206
33	1563	2462	1499	2459
34	1746	2717	1680	2707
35	1939	2972	1871	2945
36	2143	3215	2071	3167
37	2356	3434	2279	3360
38	2565	3613	2482	3515
39	2739	3746	2652	3632
40	2849	3836	2764	3717
41	2908	3907	2824	3787
42	2943	3987	2854	3863
43	2963	4064	2868	3933
44	2976	4138	2875	3999

P10_M: 10%, Male; P90_M: 90%, Male; *P10_F: 10%, Female; *P90_F: 90%, Female.

Apgar Score: The Apgar score was composed by 10 variables measuring 5 aspects (Pulse, Respiration, Activity, Grimace, and Appearance) of infant's appearance at 1 minute after birth and at 5 minutes after birth. Except Appearance, most variables could achieve at least 96% in better score(2 points) at both 1-minute measurement and 5-minute measurement, such as Pulse (1 minute=3,211/99.5%; 5 minutes=3,218/99.8%), Respiration (1 minute =3,100/96.1%; 5 minutes =3,183/98.7%), Activity (1 minute =3,102/96.2%; 5 minutes =3,180/98.6%), Grimace (1 minute =3,175/98.4%;5 minutes=3,209/99.5%). Only Appearance has a lower score 1 (n =1,704/52.8%) at 1-minute measurement, while most babies (n=3,151/97.7%) could have improved appearance at 5-minutes measurement.

Figure 5.6. Boxplot for Numerical Variables



5.6.d. ICD-10 Diagnosis Code Summary

In this study, a total of 206 ICD10 codes were listed 7,680 times in 3,226 obstetric records. Appendix B listed all 206 ICD10, frequency, and recoding category and Table 5.10. showed the first 15 ICD 10 codes with the highest frequency. The O69.1 (Labor and delivery complicated by cord around neck, with compression) appeared to be the most common diagnosis code, while Anemia (O99.0, n=810) was found to be the most common condition complicating the pregnancy, childbirth, and the puerperium.

Table 5.10. Top 15 ICD-10 Codes in Category of Pregnancy, Childbirth, and the Puerperium.

ICD10	Code Description	Freq.	Category
O69.1	Labor and delivery complicated by cord around neck, with compression	1107	7
O99.0	Anemia complicating pregnancy, childbirth and the puerperium	810	3
O33.9	Maternal care for disproportion, unspecified. Cephalopelvic disproportion NOS, Fetopelvic disproportion NOS	592	2
O41.0	Oligohydramnios	502	2
O42.9	Premature rupture of membranes, unspecified	486	4
O23.9	Other and unspecified genitourinary tract infection in pregnancy	464	3
O34.2	Maternal care due to uterine scar from previous surgery	382	1
O80.0	Spontaneous vertex delivery	298	4
O36.3	Maternal care for signs of fetal hypoxia	269	6
O13	Gestational (Pregnancy-induced) hypertension	254	2
N76.1	Subacute and chronic vaginitis	219	3
O32.1	Maternal care for breech presentation	161	2
O98.4	Viral hepatitis complicating pregnancy, childbirth and the puerperium	138	3
O64.0	Obstructed labor due to incomplete rotation of fetal head	119	4
O99.5	Diseases of the respiratory system complicating pregnancy, childbirth and the puerperium	113	3

A summary of the diagnosis datasets shows that most mothers (n=1007/32.22%) had only 1 diagnosis code, while nearly half mothers had two or three diagnosis codes (n=1608/49.85%) (Table 5.11.). To certain degree, the number of diagnosis code could indicate the general health condition of the mother and infant. The more diagnosis codes the mother and baby have the more complicated health condition can be found. From diagnosis code table, we could know that 94% of mothers and infants had 4 or less than 4 diagnosis codes while only 6% mothers and infants had more complicated medical conditions. In this study, only one observation was diagnosed with extreme risk by having 12 diagnosis code. A closer scrutiny showed that this mother and infant had E77.8 (Other disorders of glycoprotein metabolism), 024.4 (Diabetes), O26.6 (Intrahepatic cholestasis of pregnancy), O99.1 (Pregnancy combined with thrombocytopenia), O98.4 (Viral hepatitis complicating pregnancy, childbirth and the puerperium), R16.1 (Splenomegaly, not elsewhere classified), O99.6 (Diseases of the digestive system complicating pregnancy, childbirth and the puerperium) , O99.4 (Disease of the circulatory system complicating pregnancy, childbirth and the puerperium), O72 (Postpartum hemorrhage), O99.0 (Anemia), O41.8 (Other specified disorders of amniotic fluid and membranes), and P07.3 (Preterm Infants).

Table 5.11. ICD-10 Code Frequency for Each Mother.

No. Codes	No.	(%)	Cumulated (%)
1	1007	31.22	31.22
2	901	27.93	59.15
3	707	21.92	81.07
4	419	12.99	94.06
5	124	3.84	97.9
6	43	1.33	99.23
7	13	0.40	99.63
8	7	0.22	99.85
9	2	0.06	99.91
10	2	0.06	99.97
11	0	0.00	99.97
12	1	0.03	100

Moreover, according to the association with agents and timing, all ICD10 codes were recoded into new 8 categories (Table 5.12.). The pre-pregnancy codes (category 1=45/21.84%) were mother's diseases happened before pregnancy, such as O34.2 (Maternal care due to uterine scar from previous surgery). The pregnancy-related (mother) (category 2=31/15.05%) were the diseases happened during the period of pregnancy, such as O33.9(Maternal care for disproportion, unspecified). As to the disease that cannot be decided when happened (n=24/11.65), the pre-pregnancy and pregnancy-related (mother) (category 3=24/11.65%) were used, such as O99.0(Anemia complicating pregnancy, childbirth and the puerperium). The mother's accidents or complications (n=16/7.77%) happened during the delivery were classified as category 4, such as O64.0 (Obstructed labor due to incomplete rotation of fetal head). The mother's diseases that were happened and diagnosed after the delivery were classified as category 5 (n=7/3.40%), such as Z30.2 (Sterilization). Similarly, based on the timing, the baby's situations were classified as category 6 (pregnancy-related (baby), such as O36.3: Maternal care for signs of fetal hypoxia), 7(delivery (baby), such as O69.1: Labor and delivery complicated by cord around neck, with compression), and 8 (post-delivery(baby), such as P07,1: Other low birth weight). Within all diagnosis codes, the diabetes had both pre-pregnancy diagnosis code and pregnancy-related code. However, in most obstetric records, these two types of codes were not distinguished very clearly and seriously. In order to reduce confusion, a comprehensive variable (Diabetes) was created as the combination of pre-pregnancy and pregnancy-related code. The new variable was created as the combination of O24.3(Pre-existing diabetes mellitus, unspecified, n=2) and O24.4(Diabetes mellitus arising in pregnancy, n=49).

Table 5.12. ICD-10 Code Recoding Summary.

Code	Category	No. Codes	(%)	Cumulated (%)
1	Pre-pregnancy	45	21.84	21.84
2	Pregnancy-related（Mother）	31	15.05	36.89
3	Pre-pregnancy and Pregnancy-related	24	11.65	48.54
4	Delivery (Mother)	16	7.77	56.31
5	Post-delivery (Mother)	7	3.40	59.71
6	Pregnancy-related (Baby)	28	13.59	73.3
7	Delivery (Baby)	15	7.28	80.58
8	Post-delivery(Baby)	40	19.42	100

Among all categories, the diagnosis codes in mother's pre-pregnancy, pregnancy-related, and pre-pregnancy and pregnancy-related categories are theoretically more directly correlated with haze density. In order to test these diseases' mediating effect, the diagnosis codes in these three categories are further divided into 16 classes based on their clinical features (Table 5.13.). The first 12 classes with n>30 will be tested their mediating effects on the relationships between birth outcomes and haze measurements.

Table 5.13. Clinical Classification for ICD-10 Codes in Pre-pregnancy, Pregnancy-Related, and Pre-pregnancy and Pregnancy-Related Categories.

	Observation			Diagnosis Codes		
Class	No.	(%)	Cumulative (%)	No.	(%)	Cumulative (%)
Gynecological diseases	972	21.00	21.00	24	24.24	24.24
Anemia	810	17.50	38.50	1	1.01	25.25
Cardiopathy	707	15.27	53.77	5	5.05	30.30
Fetal membranes	470	10.15	63.92	4	4.04	34.34
Liver, pancreas, spleen	461	9.96	73.88	7	7.07	41.41
Placenta previa, abruption or abnormality	410	8.86	82.74	4	4.04	45.45
Hypertension	276	5.96	88.70	6	6.06	51.52
Medical co-morbidities--Obstetric	186	4.02	92.72	8	8.08	59.60
Digestive diseases	115	2.48	95.20	2	2.02	61.62
Medical co-morbidities--Chronic	87	1.88	97.08	15	15.15	76.77
Chronic or gestational diabetes mellitus	51	1.10	98.19	2	2.02	78.79
Medical co-morbidities—Infectious	44	0.95	99.14	5	5.05	83.84
Metabolic diseases	22	0.48	99.61	5	5.05	88.89
Others	14	0.30	99.91	7	7.07	95.96
Mental, neurological disorders	3	0.06	99.98	3	3.03	98.99
Respiratory diseases	1	0.02	100.00	1	1.01	100.00

5.6.e. Multicollinearity

This study included two types of variables, continuous variables summarized, and categorical variables summarized. The multicollinearity tests were also conducted within and among two types of variables. Within continuous variables, the Variance Inflation Factor (VIF) and Pearson Correlation Matrix were used to determine the multicollinearity. Within categorical variables, the VIF and The Pearson Chi-square were conducted to measure the multicollinearity.

Since haze density was the key continuous IV, the ANOVA test was used to assess the collinearity between UVAI variable and Categorical IVs.

VIF**:** Within all numerical IVs, the UVAI, UVAITriMin, and UVAITriMax were created based on the three trimesters' UVAI means, which were removed from VIF test due to their known collinearity with trimester UVAI means. Similarly, within all categorical IVs, all derivative IVs, including Age1, BPHigh1, BPLow1, BPHyper, and BPHypo, were removed too. The results showed that all numerical and categorical IVs had VIF lower than 5, indicating low collinearity (APPENDIX C).

Numerical Variable VS Numerical Variable: Pearson Correlation Matrix: The P-value in Pearson Correlation Matrix indicated whether two numerical variables are statistically significant correlated with each other. The Null hypothesis is that their correlation equals 0. Since 0 in correlation table means randomly distributed and +/-1 means positively/negatively linear correlated, the null hypothesis assumes two variables are not correlated. For pair of independent variables, we are looking for p value >0.05 and accept null hypothesis. Table 5.14. showed that UVAIT1Mean was significantly correlated with UVAIT2Mean and UVAIT3Mean. Since UVAI, UVAITriMin, and UVAITriMax were created on the basis of UVAIT1Mean, UVAIT2Mean, and UVAIT3Mean, it was not uncommon that they are significantly correlated with trimesters' averages. In all haze variables, UVAIT2Mean and UVAIT3mean as well as UVAITriMin and UVAITriMax were not correlated IVs.

For dependent variable, Birth Weight, we are looking for the independent variables with p value<0.05. Table 5.14. showed that the UVAIT1Mean, UVAIT2Mean, UVAIT3Mean, UVAITriMin, and Age were not significant to the Birth Weight. However, the pregnancy averaged UVAI and UVAITriMax were statistically significant factor for all numerical independent variables and dependent variable. This table was also used in regression analyses to determine the combination of IVs from statistical perspective.

Continuous Variable VS Categorical Variables: ANOVA: The ANOVA (analysis of variance) is a statistical model used to test the differences among group means in a sample. It is also a special case of linear model where the IV are categorical variables while the DV is continuous variable. This test was conducted to measure the collinearity between selected haze variable and other IVs in regression models. When the p value<0.05, we need reject the null hypothesis and states two variables are statistically correlated, which is not good. When the P value>0.05, we can accept the null hypothesis that two variables are independent. In this study, the ANOVA was also used to find the IV(s) that was/were uncorrelated to haze variable and statistically significant to Birth Weight (Table 5.15.).

After the pre-tests, the UVAI was determined as the only haze variable in initial regression model. Here the bivariate ANOVA were conducted to test the statistical significance between continuous variable (UVAI) and all categorical IVs. The results showed that all mother demographic variables(Urban, Nutrition, Occupation, and Marital), three mother health variables(Parity, BPHyper, and Preterm), two fetus health variables(LowBW and SGA), and three medical condition variables(code count, Preg_M, and Deliv_B) were correlated to UVAI (Table 5.15.).

Table 5.14. Pearson Correlation for Numerical Variables

	UVAI T1 Mean	UVAI T2 Mean	UVAI T3 Mean	UVAI	UVAI TriMin	UVAI TriMax	Age	Hospl Day	Gest day	First Prenatal	Total Prenatal	BPHigh	BPLow	Birth Weight
UVAIT 1 Mean	NA	4.20E-06	0.00E+00	2.13E-14	0	5.65E-06	8.85E-01	4.38E-02	3.04E-01	4.45E-05	7.47E-04	6.91E-02	5.81E-01	3.72E-01
UVAIT 2 Mean	4.20E-06	NA	1.60E-01	0.00E+00	0	0	9.09E-02	5.78E-01	6.79E-03	9.12E-04	2.81E-01	1.98E-04	5.07E-06	9.52E-02
UVAIT 3 Mean	0.00E+00	1.60E-01	NA	0.00E+00	5.56E-07	0	1.05E-01	3.76E-01	9.04E-01	6.83E-01	4.03E-01	9.84E-02	4.40E-01	1.53E-01
UVAI	2.13E-14	0.00E+00	0.00E+00	NA	0	0	6.10E-03	3.24E-03	7.66E-04	2.09E-11	2.18E-03	1.85E-03	4.39E-04	5.02E-04
UVAI TriMin	0	0	5.56E-07	0	NA	0.215515	0.691163	0.691163	0.009724	0.617001	0.009724	7.48E-07	0.288	0.164821
UVAI TriMax	5.65E-06	0	0	0	0.215515	NA	0.006066	0.006066	0.017689	5.05E-05	0.017689	0.000804	0.007099	7.13E-06
Age	8.85E-01	9.09E-02	1.05E-01	6.10E-03	0.691163	0.006066	NA	4.92E-03	5.03E-10	4.56E-01	3.98E-01	1.26E-03	1.02E-01	5.01E-01
Hospl Day	4.38E-02	5.78E-01	3.76E-01	3.24E-03	0.691163	0.006066	4.92E-03	NA	7.72E-06	4.70E-05	3.90E-01	4.57E-03	4.96E-03	6.15E-03
Gest Day	3.04E-01	6.79E-03	9.04E-01	7.66E-04	0.009724	0.017689	5.03E-10	7.72E-06	NA	6.81E-02	6.65E-10	1.36E-09	1.98E-07	0.00E+00
First Prenatal	4.45E-05	9.12E-04	6.83E-01	2.09E-11	0.617001	5.05E-05	4.56E-01	4.70E-05	6.81E-02	NA	0.00E+00	1.28E-01	5.42E-01	2.91E-02
Total Prenatal	7.47E-04	2.81E-01	4.03E-01	2.18E-03	0.009724	0.017689	3.98E-01	3.90E-01	6.65E-10	0.00E+00	NA	3.09E-01	5.33E-01	4.44E-16
BPHigh	6.91E-02	1.98E-04	9.84E-02	1.85E-03	7.48E-07	0.000804	1.26E-03	4.57E-03	1.36E-09	1.28E-01	3.09E-01	NA	0.00E+00	1.26E-10
BPLow	5.81E-01	5.07E-06	4.40E-01	4.39E-04	0.288	0.007099	1.02E-01	4.96E-03	1.98E-07	5.42E-01	5.33E-01	0.00E+00	NA	2.33E-07
Birth Weight	3.72E-01	9.52E-02	1.53E-01	5.02E-04	0.164821	7.13E-06	5.01E-01	6.15E-03	0.00E+00	2.91E-02	4.44E-16	1.26E-10	2.33E-07	NA

Table 5.15. ANOVA Test between UVAI and Categorical IVs.

Class	Categorical IV	ANOVA P-value
Mother Demographic Variables	Urban	0.000
	Nutrition	0.003
	Occupation	0.000
	Marital	0.031
Mother Health Variables	PregnancyH	0.447
	Parity	0.010
	BPHypo	0.933
	BPHyper	0.000
	Amfluid	0.196
	Preterm	0.000
	Overdue	0.603
Fetus Health Variables	LowBW	0.005
	ExcessiveBW	0.395
	BWbyGest	0.615
	LGA	0.325
	SGA	0.028
	Gender	0.809
Medical Condition Variables	code_count	0.000
	Pre_M	0.596
	Preg_M	0.003
	Pre_Preg_M	0.932
	Delivery_M	0.960
	Post_Deliv_M	0.780
	Preg_B	0.683
	Deliv_B	0.000
	Post_Deliv_B	0.461

5.7. Multiple Linear Regressions

In this study, the multiple linear regressions were estimated to examine the relationship between trimester haze exposure (UVAIT1Mean and UVAIT3Mean) and birth outcomes (Birth Weight and Birth Weight by Gestation) controlling potential confounding variables. The results showed that T1 exposure and T3 exposure had statistically significant and negative impact on the birth weight in different mother groups (Table 5.16.). The UVAIT1Mean demonstrated nearly significant impact (Pr=0.098) on infant birth weight in urban mother who had no prior pregnancy (n=937), while the UVAIT3Mean had statistically significant influence (Pr=0.039) on birth weight in urban mother who worked mostly outside and had no prior pregnancy (n=230).

Table 5.16. Multiple Linear Regression Results.
a. UVAIT1Mean.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	2281.526	11017.469	0.207	0.836
Gest(week)	134.963	10.072	13.400	<2e-16***
Age	11.765	4.828	2.437	0.015*
Female	-184.713	27.885	-6.624	5.92e-11***
Year	-3.674	5.494	-0.669	0.504
Occupation	-17.491	33.639	-0.520	0.603
UVAI T1	-81.685	49.297	-1.657	0.098

* Residual standard error: 421.3 on 925 degrees of freedom.
*Multiple R-squared: 0.1861, Adjusted R-squared: 0.1808.
*F-statistic: 35.24 on 6 and 925 DF, p-value: <2.2e-16

b. UVAIT3Mean.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-5320.589	813.63	-6.539	4.10e-10***
Gest(week)	143.818	20.207	7.117	1.46e-11***
Age	3.206	9.258	0.346	0.73
Month	-12.981	11.298	-1.149	0.252
UVAI T3	-271.845	131.1	-2.074	0.039*

* Residual standard error: 400.3 on 225 degrees of freedom.
*Multiple R-squared: 0.1966, Adjusted R-squared: 0.1823.
*F-statistic: 13.76 on 4 and 225 DF, p-value: 4.688e-10

5.8. Mediating Models

In the previous section, the results of multiple regressions proved that haze exposure in first and third trimester during the pregnancy had negative impact on birth outcomes in different mother groups. In this section we will move forward to test the mediating effect of maternal medical conditions on haze. First, as we have mentioned before, we selected all diagnosis codes in three categories (Pre-pregnancy, Pregnancy-related, and Pre-pregnancy and Pregnancy-related) and further recoded them into 16 classes based on their clinical features. For maternal medical conditions, we decided to only test the classes that had adequate sample size (n>30). Second, for haze density, instead of testing trimester exposure, we selected UVAI, UVAITriMin, and UVAITriMax as key haze measurement because they represented the average, lowest, and the highest density of haze that mothers were exposed during the pregnancy. Third, since in mediating test it was okay for haze measurement being insignificant to DV, we decided to include more dichotomous DVs here, including SGA, LGA, Preterm, and LBW. At last, since mediating test requires a larger sample size (n>300), we decided to conduct mediating tests in all mother group.

Table 5.17. to Table 5.28. showed that within 12 clinical classes a total of 6 classes showed statistical significance to one or more haze measurement(s), including Cardiomyopathy, Maternal Co-Morbidity (Chronic), Diabetes, Gynecology, Hypertension and Maternal Co-Morbidity (Obstetric). First, the Cardiomyopathy was almost significant mediator to birth weight (ACME p-value=0.05) and significantly mediated 6% (p-value=0.05) change in UVAI Model. Second, the Chronic Maternal Co-morbidities was significant mediator to birth weight (ACME p-value=0.012), gestation (ACME p-value=0.012), LBW (ACME p-value=0.02), and Preterm (ACME p-value=0.016) in UVAI Model. It significantly mediated 15 % change (p-value=0.012) in birth weight, 21% (p-value=0.014) in gestation, 18% (p-value=0.02) in LBW, and 12%(p-value=0.016) in Preterm. Third, the Diabetes was significant mediator to birth weight (ACME p-value=0.016) in UVAI model, where it significantly mediated 1% (p-value=0.018) change. It also significantly mediated 9% (p-value=0.012) change of LGA (ACME p-value=0.004) in UVAITriMin model. Fourth, the Genecology was significant mediator to birth weight (ACME p-value<2e-16), gestation (ACME p-value=0.012), Preterm (ACME p-value=0.016), and SGA (ACME p-value<2e-16) in UVAI Model. It significantly mediated 22% change (p-value<2e-16) in birth weight, 3% (p-value=0.0014) in gestation, 4% (p-value=0.02) in Preterm, and 9% (p-value=0.02) in SGA. The Genecology also significantly mediated 17% (p-value=0.008) change of birth weight

(ACME p-value=0.004) and 3% (p-value=0.028) change of Preterm (ACME p-value=0.024) in UVAITriMax model. Fifth, the Hypertension was the significant mediator to birth weight (ACME p-value<2e-16), gestation (ACME p-value<2e-16), LBW (ACME p-value<2e-16), Preterm (ACME p-value<2e-16), and SGA (ACME p-value=0.04) in UVAI Model. It significantly mediated 14% change (p-value=0.002) in birth weight, 14% (p-value<2e-16) in gestation, 23% (p-value=0.006) in LBW, 16% (p-value=0.004) in Preterm, and 11% (p-value=0.036) in SGA. The Hypertension also significantly mediated 21% (p-value=0.002) change of birth weight (ACME p-value<2e-16), 29% (p-value=0.018) change of gestation (ACME p-value<2e-16), 30% (p-value=0.004) change of LBW (ACME p-value<2e-16), and 23% (p-value=0.004) change of Preterm (ACME p-value<2e-16) in UVAITriMax model. Sixth, the Obstetric maternal co-morbidity significantly mediated 5% (p-value=0.04) change of LGA (ACME p-value=0.016) in UVAITriMin model.

Table 5.17. Mediating Result for All Mother Group: Anemia.

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Anemia (Urban=402, Rural=400)	ACME	-1.71	-9.21	3.82	0.60	-0.01	-4.33	3.82	0.98	-3.62	-11.25	1.30	0.19
	ADE	293.04	105.03	484.48	0.002 **	178.00	69.60	295.39	0.002 **	34.01	-104.63	169.55	0.62
	Total Effect	291.34	105.75	481.72	0.002 **	178.00	69.10	294.00	0.002 **	30.39	-109.64	166.11	0.67
	Prop. Mediated	-0.01	-0.04	0.02	0.60	0.00	-0.03	0.03	0.98	-0.12	-0.54	0.96	0.78
	GestCenter												
	ACME	0.02	-0.06	0.16	0.74	0.00	-0.05	0.08	0.94	0.04	-0.06	0.20	0.48
	ADE	6.69	2.44	11.02	0.006 **	2.85	-0.06	5.56	0.052 .	4.56	0.74	8.15	0.026 *
	Total Effect	6.70	2.48	11.19	0.006 **	2.85	-0.03	5.54	0.056 .	4.60	0.77	8.28	0.024 *
	Prop. Mediated	0.00	-0.01	0.03	0.74	0.00	-0.03	0.05	0.94	0.01	-0.01	0.07	0.48
	LBW												
	ACME	0.00	-0.01	0.00	0.80	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.62
	ADE	-0.18	-0.47	-0.02	0.018 *	-0.12	-0.31	-0.02	0.004 **	-0.05	-0.15	0.02	0.18
	Total Effect	-0.18	-0.47	-0.02	0.016 *	-0.12	-0.31	-0.02	0.004 **	-0.05	-0.15	0.02	0.17
	Prop. Mediated	0.00	-0.02	0.04	0.80	0.00	-0.02	0.02	0.95	0.01	-0.12	0.20	0.71
	LGA												
	ACME	0.00	-0.01	0.00	0.56	0.00	0.00	0.00	0.88	0.00	-0.01	0.00	0.17
	ADE	-0.07	-0.24	0.05	0.31	-0.01	-0.11	0.05	0.74	-0.13	-0.25	-0.01	0.032 *
	Total Effect	-0.07	-0.25	0.05	0.31	-0.01	-0.11	0.05	0.73	-0.13	-0.25	-0.01	0.022 *
	Prop. Mediated	0.03	-0.36	0.32	0.72	0.00	-0.41	0.46	0.99	0.02	-0.01	0.15	0.19
	Preterm												
	ACME	0.00	-0.01	0.00	0.83	0.00	0.00	0.00	0.95	0.00	0.00	0.00	0.68
	ADE	-0.26	-0.55	-0.06	0.002 **	-0.16	-0.37	-0.04	0.004 **	-0.03	-0.14	0.03	0.35
	Total Effect	-0.26	-0.55	-0.07	0.002 **	-0.16	-0.37	-0.04	0.004 **	-0.03	-0.14	0.03	0.35
	Prop. Mediated	0.00	-0.01	0.02	0.83	0.00	-0.01	0.02	0.95	0.02	-0.21	0.18	0.79
	SGA												
	ACME	0.00	0.00	0.00	0.96	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.99
	ADE	-0.15	-0.36	-0.02	0.01 *	-0.05	-0.16	0.01	0.14	-0.07	-0.19	0.01	0.072 .
	Total Effect	-0.15	-0.35	-0.02	0.01 *	-0.05	-0.16	0.01	0.14	-0.07	-0.19	0.01	0.078 .
	Prop. Mediated	0.00	-0.03	0.03	0.96	0.00	-0.06	0.07	1.00	0.00	-0.07	0.12	0.99

Table 5.18. Mediating Result for All Mother Group: Cardiomyopathy.

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Cardiomyopathy (Urban=347, Rural=320)	ACME	-16.86	-27.46	-0.11	**0.05 .**	-4.67	-13.00	5.91	0.44	-7.12	-22.44	6.95	0.29
	ADE	309.65	126.94	486.37	<2e-16 ***	183.14	74.67	297.94	<2e-16 ***	39.34	-113.55	172.63	0.56
	Total Effect	292.79	113.95	472.92	<2e-16 ***	178.48	68.60	295.06	<2e-16 ***	32.21	-117.67	164.02	0.66
	Prop. Mediated	-0.06	-0.16	0.00	**0.05 .**	-0.03	-0.11	0.03	0.44	-0.22	-1.59	1.98	0.77
	GestCenter												
	ACME	0.07	-0.04	0.20	0.25	0.02	-0.04	0.10	0.51	0.04	-0.04	0.17	0.42
	ADE	6.63	2.19	11.22	0.002 **	2.82	0.10	5.55	0.046 *	4.55	1.02	8.25	0.01 *
	Total Effect	6.70	2.28	11.26	0.002 **	2.84	0.11	5.57	0.046 *	4.60	1.13	8.24	0.01 *
	Prop. Mediated	0.01	-0.01	0.04	0.25	0.01	-0.03	0.08	0.52	0.01	-0.01	0.06	0.42
	LBW												
	ACME	0.01	0.00	0.01	0.076 .	0.00	0.00	0.01	0.37	0.00	0.00	0.01	0.26
	ADE	-0.19	-0.47	-0.02	0.018 *	-0.13	-0.29	-0.02	0.014 *	-0.05	-0.15	0.02	0.20
	Total Effect	-0.19	-0.47	-0.01	0.026 *	-0.12	-0.29	-0.02	0.016 *	-0.05	-0.15	0.02	0.21
	Prop. Mediated	-0.03	-0.15	0.01	0.10	-0.02	-0.09	0.03	0.38	-0.05	-0.43	0.34	0.42
	LGA												
	ACME	-0.01	-0.02	0.00	0.052 .	0.00	-0.01	0.00	0.43	0.00	-0.01	0.00	0.32
	ADE	-0.06	-0.24	0.06	0.39	-0.01	-0.10	0.05	0.76	-0.12	-0.25	-0.01	0.038 *
	Total Effect	-0.07	-0.25	0.06	0.33	-0.01	-0.11	0.05	0.73	-0.13	-0.25	-0.01	0.032 *
	Prop. Mediated	0.11	-0.99	1.28	0.36	0.26	-1.04	1.01	0.87	0.02	-0.06	0.25	0.32
	Preterm												
	ACME	0.00	0.00	0.01	0.24	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.46
	ADE	-0.27	-0.53	-0.06	<2e-16 ***	-0.16	-0.35	-0.04	<2e-16 ***	-0.04	-0.14	0.04	0.35
	Total Effect	-0.26	-0.52	-0.06	<2e-16 ***	-0.16	-0.35	-0.04	<2e-16 ***	-0.03	-0.13	0.04	0.36
	Prop. Mediated	-0.01	-0.05	0.01	0.24	0.00	-0.03	0.01	0.55	-0.02	-0.25	0.22	0.66
	SGA												
	ACME	0.01	0.00	0.02	0.046 *	0.00	0.00	0.00	0.99	0.01	-0.01	0.01	0.28
	ADE	-0.16	-0.37	-0.03	0.012 *	-0.05	-0.16	0.01	0.14	-0.08	-0.19	0.00	0.08 .
	Total Effect	-0.15	-0.36	-0.01	0.028 *	-0.05	-0.16	0.01	0.14	-0.07	-0.18	0.01	0.10
	Prop. Mediated	-0.08	-0.50	0.02	0.074 .	0.00	-0.06	0.07	1.00	-0.09	-0.81	0.51	0.37

Table 5.19. Mediating Result for All Mother Group: Maternal Co-Morbidity (Chronic).

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
	ACME	48.24	5.31	152.28	**0.012** *	27.35	-0.90	92.63	0.074 .	13.22	-4.39	58.48	0.18
	ADE	268.49	79.45	445.21	<2e-16 ***	165.36	60.28	282.14	0.002 **	20.03	-122.96	147.19	0.82
	Total Effect	316.73	128.74	515.43	<2e-16 ***	192.71	74.60	323.11	0.002 **	33.25	-97.35	174.96	0.64
	Prop. Mediated	0.15	0.02	0.48	**0.012** *	0.14	-0.01	0.44	0.076 .	0.40	-3.29	3.59	0.64
	GestCenter												
	ACME	1.60	0.22	4.85	**0.012** *	0.70	-0.04	2.73	0.072 .	0.38	-0.11	1.56	0.15
	ADE	5.98	1.72	10.25	0.004 **	2.45	0.01	5.18	0.050 .	4.26	0.88	7.76	0.014 *
	Total Effect	7.59	2.95	12.93	0.002 **	3.15	0.54	6.61	0.016 *	4.63	1.16	8.39	0.008 **
	Prop. Mediated	0.21	0.03	0.56	**0.014** *	0.22	-0.04	0.82	0.088 .	0.08	-0.03	0.43	0.15
	LBW												
	ACME	-0.04	-0.11	0.00	**0.020** *	-0.02	-0.05	0.00	0.098 .	-0.01	-0.03	0.00	0.19
	ADE	-0.16	-0.41	-0.01	0.026 *	-0.11	-0.29	-0.01	0.018 *	-0.04	-0.13	0.03	0.31
Chronic (Urban=44, Rural=42)	Total Effect	-0.20	-0.46	-0.02	0.008 **	-0.13	-0.31	-0.02	0.008 **	-0.04	-0.14	0.02	0.24
	Prop. Mediated	0.18	0.02	0.73	**0.028** *	0.14	-0.01	0.58	0.098 .	0.18	-1.51	2.16	0.35
	LGA												
	ACME	0.00	-0.01	0.02	0.58	0.00	-0.01	0.01	0.58	0.00	0.00	0.01	0.59
	ADE	-0.08	-0.26	0.05	0.28	-0.01	-0.12	0.05	0.71	-0.13	-0.27	-0.02	0.012 *
	Total Effect	-0.07	-0.26	0.05	0.33	-0.01	-0.12	0.05	0.76	-0.13	-0.27	-0.02	0.014 *
	Prop. Mediated	-0.05	-1.08	1.05	0.74	-0.10	-1.77	1.32	0.93	-0.01	-0.08	0.03	0.59
	Preterm												
	ACME	-0.03	-0.10	0.00	**0.016** *	-0.02	-0.06	0.00	0.086 .	-0.01	-0.03	0.00	0.16
	ADE	-0.25	-0.56	-0.06	0.002 **	-0.16	-0.34	-0.04	0.002 **	-0.03	-0.12	0.04	0.48
	Total Effect	-0.28	-0.60	-0.08	<2e-16 ***	-0.17	-0.37	-0.05	0.002 **	-0.03	-0.13	0.04	0.37
	Prop. Mediated	0.12	0.01	0.42	**0.016** *	0.09	-0.01	0.36	0.088 .	0.23	-1.92	1.99	0.47
	SGA												
	ACME	-0.01	-0.05	0.00	0.10	-0.01	-0.02	0.00	0.13	0.00	-0.01	0.00	0.21
	ADE	-0.15	-0.36	-0.02	0.02 *	-0.05	-0.17	0.02	0.17	-0.07	-0.19	0.00	0.064 .
	Total Effect	-0.16	-0.38	-0.02	0.01 *	-0.06	-0.17	0.01	0.13	-0.07	-0.19	0.00	0.050 .
	Prop. Mediated	0.07	-0.01	0.38	0.11	0.10	-0.46	0.75	0.25	0.03	-0.04	0.36	0.26

Table 5.20. Mediating Result for All Mother Group: Diabetes.

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Diabetes (Urban=34, Rural=17)	ACME	3.31	0.53	8.20	**0.016** *	1.98	-4.15	3.68	0.37	10.12	1.65	20.70	0.022 *
	ADE	277.00	115.00	460.97	0.002 **	175.74	66.83	282.36	0.004 **	16.16	-118.53	153.50	0.78
	Total Effect	280.00	119.00	464.79	0.002 **	177.71	67.63	282.84	0.004 **	26.28	-109.37	163.26	0.65
	Prop. Mediated	0.01	0.00	0.05	**0.018** *	0.01	-0.03	0.03	0.37	0.39	-1.80	3.36	0.66
	GestCenter												
	ACME	-0.08	-0.17	0.00	0.050 .	-0.02	-0.07	0.07	0.44	-0.12	-0.41	0.00	0.052 .
	ADE	6.97	2.59	11.50	0.002 **	2.89	-0.05	5.67	0.054 .	4.84	1.58	8.19	0.002 **
	Total Effect	6.89	2.50	11.40	0.002 **	2.86	-0.09	5.66	0.056 .	4.72	1.42	7.96	0.002 **
	Prop. Mediated	-0.01	-0.04	0.00	0.052 .	-0.01	-0.05	0.04	0.48	-0.03	-0.17	0.00	0.054 .
	LBW												
	ACME	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.45	0.00	0.00	0.01	0.17
	ADE	-0.19	-0.47	-0.02	0.014 *	-0.13	-0.31	-0.02	0.004 **	-0.05	-0.16	0.02	0.16
	Total Effect	-0.19	-0.47	-0.02	0.018 *	-0.13	-0.31	-0.02	0.004 **	-0.05	-0.16	0.02	0.18
	Prop. Mediated	-0.01	-0.05	0.01	0.17	0.00	-0.03	0.02	0.46	-0.06	-0.42	0.38	0.32
	LGA												
	ACME	0.01	0.00	0.01	<2e-16 ***	0.00	-0.01	0.00	0.36	0.01	0.00	0.02	**0.004** **
	ADE	-0.09	-0.27	0.04	0.18	-0.02	-0.11	0.05	0.64	-0.15	-0.29	-0.04	0.002 **
	Total Effect	-0.09	-0.26	0.04	0.21	-0.01	-0.11	0.05	0.65	-0.14	-0.27	-0.03	0.008 **
	Prop. Mediated	-0.06	-0.63	0.41	0.21	-0.23	-0.79	0.70	0.81	-0.09	-0.39	-0.03	**0.012** *
	Preterm												
	ACME	0.00	0.00	0.01	0.058 .	0.00	0.00	0.00	0.46	0.00	0.00	0.01	0.096 .
	ADE	-0.29	-0.56	-0.07	0.002 **	-0.17	-0.37	-0.04	0.002 **	-0.04	-0.15	0.02	0.27
	Total Effect	-0.28	-0.56	-0.07	0.002 **	-0.17	-0.37	-0.04	0.002 **	-0.04	-0.14	0.03	0.32
	Prop. Mediated	-0.01	-0.04	0.00	0.060 .	-0.01	-0.02	0.02	0.46	-0.09	-1.01	1.07	0.41
	SGA												
	ACME	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.59
	ADE	-0.15	-0.36	-0.01	0.028 *	-0.05	-0.16	0.01	0.15	-0.07	-0.19	0.01	0.092 .
	Total Effect	-0.15	-0.36	-0.01	0.028 *	-0.05	-0.16	0.01	0.14	-0.07	-0.19	0.01	0.088 .
	Prop. Mediated	0.00	-0.02	0.03	0.64	0.00	-0.05	0.05	0.75	0.01	-0.12	0.14	0.65

Table 5.21. Mediating Result for All Mother Group: Digestive Disorder.

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Digestive (Urban=41, Rural=72)	ACME	3.84	-2.72	19.46	0.32	3.58	-2.91	16.74	0.29	-4.06	-10.66	1.90	0.17
	ADE	289.04	111.73	465.99	0.002 **	175.92	66.31	287.89	0.002 **	35.63	-86.78	175.50	0.60
	Total Effect	292.88	115.98	471.74	0.002 **	179.50	71.26	291.78	0.002 **	31.57	-92.21	172.57	0.63
	Prop. Mediated	0.01	-0.01	0.09	0.33	0.02	-0.02	0.12	0.29	-0.13	-0.66	0.69	0.70
	GestCenter												
	ACME	0.09	-0.05	0.48	0.27	0.11	-0.03	0.40	0.17	-0.10	-0.26	0.01	0.068 .
	ADE	6.64	2.13	11.35	0.002 **	2.79	-0.13	5.46	0.056 .	4.73	1.23	8.33	0.002 **
	Total Effect	6.73	2.24	11.42	0.002 **	2.89	0.02	5.50	0.050 .	4.63	1.13	8.16	0.002 **
	Prop. Mediated	0.01	-0.01	0.09	0.27	0.04	-0.04	0.25	0.22	-0.02	-0.11	0.00	0.070 .
	LBW												
	ACME	0.00	-0.02	0.00	0.27	0.00	-0.02	0.00	0.14	0.00	0.00	0.01	0.17
	ADE	-0.18	-0.44	-0.02	0.028 *	-0.12	-0.30	-0.02	0.006 **	-0.05	-0.16	0.02	0.16
	Total Effect	-0.19	-0.45	-0.02	0.022 *	-0.13	-0.31	-0.03	0.002 **	-0.05	-0.16	0.02	0.18
	Prop. Mediated	0.02	-0.01	0.18	0.26	0.03	-0.01	0.19	0.14	-0.06	-0.42	0.38	0.32
	LGA												
	ACME	0.00	-0.01	0.00	0.69	0.00	-0.01	0.00	0.58	0.00	0.00	0.01	0.53
	ADE	-0.07	-0.24	0.05	0.29	-0.01	-0.11	0.05	0.75	-0.13	-0.26	-0.02	0.016 *
	Total Effect	-0.07	-0.24	0.05	0.28	-0.01	-0.11	0.05	0.74	-0.13	-0.26	-0.02	0.016 *
	Prop. Mediated	0.02	-0.21	0.46	0.75	0.08	-0.64	0.69	0.90	-0.01	-0.10	0.02	0.54
	Preterm												
	ACME	0.00	-0.01	0.01	0.81	0.00	-0.01	0.01	0.81	0.00	0.00	0.00	0.64
	ADE	-0.27	-0.55	-0.05	0.006 **	-0.16	-0.36	-0.04	0.002 **	-0.04	-0.15	0.03	0.31
	Total Effect	-0.27	-0.55	-0.05	0.004 **	-0.16	-0.36	-0.04	0.004 **	-0.04	-0.14	0.03	0.32
	Prop. Mediated	0.00	-0.03	0.05	0.81	0.01	-0.05	0.07	0.81	-0.02	-0.40	0.29	0.73
	SGA												
	ACME	0.00	-0.01	0.00	0.59	0.00	-0.01	0.00	0.59	0.00	0.00	0.01	0.41
	ADE	-0.15	-0.36	-0.02	0.024 *	-0.05	-0.17	0.01	0.14	-0.08	-0.19	0.01	0.076 .
	Total Effect	-0.15	-0.36	-0.02	0.022 *	-0.06	-0.17	0.01	0.13	-0.07	-0.18	0.01	0.086 .
	Prop. Mediated	0.01	-0.03	0.13	0.58	0.03	-0.22	0.36	0.65	-0.02	-0.15	0.10	0.47

Table 5.22. Mediating Result for All Mother Group: Fetal Membrane.

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Fetal (Urban=238, Rural=231)	ACME	0.80	-2.94	6.08	0.59	0.81	-2.21	3.40	0.62	-3.11	-10.29	2.34	0.30
	ADE	290.31	102.32	470.11	<2e-16 ***	177.39	71.94	289.07	<2e-16 ***	33.35	-108.37	172.03	0.62
	Total Effect	291.11	105.92	472.93	<2e-16 ***	178.20	73.62	287.48	0.002 **	30.23	-110.61	166.83	0.66
	Prop. Mediated	0.00	-0.01	0.03	0.59	0.00	-0.01	0.03	0.61	-0.10	-0.74	0.78	0.79
	GestCenter												
	ACME	0.00	-0.06	0.08	0.87	0.00	-0.04	0.06	0.88	-0.02	-0.14	0.12	0.77
	ADE	6.70	2.44	11.15	0.006 **	2.85	0.10	5.59	0.034 *	4.61	1.22	8.22	0.004 **
	Total Effect	6.71	2.45	11.18	0.006 **	2.85	0.10	5.59	0.036 *	4.59	1.16	8.19	0.004 **
	Prop. Mediated	0.00	-0.01	0.02	0.87	0.00	-0.03	0.04	0.89	0.00	-0.04	0.03	0.77
	LBW												
	ACME	0.00	0.00	0.00	0.99	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.85
	ADE	-0.18	-0.47	-0.02	0.01 *	-0.13	-0.29	-0.02	0.01 *	-0.05	-0.14	0.02	0.21
	Total Effect	-0.18	-0.47	-0.02	0.01 *	-0.13	-0.29	-0.02	0.01 *	-0.05	-0.15	0.02	0.21
	Prop. Mediated	0.00	-0.02	0.02	0.98	0.00	-0.02	0.02	0.90	0.00	-0.18	0.14	0.86
	LGA												
	ACME	0.00	0.00	0.00	0.81	0.00	0.00	0.00	0.69	0.00	-0.01	0.00	0.56
	ADE	-0.07	-0.25	0.06	0.27	-0.01	-0.11	0.05	0.75	-0.13	-0.25	-0.02	0.012 *
	Total Effect	-0.07	-0.25	0.06	0.28	-0.01	-0.11	0.05	0.75	-0.13	-0.26	-0.02	0.010 *
	Prop. Mediated	-0.01	-0.14	0.11	0.84	-0.01	-0.25	0.25	0.90	0.01	-0.03	0.08	0.57
	Preterm												
	ACME	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.95	0.00	-0.01	0.00	0.56
	ADE	-0.27	-0.56	-0.06	<2e-16 ***	-0.16	-0.34	-0.04	0.006 **	-0.13	-0.25	-0.02	0.012 *
	Total Effect	-0.27	-0.56	-0.07	<2e-16 ***	-0.16	-0.34	-0.04	0.006 **	-0.13	-0.26	-0.02	0.010 *
	Prop. Mediated	0.00	-0.01	0.02	0.85	0.00	-0.01	0.02	0.94	0.01	-0.03	0.08	0.57
	SGA												
	ACME	0.00	-0.01	0.00	0.52	0.00	0.00	0.00	0.49	0.00	0.00	0.01	0.14
	ADE	-0.15	-0.36	-0.02	0.02 *	-0.05	-0.16	0.01	0.13	-0.08	-0.18	0.00	0.066 .
	Total Effect	-0.15	-0.37	-0.02	0.02 *	-0.05	-0.16	0.01	0.12	-0.07	-0.17	0.01	0.074 .
	Prop. Mediated	0.01	-0.04	0.06	0.54	0.02	-0.09	0.16	0.56	-0.04	-0.26	0.09	0.20

Table 5.23. Mediating Result for All Mother Group: Gynecology.

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Gynecology (Urban=533, Rural=325)	ACME	57.04	34.82	82.00	**<2e-16** ***	28.05	7.65	46.58	**0.004** **	13.77	-26.56	42.88	0.59
	ADE	207.19	39.25	380.40	0.014 *	141.39	32.08	246.53	0.014 *	19.59	-105.59	155.30	0.81
	Total Effect	264.24	98.28	439.80	<2e-16 ***	169.44	64.72	274.42	0.004 **	33.35	-98.12	168.88	0.70
	Prop. Mediated	0.22	0.12	0.60	**<2e-16** ***	0.17	0.05	0.47	**0.008** **	0.41	-2.76	3.13	0.76
	GestCenter												
	ACME	0.23	0.04	0.40	**0.012** *	0.11	0.01	0.23	**0.022** *	0.03	-0.10	0.20	0.61
	ADE	6.41	2.30	11.10	0.002 **	2.71	0.15	5.36	0.046 *	4.55	1.09	8.00	0.01 *
	Total Effect	6.64	2.46	11.20	0.002 **	2.82	0.26	5.47	0.038 *	4.59	1.09	8.03	0.01 *
	Prop. Mediated	0.03	0.01	0.10	**0.014** *	0.04	0.00	0.19	0.060 .	0.01	-0.03	0.06	0.61
	LBW												
	ACME	-0.01	-0.01	0.00	0.068 .	0.00	-0.01	0.00	0.066 .	0.00	0.00	0.00	0.56
	ADE	-0.17	-0.41	-0.02	0.026 *	-0.12	-0.30	-0.02	0.008 **	-0.04	-0.15	0.02	0.21
	Total Effect	-0.18	-0.42	-0.02	0.022 *	-0.12	-0.30	-0.02	0.008 **	-0.04	-0.15	0.02	0.20
	Prop. Mediated	0.04	-0.01	0.13	0.090 .	0.02	0.00	0.09	0.074 .	0.02	-0.18	0.20	0.65
	LGA												
	ACME	0.07	0.04	0.09	<2e-16 ***	0.03	0.01	0.05	0.008 **	0.01	-0.02	0.04	0.56
	ADE	-0.18	-0.36	-0.03	0.006 **	-0.05	-0.15	0.02	0.19	-0.15	-0.28	-0.05	<2e-16 ***
	Total Effect	-0.11	-0.31	0.03	0.13	-0.02	-0.11	0.05	0.60	-0.14	-0.27	-0.03	0.004 **
	Prop. Mediated	-0.66	-8.13	3.81	0.13	-1.71	-8.23	9.71	0.61	-0.09	-0.69	0.15	0.56
	Preterm												
	ACME	-0.01	-0.02	0.00	**0.016** *	0.00	-0.01	0.00	**0.024** *	0.00	0.00	0.00	0.56
	ADE	-0.25	-0.52	-0.05	0.004 **	-0.16	-0.34	-0.04	0.004 **	-0.03	-0.13	0.03	0.39
	Total Effect	-0.26	-0.53	-0.05	0.004 **	-0.16	-0.35	-0.04	0.004 **	-0.03	-0.13	0.03	0.37
	Prop. Mediated	0.04	0.01	0.13	**0.020** *	0.03	0.00	0.09	**0.028** *	0.04	-0.43	0.48	0.69
	SGA												
	ACME	-0.01	-0.02	-0.01	**<2e-16** ***	-0.01	-0.01	0.00	0.012 *	0.00	-0.01	0.01	0.58
	ADE	-0.14	-0.33	0.00	0.046 *	-0.05	-0.16	0.02	0.19	-0.07	-0.18	0.01	0.086 .
	Total Effect	-0.15	-0.35	-0.01	0.020 *	-0.06	-0.16	0.01	0.14	-0.07	-0.18	0.01	0.078 .
	Prop. Mediated	0.09	0.03	0.53	**0.020** *	0.10	-0.64	0.96	0.16	0.03	-0.20	0.28	0.61

Table 5.24. Mediating Result for All Mother Group: Hypertension.

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Hypertension (Urban=336, Rural=348)	ACME	43.17	17.82	73.38	**<2e-16 *****	38.80	20.18	61.90	**<2e-16 *****	-11.52	-25.20	3.35	0.12
	ADE	256.10	85.78	441.85	0.004 **	148.10	30.20	254.40	0.006 **	42.46	-95.32	188.93	0.52
	Total Effect	299.28	121.41	488.33	0.002 **	186.91	71.06	294.88	0.002 **	30.94	-102.78	172.71	0.65
	Prop. Mediated	0.14	0.06	0.35	**0.002 ****	0.21	0.10	0.56	**0.002 ****	-0.37	-2.10	2.70	0.70
	GestCenter												
	ACME	0.99	0.42	1.76	**<2e-16 *****	0.85	0.45	1.37	**<2e-16 *****	-0.29	-0.59	0.07	0.12
	ADE	5.89	1.39	10.39	0.014 *	2.14	-0.48	4.79	0.10	4.87	1.33	8.45	0.006 **
	Total Effect	6.88	2.48	11.44	<2e-16 ***	2.99	0.43	5.73	0.018 *	4.58	1.13	8.09	0.008 **
	Prop. Mediated	0.14	0.06	0.44	**<2e-16 *****	0.29	0.11	1.38	**0.018 ***	-0.06	-0.26	0.02	0.13
	LBW												
	ACME	-0.04	-0.08	-0.02	**<2e-16 *****	-0.04	-0.06	-0.02	**<2e-16 *****	0.01	0.00	0.02	0.13
	ADE	-0.15	-0.41	0.00	0.060 .	-0.09	-0.24	0.00	0.060 .	-0.06	-0.17	0.01	0.13
	Total Effect	-0.19	-0.47	-0.03	0.006 **	-0.13	-0.29	-0.02	0.004 **	-0.05	-0.16	0.02	0.20
	Prop. Mediated	0.23	0.09	1.03	**0.006 ****	0.30	0.15	1.11	**0.004 ****	-0.17	-1.36	1.31	0.31
	LGA												
	ACME	0.01	-0.01	0.02	0.41	0.00	-0.01	0.02	0.41	0.00	-0.01	0.00	0.54
	ADE	-0.08	-0.24	0.04	0.24	-0.02	-0.11	0.05	0.69	-0.13	-0.25	-0.01	0.036 *
	Total Effect	-0.07	-0.23	0.05	0.28	-0.01	-0.11	0.05	0.77	-0.13	-0.25	-0.02	0.034 *
	Prop. Mediated	-0.08	-1.20	0.89	0.57	-0.37	-2.54	1.81	0.83	0.01	-0.02	0.06	0.55
	Preterm												
	ACME	-0.04	-0.07	-0.02	**<2e-16 *****	-0.04	-0.06	-0.02	**<2e-16 *****	0.01	0.00	0.02	0.11
	ADE	-0.22	-0.50	-0.02	0.016 *	-0.13	-0.32	-0.02	0.014 *	-0.04	-0.15	0.03	0.32
	Total Effect	-0.26	-0.54	-0.04	0.004 **	-0.17	-0.37	-0.04	0.004 **	-0.03	-0.14	0.03	0.42
	Prop. Mediated	0.16	0.06	0.54	**0.004 ****	0.23	0.10	0.54	**0.004 ****	-0.20	-1.87	2.22	0.49
	SGA												
	ACME	-0.02	-0.03	0.00	**0.004 ****	-0.01	-0.03	0.00	**0.018 ***	0.00	0.00	0.01	0.13
	ADE	-0.14	-0.34	0.00	0.052 .	-0.04	-0.14	0.02	0.22	-0.08	-0.19	0.01	0.078 .
	Total Effect	-0.15	-0.35	-0.01	0.032 *	-0.06	-0.16	0.01	0.12	-0.08	-0.18	0.01	0.092 .
	Prop. Mediated	0.11	0.02	0.42	**0.036 ***	0.23	-1.26	1.74	0.14	-0.04	-0.37	0.23	0.22

Table 5.25. Mediating Result for All Mother Group: Maternal Co-Morbidity (Infectious).

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Infectious (Urban=18, Rural=25)	ACME	-0.22	-2.89	6.85	0.99	1.99	-6.24	20.94	0.64	-1.55	-7.49	3.43	0.52
	ADE	292.00	117.00	489.01	<2e-16 ***	177.23	71.51	283.35	<2e-16 ***	33.06	-97.48	172.09	0.65
	Total Effect	291.00	116.00	488.79	<2e-16 ***	179.22	74.52	285.20	<2e-16 ***	31.50	-101.59	170.31	0.68
	Prop. Mediated	0.00	-0.01	0.02	0.99	0.01	-0.05	0.14	0.64	-0.05	-0.47	0.74	0.89
	GestCenter												
	ACME	0.00	-0.04	0.15	0.87	0.02	-0.14	0.32	0.75	-0.02	-0.11	0.07	0.61
	ADE	6.71	2.12	11.63	0.002 **	2.84	-0.05	5.58	0.054 .	4.63	1.16	8.39	0.02 *
	Total Effect	6.71	2.11	11.63	0.002 **	2.86	0.05	5.61	0.050 .	4.61	1.13	8.29	0.02 *
	Prop. Mediated	0.00	-0.01	0.03	0.88	0.01	-0.10	0.14	0.78	0.00	-0.04	0.02	0.62
	LBW												
	ACME	0.00	0.00	0.00	0.97	0.00	-0.01	0.01	0.70	0.00	0.00	0.00	0.61
	ADE	-0.18	-0.45	-0.02	0.012 *	-0.12	-0.30	-0.02	0.016 *	-0.05	-0.16	0.02	0.18
	Total Effect	-0.18	-0.45	-0.02	0.012 *	-0.13	-0.29	-0.02	0.012 *	-0.05	-0.16	0.02	0.19
	Prop. Mediated	0.00	-0.02	0.04	0.96	0.01	-0.08	0.16	0.70	-0.02	-0.28	0.19	0.71
	LGA												
	ACME	0.00	0.00	0.01	0.94	0.00	0.00	0.02	0.32	0.00	0.00	0.00	0.61
	ADE	-0.07	-0.25	0.05	0.32	-0.01	-0.12	0.05	0.70	-0.05	-0.16	0.02	0.18
	Total Effect	-0.07	-0.25	0.05	0.32	-0.01	-0.11	0.05	0.77	-0.05	-0.16	0.02	0.19
	Prop. Mediated	0.00	-0.13	0.16	0.92	-0.26	-1.67	1.61	0.84	-0.02	-0.28	0.19	0.71
	Preterm												
	ACME	0.00	-0.01	0.00	0.96	0.00	-0.02	0.01	0.68	0.00	0.00	0.00	0.64
	ADE	-0.27	-0.56	-0.06	0.004 **	-0.16	-0.36	-0.04	0.002 **	-0.04	-0.15	0.03	0.32
	Total Effect	-0.26	-0.57	-0.06	0.004 **	-0.16	-0.36	-0.04	0.002 **	-0.04	-0.15	0.03	0.32
	Prop. Mediated	0.00	-0.01	0.03	0.96	0.01	-0.05	0.11	0.68	-0.02	-0.59	0.25	0.71
	SGA												
	ACME	0.00	0.00	0.00	0.86	0.00	-0.01	0.01	0.54	0.00	0.00	0.01	0.38
	ADE	-0.15	-0.37	-0.01	0.032 *	-0.05	-0.17	0.01	0.11	-0.08	-0.19	0.01	0.088 .
	Total Effect	-0.15	-0.37	-0.01	0.032 *	-0.06	-0.17	0.01	0.10	-0.07	-0.19	0.01	0.088 .
	Prop. Mediated	0.00	-0.03	0.05	0.84	0.03	-0.41	0.52	0.57	-0.02	-0.18	0.07	0.44

Table 5.26. Mediating Result for All Mother Group: Liver, Pancreas, Spleen.

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Liver (Urban=228, Rural=214)	ACME	0.03	-0.07	0.20	0.61	3.47	-1.14	12.89	0.19	-0.06	-5.76	7.84	0.91
	ADE	6.68	2.32	11.20	0.002 **	175.20	59.03	289.40	<2e-16 ***	30.50	-115.00	172.17	0.67
	Total Effect	6.71	2.37	11.27	0.002 **	178.67	60.97	292.12	<2e-16 ***	30.40	-113.00	175.16	0.66
	Prop. Mediated	0.00	-0.01	0.04	0.61	0.02	-0.01	0.09	0.19	0.00	-0.50	0.48	0.90
	GestCenter												
	ACME	0.03	-0.07	0.20	0.61	0.02	-0.05	0.15	0.54	0.00	-0.07	0.09	0.94
	ADE	6.68	2.32	11.20	0.002 **	2.83	0.18	5.41	0.032 *	4.59	1.03	7.90	0.018 *
	Total Effect	6.71	2.37	11.27	0.002 **	2.85	0.23	5.45	0.032 *	4.59	1.05	7.89	0.018 *
	Prop. Mediated	0.00	-0.01	0.04	0.61	0.01	-0.03	0.09	0.54	0.00	-0.02	0.02	0.96
	LBW												
	ACME	0.00	-0.01	0.00	0.68	0.00	-0.01	0.00	0.64	0.00	0.00	0.00	0.93
	ADE	-0.18	-0.47	-0.02	0.016 *	-0.12	-0.31	-0.02	0.014 *	-0.05	-0.15	0.02	0.21
	Total Effect	-0.18	-0.47	-0.02	0.016 *	-0.12	-0.31	-0.02	0.014 *	-0.05	-0.15	0.02	0.22
	Prop. Mediated	0.00	-0.03	0.06	0.68	0.01	-0.03	0.06	0.64	0.00	-0.08	0.08	0.90
	LGA												
	ACME	0.00	0.00	0.01	0.41	0.00	0.00	0.01	0.33	0.00	0.00	0.00	0.85
	ADE	-0.07	-0.25	0.05	0.26	-0.01	-0.12	0.05	0.70	-0.13	-0.27	-0.02	0.026 *
	Total Effect	-0.07	-0.25	0.05	0.27	-0.01	-0.12	0.05	0.73	-0.13	-0.27	-0.02	0.028 *
	Prop. Mediated	-0.03	-0.47	0.20	0.56	-0.11	-0.67	0.59	0.82	0.00	-0.06	0.03	0.84
	Preterm												
	ACME	0.00	-0.01	0.00	0.72	0.00	-0.01	0.00	0.65	0.00	0.00	0.00	0.97
	ADE	-0.26	-0.55	-0.05	0.002 **	-0.16	-0.36	-0.04	0.002 **	-0.03	-0.13	0.03	0.37
	Total Effect	-0.26	-0.55	-0.05	0.002 **	-0.16	-0.36	-0.04	0.002 **	-0.03	-0.13	0.03	0.37
	Prop. Mediated	0.00	-0.02	0.04	0.72	0.00	-0.02	0.04	0.64	0.00	-0.14	0.11	0.98
	SGA												
	ACME	0.00	-0.01	0.00	0.55	0.00	-0.01	0.00	0.53	0.00	0.00	0.00	0.92
	ADE	-0.15	-0.34	-0.01	0.032 *	-0.05	-0.16	0.01	0.15	-0.07	-0.19	0.01	0.088 .
	Total Effect	-0.15	-0.35	-0.02	0.028 *	-0.05	-0.16	0.01	0.14	-0.07	-0.19	0.01	0.086 .
	Prop. Mediated	0.01	-0.02	0.09	0.55	0.02	-0.13	0.23	0.58	0.01	-0.06	0.06	0.92

Table 5.27. Mediating Result for All Mother Group: Maternal Co-Morbidity (Obstetric).

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Obstetric (Urban=87, Rural=85)	ACME	1.05	-3.26	5.06	0.67	-1.61	-12.57	4.18	0.54	2.70	-6.92	13.57	0.60
	ADE	289.71	101.04	462.33	<2e-16 ***	179.43	78.94	288.43	<2e-16 ***	26.83	-106.77	169.99	0.72
	Total Effect	290.77	101.24	467.35	<2e-16 ***	177.82	78.66	285.32	<2e-16 ***	29.53	-102.89	169.28	0.69
	Prop. Mediated	0.00	-0.01	0.03	0.67	-0.01	-0.09	0.03	0.54	0.09	-0.90	0.77	0.86
	GestCenter												
	ACME	-0.05	-0.15	0.02	0.18	0.06	-0.04	0.27	0.31	-0.15	-0.37	0.02	0.096 .
	ADE	6.81	2.59	10.99	0.002 **	2.80	-0.06	5.59	0.058 .	4.81	1.17	8.38	0.006 **
	Total Effect	6.76	2.59	10.93	0.002 **	2.87	0.07	5.67	0.044 *	4.66	1.02	8.23	0.010 *
	Prop. Mediated	-0.01	-0.03	0.00	0.18	0.02	-0.04	0.25	0.34	-0.03	-0.16	0.00	0.11
	LBW												
	ACME	0.00	0.00	0.01	0.098 .	0.00	-0.02	0.00	0.18	0.01	0.00	0.01	0.044 *
	ADE	-0.19	-0.46	-0.02	0.008 **	-0.12	-0.29	-0.01	0.018 *	-0.05	-0.16	0.02	0.16
	Total Effect	-0.19	-0.45	-0.02	0.010 *	-0.12	-0.29	-0.02	0.018 *	-0.05	-0.15	0.02	0.21
	Prop. Mediated	-0.02	-0.09	0.01	0.11	0.03	-0.01	0.17	0.19	-0.12	-1.18	0.97	0.25
	LGA												
	ACME	0.00	0.00	0.01	0.098 .	0.00	-0.02	0.00	0.15	0.01	0.00	0.02	**0.016 ***
	ADE	-0.08	-0.24	0.05	0.28	-0.01	-0.11	0.05	0.76	-0.14	-0.28	-0.02	0.016 *
	Total Effect	-0.08	-0.24	0.05	0.30	-0.01	-0.11	0.05	0.71	-0.13	-0.28	-0.02	0.024 *
	Prop. Mediated	-0.04	-0.46	0.30	0.37	0.28	-1.52	1.09	0.72	-0.05	-0.35	0.00	**0.040 ***
	Preterm												
	ACME	0.00	0.00	0.01	0.22	0.00	-0.01	0.00	0.33	0.01	0.00	0.01	0.044 *
	ADE	-0.27	-0.55	-0.08	0.006 **	-0.16	-0.34	-0.04	<2e-16 ***	-0.05	-0.16	0.02	0.16
	Total Effect	-0.27	-0.54	-0.08	0.006 **	-0.16	-0.35	-0.04	<2e-16 ***	-0.05	-0.15	0.02	0.21
	Prop. Mediated	-0.01	-0.04	0.00	0.23	0.02	-0.01	0.10	0.33	-0.12	-1.18	0.97	0.25
	SGA												
	ACME	0.00	0.00	0.00	0.98	0.00	0.00	0.01	0.90	0.00	-0.01	0.01	1.00
	ADE	-0.15	-0.36	-0.01	0.026 *	-0.05	-0.15	0.01	0.16	-0.07	-0.19	0.01	0.10
	Total Effect	-0.15	-0.37	-0.01	0.026 *	-0.05	-0.15	0.01	0.17	-0.07	-0.19	0.01	0.09 .
	Prop. Mediated	0.00	-0.04	0.03	0.97	0.00	-0.28	0.33	0.94	0.00	-0.19	0.18	1.00

Table 5.28. Mediating Result for All Mother Group: Placenta Previa, Abruption or Abnormality.

		UVAI				UVAITriMax				UVAITriMin			
	BWCenter	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value	Estimate	95% CI Lower	95% CI Upper	p-value
Placenta (Urban=173, Rural=227)	ACME	1.26	-3.99	10.35	0.70	2.71	-0.87	11.05	0.18	-3.01	-9.39	1.18	0.16
	ADE	290.28	109.91	470.88	0.002 **	175.74	70.78	288.44	0.002 **	34.51	-102.41	168.69	0.62
	Total Effect	291.55	112.04	472.11	0.002 **	178.45	73.57	292.68	0.002 **	31.51	-105.13	165.32	0.65
	Prop. Mediated	0.00	-0.02	0.05	0.70	0.02	-0.01	0.08	0.18	-0.10	-0.63	0.60	0.72
	GestCenter												
	ACME	0.06	-0.13	0.32	0.66	0.09	-0.03	0.30	0.17	-0.11	-0.28	0.02	0.094 .
	ADE	6.67	2.20	11.08	<2e-16 ***	2.77	0.23	5.68	0.036 *	4.71	1.36	8.36	0.008 **
	Total Effect	6.73	2.22	11.17	<2e-16 ***	2.86	0.23	5.73	0.032 *	4.60	1.20	8.23	0.008 **
	Prop. Mediated	0.01	-0.02	0.06	0.66	0.03	-0.03	0.21	0.20	-0.02	-0.10	0.00	0.10
	LBW												
	ACME	0.00	0.00	0.01	0.70	0.00	0.00	0.01	0.34	0.00	0.00	0.00	0.33
	ADE	-0.18	-0.44	-0.03	0.014 *	-0.12	-0.30	-0.02	0.006 **	-0.04	-0.15	0.02	0.24
	Total Effect	-0.18	-0.44	-0.03	0.014 *	-0.12	-0.29	-0.02	0.006 **	-0.05	-0.15	0.02	0.24
	Prop. Mediated	0.00	-0.06	0.02	0.70	-0.01	-0.09	0.02	0.34	0.02	-0.22	0.23	0.46
	LGA												
	ACME	0.00	0.00	0.01	0.72	0.00	0.00	0.01	0.32	0.00	-0.01	0.00	0.26
	ADE	-0.07	-0.24	0.05	0.26	-0.01	-0.10	0.05	0.75	-0.13	-0.24	-0.02	0.022 *
	Total Effect	-0.07	-0.24	0.05	0.28	-0.01	-0.10	0.05	0.77	-0.13	-0.24	-0.02	0.020 *
	Prop. Mediated	-0.01	-0.27	0.22	0.79	-0.18	-0.71	0.52	0.86	0.02	-0.01	0.09	0.28
	Preterm												
	ACME	0.00	0.00	0.01	0.81	0.00	0.00	0.01	0.55	0.00	0.00	0.00	0.63
	ADE	-0.27	-0.55	-0.06	<2e-16 ***	-0.16	-0.36	-0.04	0.006 **	-0.03	-0.14	0.03	0.34
	Total Effect	-0.27	-0.55	-0.06	<2e-16 ***	-0.16	-0.36	-0.04	0.006 **	-0.03	-0.14	0.03	0.34
	Prop. Mediated	0.00	-0.03	0.01	0.81	-0.01	-0.05	0.02	0.55	0.01	-0.25	0.17	0.76
	SGA												
	ACME	0.00	-0.01	0.00	0.78	0.00	-0.01	0.00	0.43	0.00	0.00	0.01	0.38
	ADE	-0.15	-0.35	-0.01	0.034 *	-0.05	-0.17	0.01	0.12	-0.07	-0.19	0.01	0.090 .
	Total Effect	-0.15	-0.35	-0.01	0.034 *	-0.06	-0.18	0.01	0.11	-0.07	-0.19	0.01	0.092 .
	Prop. Mediated	0.00	-0.02	0.06	0.79	0.03	-0.12	0.22	0.51	-0.02	-0.17	0.08	0.43

5.9. Discussion

As the core of this dissertation research, this chapter focused on the exploration of relationship between maternal haze exposure and birth outcomes. The level of haze exposure for each mother was obtained from the OMI daily UVAI images, which was divided into three trimesters (UVAIT1Mean, UVAIT2Mean, UVAIT3Mean) in pregnancy. Moreover, another three haze derivatives were calculated based on the three trimester values, UVAI (entire pregnancy averaged haze), UVAITriMin (minimum among three trimesters), and UVAITriMax (maximum among three trimesters). For this health analysis, a total of 29 variables were collected and constructed from the obstetric records, covering mother demographic conditions, mother health conditions, fetus health conditions, and medical conditions. BW was selected as the primary DV, indicating the condition of infant health immediately after the birth. More birth outcome variables were tested in mediating analysis as extra models, such as Gestation, LBW, SGA, LGA, and Preterm.

The multiple linear regressions were used to quantify the relationship between birth weight and first and third trimester maternal average haze exposure. The Pearson and ANOVA tests were conducted to find the variables with low collinearity. The results indicated that the haze exposure during T1 and T3 showed significant relationship with birth weight in different group of mothers. Within the group of urban mothers who had no prior pregnancy, the haze exposure during first trimester had significant negative impact on birth weight. Within an even smaller group, urban mothers who had no prior pregnancy and worked mostly outside, the haze exposure during third trimester had significant negative influence on birth weight.

In mediating tests, in order to ensure the size of sample, a total of 12 clinical classes were tested on three haze measurements to measure their mediating effects on 6 DVs in whole mother group. The results showed that 6 of them were statistically significant to one or more UVAI measurements, including Cardiomyopathy, Chronic Maternal Co-Morbidity, Diabetes, Gynecology, Hypertension and Obstetric Maternal Co-Morbidity.

Hypertension was the most common maternal disease that significantly mediated the relationship between birth outcomes and haze. In UVAI model it significantly mediated five DVs (birth weight, gestation, LBW, Preterm, and SGA), while in UVAITriMax model it mediated four DVs (birth weight, gestation, LBW, and Preterm). The next most common maternal disease was Genecology, which significantly mediated four DVs (birth weight, gestation, Preterm, and SGA) in UVAI Model and two DVs (birth weight and LGA) in UVAITriMax model. The third most common maternal disease was Chronic Maternal Co-morbidities, which significantly mediated for DVs (birth weight, gestation, Preterm, and LBW) in UVAI model.

From the perspective of birth outcome, Table 5.17. showed that Birth Weight was the most sensitive DV that was significantly mediated by five maternal clinical features (Cardiomyopathy, Chronic Co-Morbidity, Diabetes, Genecology, and Hypertension) in two UVAI measurements (UVAI and UVAITriMax). Both Gestation and Preterm were significantly mediated by three clinical features (Chronic Co-Morbidity, Genecology, and Hypertension).

Another factor to measure the strength of a mediator was the percentage of change that were mediated. Table 5.18. showed that seven models had explained mediation above 20%, eight models between 10-20%, and 9 models below 10%. The LBW was significantly mediated by hypertension and 30 % of change between hypertension and UVAI max as well as 23% of change with UVAI mean can be explained. The Gestation was significantly mediated by both Hypertension with 29% of change explained in UVAI max and Chronic Co-Morbidity with 21 % in UVAI mean. The Birth Weight was significantly mediated by both Gynecology (22%) with

UVAI mean and Hypertension (21%) with UVAI max. The Preterm was significantly mediated by Hypertension (23%) with UVAI max. The LGA and SGA explained less than 10% mediation in all models.

5.29. Mediating Medical Conditions in the Haze and Birth Outcome Relationships: Percentage Mediation Explained.

Mediating Effect	Birth Outcome	UVAI Measure	Explained (%)
Cardiomyopathy	Birth Weight	UVAI mean	6
Chronic Co-Morbidity	Birth Weight	UVAI mean	15
Diabetes	Birth Weight	UVAI mean	1
Gynecology	Birth Weight	UVAI mean	22
Gynecology	Birth Weight	UVAI max	17
Hypertension	Birth Weight	UVAI mean	14
Hypertension	Birth Weight	UVAI max	21
Chronic Co-Morbidity	LBW	UVAI mean	18
Hypertension	LBW	UVAI mean	23
Hypertension	LBW	UVAI max	30
Diabetes	LGA	UVAI min	9
Obstetric Co-Morbidity	LGA	UVAI min	5
Cardiomyopathy	SGA	UVAI mean	4.6
Gynecology	SGA	UVAI mean	9
Hypertension	SGA	UVAI mean	11
Chronic Co-Morbidity	Gestation	UVAI mean	21
Gynecology	Gestation	UVAI mean	3
Hypertension	Gestation	UVAI mean	14
Hypertension	Gestation	UVAI max	29
Chronic Co-Morbidity	Preterm	UVAI mean	12
Gynecology	Preterm	UVAI mean	4
Gynecology	Preterm	UVAI max	3
Hypertension	Preterm	UVAI mean	16
Hypertension	Preterm	UVAI max	23

5.10. Conclusion

To summary, this study investigated the impact of haze compound on maternal health and infant health in Xianyang City utilizing OMI UVAI and a primary dataset composed of a sample of infants born in Xianyang Area from January 2008 to December 2016. The results of multiple linear regressions indicated that the haze exposure during T1 and T3 showed significant and negative relationship with birth weight in different group of mothers. Moreover, the results of mediating tests indicated that Hypertension was the most common maternal disease that significantly mediated the relationship between nine birth outcomes and two haze measurements, followed by Genecology (six birth outcomes and two haze measurements). From DV's perspective, the most sensitive birth outcome was Birth Weight, followed by Gestation and Preterm. Also, based on the percentage of mediation explained, the LBW, Gestation, Preterm, and Birth Weight was explained more than 20% of change after adding the consideration of mediators. LGA was more influenced by UVAI minimal and SGA was more influenced by UVAI mean, which had lower percentage of mediation explained in all models.

These results provided strong evidence for the policymakers showing that the need for immediate actions in air clean and maternal and infant health protection is urgent. Moving forward from this study, more tests could be conducted to further understand the situation of infant health in China by applying different criteria. For example, in order to better fit the reality, the birth weight and gestation referential table that was used in this study to classify birth weight by gestation as SGA, NGA, and LGA was the result of a previous study that was conducted on the basis of Chinese infant birth weight and gestation (Dai et al., 2014). It would be interesting to cross compare the performance of birth outcomes by using U.S. standards.

CHAPTER VI

DISCUSSION OF RESULTS

6.1. Major Findings

In China today, people are very concerned about the health effects of haze on themselves and their families and children. People are also suspicious that the day-to-day haze they experience is worse than what they are being told by the government and the media (Author personal experience, 2016). While there is some public health messaging about the effects of haze on respiratory diseases such as asthma at the national level; there is no information on the effect of haze on maternal medical complications and birth outcomes. In China there is no national birth data registration system (also referred to as a vital registry of all births and deaths in the country). When a mother goes to the hospital to deliver her baby, the details of her visit will be in her obstetric record, which can also be linked to her infant's hospital record. If the infant is born a stillbirth or dies in the early neonatal (< 7 days) period, there will be no death certificate only the absence of a birth certificate for a woman who delivered a baby as identified by the diagnostic code in her obstetric record. These records are generally stored as paper-copies randomly stacked by month and years in piles in a medical records or storage room. The analyses from this dissertation used photocopied and digitally translated catalogue, obstetric and infant hospital records collected over a two-month period. The catalogues for the years 2008 to 2016 were photocopied first, and from that list a random selection of mothers who gave birth within each month and year were obtained from their appropriate piles and photocopied to a password protected secure drive (refer to sampling methodology in Chapter IV). This dataset of maternal/obstetric records and linked birth/infant records is thus unique and a valuable population-based resource for the study of haze and birth outcomes. This study also overcame the barrier to representative data on haze in Xianyang by using state-of-the-art satellite imagery. Following the assignment of a maternal haze exposures (average UVAI) mid-trimesters 1 and 3 and across the entire pregnancy, the analyses were conducted and reported above. Here the most important findings from the analyses are provided and discussed within the context of China's economic development and soft target for public health. The methodologies and results are also intended to inform the field of Health Geography in China. Finally, the results from this study will help to answer the questions people in China are asking about haze and their health. The dissertation Concludes in Chapter 7 with recommendations for future environmental health research in China.

The first paper (Chapter II), Environmental Policy Assessment in China: Historical to Present, chronologically reviewed the evolution of environmental policies and regulations and found that even though China had a long history and rich variety of Chinese environmental policies and regulations, the hierarchical structure in the Target Pyramid System not only determined the rank of different political priorities but also revealed the problem of mismatched power structure and ownership of responsibility inherited within the executive. Even the One2 system could result in highly consistent party consciousness to facilitate the efficiency of policy application, it also created a governmental monitoring atmosphere filled with high political pressure, which greatly limited the enforcement of regulations and activeness of public participation in environmental protection.

The second paper (Chapter III), Haze Assessment, used OMI UVAI to understand the spatial and temporal trend of Haze in Xianyang, China. It compared the monthly average ground monitoring AQI data as well as particulate matters ($PM_{10,}$ $PM_{2.5}$) during 2014~2016 in Xianyang Municipality with AOT and UVAI obtained from OMI and found that 1) most UVAI distribution lines lay within the dispersion range of AQI, PM10, and PM2.5; 2) UVAI was highly correlated with AQI and particulate matters from mathematical perspective; and 3) UVAI was statistically significant to AQI (P-value: 0.0000000767, R-square: 0.5649). In addition, by plotting UVAI, the researcher detected 1) clear growing trends of haze annual density in both urban and rural areas; 2) the consistent winter peak, the appearance of spring peak after 2009, and the addition of summer peak after 2014; 3) the increasing coverage, duration, and severity of three seasonal peaks; and 4) the haze hotspot that was formed by the southeastern counties, including Xianyang, Jingyang, Xingping, and Liquan.

The third paper (Chapter IV), Haze Air Pollution Impacts on Maternal and Infant health in Xianyang, China, investigated the impact of haze compound on infant health in Xianyang City utilizing OMI UVAI and a primary dataset composed of a sample of infants born at Shaanxi University of Chinese Medicine First Affiliated Hospital in Xianyang City from January 2008 to December 2016 in Xianyang Area. The results of multiple linear regressions indicated that the T1 haze exposure demonstrated significantly negative influence on infant birth weight within the group of urban mothers who had no prior pregnancy, while the T3 exposure showed similar influence in an even smaller group, urban mothers who had no prior pregnancy and worked mostly outside. Moreover, the results of mediating tests indicated that the Hypertension followed by the Genecology was the most common maternal disease that significantly mediated the relationship between birth outcomes and haze measurements, while the most sensitive birth outcome was Birth Weight followed by Gestation and Preterm. Also, based on the percentage of mediation explained, the LBW, Gestation, Preterm, and Birth Weight was explained more than 20% of change after adding the consideration of mediators. LGA was more influenced by UVAI minimal and SGA was more influenced by UVAI mean, which had lower percentage of mediation explained in all models.

6.2. Limitations

This dissertation was not free of limitations. First, using the satellite imagery as an indirect measure of haze has its own inherited limitations because the measurement of haze is calculated based on the volume of light reflected and scattered by the pollutants situated between the satellite sensor and the ground. The higher level of atmosphere may have a bigger influence on the measurements than the ground level air. Also, the data about ground weather conditions were missing. People live within the ground level atmosphere, where the breathable air is under the influence of local weather conditions, such as wind direction and strength, precipitation, temperature, and humidity. However, most direct data about these factors were collected and managed by local weather stations, which do not allow public access. Even though it is possible to estimate these factors by using other types of satellite imagery products, more uncertainty could further compromise the quality of haze dataset. Second, the satellite imagery (UVAI) cannot directly provide information or measurement on the chemical composition of haze. Instead, this study viewed haze as a holistic weather phenomenon that is comprehensively measured by two dimensionless indexes, UVAI and AQI, to avoid the concentration of any specific component of haze. Importantly, however was that OMI UVAI was positively and significantly correlated with ground monitoring AQI data and could be used as substitute to present the density of haze. This was an important finding that will inform future air pollution research in China and the world. Third, the maternal obstetric hospital data was missing important information that may be potential confounding variables in the haze and birth outcome relationship, such as smoking and alcohol history of the mother and there may be under-reporting of pre-pregnancy and pregnancy-related conditions. Fortunately, Chinese women have a very low smoking rate (1.9%) so this limitation should not have a large impact on the results (World Bank, 2018). Fourth, data on the socioeconomic status of the local contexts in which mother's live will not be addressed in this study—as there is not substantial variation in neighborhood quality (Qiong Zhang, Personal Observation). The information on the obstetric records contained data such as marital status and occupation that was used to adjust for these socioeconomic differences as needed in the analytical models. Fifth, due to the consideration of national security, a lot of governmental policy documents and reports with detailed information are not published on the Internet. It was, therefore, difficult to link the change in haze to any specific requirement within one policy document. While this finding did not affect the evaluation of environmental policy in China, future research will continue to uncover gaps and barriers to environmental protection to more efficiently link these policies to air quality levels and poor maternal and infant health outcomes.

6.3. Significance of the Study

Even though numerous human and animal studies have assessed the impact of air pollutants on maternal health and prenatal development (Stevenson et al., 2003; Brook et al., 2004; Parker et al., 2005; Bell et al., 2010; Sun et al., 2010; Choi et al., 2012; Backes et al., 2013; Pui et al., 2014), few if any studies have been conducted to examine the health consequences caused by haze in China, largely due to limited air quality data and population-based health datasets. On one hand, neither a complete, mature protocol nor a public platform was established by the Chinese government to collect, store, publish, and share real-time and historical haze data. On the other hand, the perception that haze has caused irreversible damage on infant exists in everyone's suspicion, because national hospital networks/birth registration system do not exist in China and all information are fragmented. This study overcome this data gap and addressed the public health concerns perceived to be caused by haze by utilizing state-of-the art satellite imagery and available monitoring data and collecting catalogues from 2008 to 2016 and a large sample of obstetric and infant records by month for the same time period.

6.4. Knowledge Improvement in Chinese Environmental Policy

This study provided a comprehensive understanding of the history about Chinese environmental protection policies and regulations by chronologically examining the evolution of environmental policies, regulation, and managing facilities within the central government and across different levels of government. The milestones created for each phase present and facilitated the understanding of evolutionary change in Chinese environmental protection history. The diminishing trend of executional willingness and force could be identified through the transition of authoritative power from central government to local government. Additionally, the associated reasons could be revealed. The hierarchical structure in the political Target Pyramid System illustrated the priority of choices among local administration and clearly pointed out the low status of environmental protection resulting in the inefficiency in policy execution. Meanwhile, the discussion on "One2" System further explained how the universal political awareness in Communist Party could influence the executive duties in every social entity.

6.5. Knowledge Improvement in Haze Assessment

In 2016 winter, Xianyang City experienced the worst strike of haze ever. The monthly maximum $PM_{2.5}$ exceeded 522 μg/m^3. This breakout became unforgettable because Chinese government approved the technical regulations on ambient AQI in 2012 and established central monitoring platform and made the real time data available for the public in 2013. However, it also means no AQI data were available before this time point, which made an analysis on the long-term evolution of haze impossible. The Haze Assessment Section of this study filled this knowledge gap by utilizing remote sensing products as a secondary source of air quality measurement. By using OMI UVAI, this study demonstrated that satellite imagery can be used to assess historical air pollution in China with application elsewhere. Additionally, the findings of this study showed the spatial and temporal changes in haze in Xianyang City from 2007 to 2016 which lead to the focus of this study on maternal and infant health.

6.6 Knowledge Improvement in Health Assessment

This research has collected a unique and highly valuable dataset of mothers who were exposed to varying levels of haze and their linked infant health outcomes. The findings from this study will begin to address people's concerns by providing epidemiological evidence for translation into health education for mothers, health care providers and public health and environmental policymakers in China. The multiple linear regressions used by this study will advance the knowledge about the association between haze exposure and birth weight by precisely showing every nuanced change of birth weight in gram when the maternal haze exposure in two sensitive windows increases or decreases one unit. It also presents the idea of modeling the potential mediating effects of maternal medical conditions into consideration to health geographers, epidemiologists, environmentalists and other researchers who would like to study the interaction between environmental pollution and maternal and infant health outcomes.

Through the publication and presentation of results from this study, it is hoped that (1) Chinese citizens will feel empowered to challenge the bureaucratic structural barriers that prevent them from actively participating environmental protection. (2) This study will stimulate the speed, the width and the depth of the execution of new environmental regulations, which are under the experience of dramatically expanding. (3) It will enhance Chinese government's determination on winning the battle of environmental protection, which eventually lead to a better maternal and infant health outcome.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

This dissertation research first provides in-depth understanding of Chinese environmental policies by comprehensively reviewing the history and investigating the barriers imposed by political structure and managerial strategy. By dividing entire modern Chinese history into 6 phases featured with different milestones, this study systematically discusses the distinguishing relationship between economic development and the evolvement of environmental policies in China. It concludes that even though a long and rich variety of environmental policies and regulations could be found, these national guidelines need to be further understood through the lenses of the Target Pyramid System and the managerial strategies “One Position Two Jobs” System.

Then, with the understanding of history and background, this dissertation demonstrates that satellite product, especially OMI UVAI, is suitable to fill the data gap of missing ground monitoring haze data before 2014. By using UVAI, this dissertation research maps the spatial and temporal distribution of haze compound in Xianyang and detect clear expanding pattern of high-density haze from the southeastern hotspot to rest rural areas as well as from winter peak only to rest of three seasons. It concluded that Xianyang has experienced noticeably increasing trend of haze in severity, duration, and coverage from 2008 to 2016.

At last, this dissertation research demonstrated strong evidence showing that haze had negatively impact on birth outcomes in different mother groups. Within the group of urban mothers who had no prior pregnancy, the haze exposure during first trimester had significant negative impact on birth weight. While, within an even smaller group, urban mothers who had no prior pregnancy and worked mostly outside, the haze exposure during third trimester had significant negative influence on birth weight. Meanwhile, the results of mediating tests indicated that Hypertension was the most common maternal disease that significantly mediated the relationship between haze measurements and birth outcomes, followed by Gynecology. Also, Birth Weight, followed by Gestation and Preterm, demonstrated most sensitivity to the mediators. Based on the percentage of mediation explained, the LBW, Gestation, Preterm, and Birth Weight was explained more than 20% of change after adding the consideration of mediators. LGA was only influenced by UVAI minimal and SGA was only influenced by UVAI mean, which had lower percentage of mediation explained in all models.

In conclude, it is important 1) to entitle the public health and health care professionals proper authoritative power to protect the public from the untoward health effects of environmental pollution, 2) to facilitate and attract more scholars exploring the topics related to the environment issues and the public health, 3) to promote the health education on the public about the impact of environmental pollution on human health, 4) to protect maternal health condition from exposing to high level of haze even before the pregnancy, and 5) to improve the air quality by all means.

7.2. Future Research Directions

This dissertation research addressed an important question for China and the international society about whether the haze in current China has caused negative influence on the health of a susceptible population group, such as the mothers and infants. The research results not only proved the correctness of this suspicion but also warned the urgency of lowering haze density nationally, enhancing maternal health, and strengthening the power of the health care professionals in the action of environmental remediation and public health protection. Moving forward from this dissertation, more empirical studies can be conducted to complete the understanding of impact of poor air quality on maternal and infant health.

First, as mentioned before, haze is a weather phenomenon that is described as the general term of multiple mixing chemical components, such as O_3, SO_2, NO_2, CO, PM_{10}, and $PM_{2.5}$. The leading component of haze is not unchangeable. Instead, it keeps varying from time to time. Therefore, it is also important to know the impact of specific pollutants on maternal and infant health. Similar to this study, different satellite products can be collected to measure the spatial and temporal distribution of certain criteria air pollutants. For example, the satellites that were launched by the Chinese government also carried various instruments that could provide accurate measurement of pollutants, especially in Chinese territory. A multilateral collaborative project mapping of different components of haze would greatly benefit academia by laying solid foundation for studies in various arenas, such as ecology, city planning, political geography, and so on. The results could also provide convincing evidence for the policy holders to issue more effective and efficient policies to reduce environmental health risks.

Second, as we mentioned above, the rapid growing per capita income and enlarging infrastructure network that China has experiencing have greatly improved the public's living standard, especially in rural area. The financial growth in rural families brought better nutrition and less physical works for the pregnant women, while the expanding transportation system between urban and rural areas provides convenient access to the advanced medical resources, such as better equipped hospitals. Under this situation, however, it is possible that the huge compensative effect of urbanization may conceal the negative influence of high-density haze on infant health. Therefore, in order to further understand the damage that was caused by the haze in rural area, more socio-economic studies and computational predictive models are needed to study rural areas only to compare the maternal and infant health with and without having high density haze controlling other demographic and physical factors.

At last, by facing such complex and conflicting environmental issues, it is critical to enhance environmental health education between the public health specialists, health care professionals and the general public. This relationship includes three key components, the educating sources, the educating channels, and the educating recipients. In order to understand the barriers that prevent people from receiving proper environmental health education, more qualitative studies could be constructed for each component. For example, it would be helpful if a national survey could be designed to investigate the general public's awareness, attitude, and expectation on the content of the environmental health knowledge. It also important to have more studies specifically for the educating sources, such as the public health professional and the health care providers, to understand their concern and difficulties. Only after the public is fully aware of the health effects of air pollution can society grow to maximize each citizen's potential.

APPENDICES

APPENDIX A: Descriptive Summary for Categorical Variables

```
 29  Variables      3226  Observations
---------------------------------------------------------------------
Urban
       n  missing distinct
    3226        0        2

Value          0    1
Frequency    1373  1853
Proportion  0.426 0.574
---------------------------------------------------------------------
Age1
       n  missing distinct
    3224        2        2

Value          0     1
Frequency    1046  2178
Proportion  0.324 0.676
---------------------------------------------------------------------
Age2
       n  missing distinct
    3224        2        3

Value          1     2     3
Frequency    735  2178   311
Proportion 0.228 0.676 0.096
---------------------------------------------------------------------
Occupation
       n  missing distinct
    3214       12        6

Value          1     2     3     4     5     6
Frequency   1511   370   275   141    76   841
Proportion 0.470 0.115 0.086 0.044 0.024 0.262
---------------------------------------------------------------------
Marriage
       n  missing distinct
    3197       29        4

Value          1     2     3     9
Frequency      7  3065     1   124
Proportion 0.002 0.959 0.000 0.039
---------------------------------------------------------------------

Nutrition
       n  missing distinct
    2974      252        3

Value         bad   Good medium
Frequency       2   1466   1506
Proportion  0.001  0.493  0.506
---------------------------------------------------------------------
BPHigh1
       n  missing distinct
    3216       10        3
```

```
Value          1     2     3
Frequency      6  2641   569
Proportion  0.002 0.821 0.177
---------------------------------------------------------------------
BPLow1
       n  missing distinct
    3216       10        3

Value          1     2     3
Frequency     12  2762   442
Proportion 0.004 0.859 0.137
---------------------------------------------------------------------
PregnancyHistory
       n  missing distinct
    3224        2        8

Value          1     2     3     4     5     6     7     8
Frequency   1515   904   461   225    83    23     9     4
Proportion 0.470 0.280 0.143 0.070 0.026 0.007 0.003 0.001
---------------------------------------------------------------------

Parity
       n  missing distinct
    3223        3        5

Value          0     1     2     3     5
Frequency   2344   822    53     3     1
Proportion 0.727 0.255 0.016 0.001 0.000
---------------------------------------------------------------------
MethDelive
       n  missing distinct
    3226        0        3

Value          1     2     6
Frequency   1176    52  1998
Proportion 0.365 0.016 0.619
---------------------------------------------------------------------
Amfluid
       n  missing distinct
    3218        8        7

Value         1      2     3     4     5     6
Frequency    2309    96   199   263   333    18
Proportion  0.716 0.030 0.062 0.082 0.103 0.006
---------------------------------------------------------------------
Fetusposit
       n  missing distinct
    3210       16        9

Value         LOA   LOP    LOT   LSA   ROA   ROP   ROT   RSA
Frequency   2131    34      3   140   841    22     3    36
Proportion 0.664 0.011  0.001 0.044 0.262 0.007 0.001 0.011
---------------------------------------------------------------------

Gender
       n  missing distinct
```

```
    3226        0        2

Value          1     2
Frequency   1675  1551
Proportion 0.519 0.481
-----------------------------------------------------------------------
TpDeliver
       n  missing distinct
    3226        0        3

Value          1     2     3
Frequency    167  3039    20
Proportion 0.052 0.942 0.006
-----------------------------------------------------------------------
Deformity
       n  missing distinct
    3215       11        3

Value          1     2
Frequency   3209     6
Proportion 0.998 0.002
-----------------------------------------------------------------------
BWbyGest
       n  missing distinct
    3226        0        3

Value          1     2     3
Frequency    251  2491   484
Proportion 0.078 0.772 0.150
-----------------------------------------------------------------------
Pulse1
       n  missing distinct
    3226        0        3

Value          0     1     2
Frequency      6     9  3211
Proportion 0.002 0.003 0.995
-----------------------------------------------------------------------
Respiration1
       n  missing distinct
    3226        0        3

Value          0     1     2
Frequency     13   113  3100
Proportion 0.004 0.035 0.961
-----------------------------------------------------------------------
Activity1
       n  missing distinct
    3226        0        3

Value          0     1     2
Frequency     13   111  3102
Proportion 0.004 0.034 0.962
-----------------------------------------------------------------------
Grimace1
       n  missing distinct
    3226        0        3
```

```
Value          0     1     2
Frequency      8    43  3175
Proportion 0.002 0.013 0.984
---------------------------------------------------------------------
Appearnce1
       n  missing distinct
    3226        0        3

Value          0     1     2
Frequency      9  1704  1513
Proportion 0.003 0.528 0.469
---------------------------------------------------------------------
Pulse5
       n  missing distinct
    3226        0        3

Value          0     1     2
Frequency      5     3  3218
Proportion 0.002 0.001 0.998
---------------------------------------------------------------------
Respiration5
       n  missing distinct
    3226        0        3

Value          0     1     2
Frequency      7    36  3183
Proportion 0.002 0.011 0.987
---------------------------------------------------------------------
Activity5
       n  missing distinct
    3226        0        3

Value          0     1     2
Frequency      7    39  3180
Proportion 0.002 0.012 0.986
---------------------------------------------------------------------
Grimace5
       n  missing distinct
    3226        0        3

Value          0     1     2
Frequency      5    12  3209
Proportion 0.002 0.004 0.995
---------------------------------------------------------------------
Appearnce5
       n  missing distinct
    3226        0        3

Value          0     1     2
Frequency      6    69  3151
Proportion 0.002 0.021 0.977
```

APPENDIX B: UVAI Exposure Calculation and Assignment

```
##Install packages
install.packages("raster")
install.packages("ncdf4")
install.packages("rgdal")
library(ncdf4)
library(raster)
library(fields)
library(maptools)
library(colorRamps)
library(rgdal)

#************************************
# Converting nc file to tif file

#1. Setting directory
setwd("D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/")

#2. Multiple files using a loop
dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2007/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
  r.nc<-raster(files.nc[i])
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}

dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2008/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
```

```
  r.nc<-raster(files.nc[i])
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}

dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2009/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
  r.nc<-raster(files.nc[i])
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}

dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2010/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
  r.nc<-raster(files.nc[i])
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}


dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2011/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
  r.nc<-raster(files.nc[i])
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}

dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2012/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
  r.nc<-raster(files.nc[i])
```

```
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}
dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2013/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
  r.nc<-raster(files.nc[i])
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}
dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2014/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
  r.nc<-raster(files.nc[i])
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}
dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2015/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
  r.nc<-raster(files.nc[i])
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}
dir.nc<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2016/'
files.nc<-list.files(dir.nc,full.names=T, recursive=T)
for(i in 1:length(files.nc)){
  r.nc<-raster(files.nc[i])
  writeRaster(r.nc,paste(files.nc[i],'tiff',sep=''),format='GTiff',overwrite=T)
}

#************************************************************
#stack tif image
#1. Read all tif image in a list
```

```
Tiff_dir<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/2010/2010tif/'
Tiff_list<-list.files(Tiff_dir,full.names=T, recursive=T)
View(Tiff_list)

#2. stack Janurary and claculate absolute-mean and export
d1<-stack(Tiff_list[1:31])
abs1<-calc(d1, fun=abs)
mean1<-calc(abs1,na.rm=TRUE, fun=mean)
writeRaster(mean1, filename="Jan_mean.tif", format='GTiff',overwrite=TRUE)
#3. stack Feb and claculate mean and export
d2<-stack(Tiff_list[32:59])
abs2<-calc(d2, fun=abs)
mean2<-calc(abs2,na.rm=TRUE, fun=mean)
writeRaster(mean2, filename="Feb_mean.tif", format='GTiff',overwrite=TRUE)
#4. stack Mar and claculate mean and export
d3<-stack(Tiff_list[60:90])
abs3<-calc(d3, fun=abs)
mean3<-calc(abs3,na.rm=TRUE, fun=mean)
writeRaster(mean3, filename="March_mean.tif", format='GTiff',overwrite=TRUE)
#5. stack Apr and claculate mean and export
d4<-stack(Tiff_list[91:120])
abs4<-calc(d4, fun=abs)
mean4<-calc(abs4,na.rm=TRUE, fun=mean)
writeRaster(mean4, filename="Apr_mean.tif", format='GTiff',overwrite=TRUE)
#6. stack May and claculate mean and export
d5<-stack(Tiff_list[121:151])
abs5<-calc(d5, fun=abs)
mean5<-calc(abs5,na.rm=TRUE, fun=mean)
writeRaster(mean5, filename="May_mean.tif", format='GTiff',overwrite=TRUE)
#7. stack Jun and claculate mean and export
```

```
d6<-stack(Tiff_list[152:181])
abs6<-calc(d6, fun=abs)
mean6<-calc(abs6,na.rm=TRUE, fun=mean)
writeRaster(mean6, filename="Jun_mean.tif", format='GTiff',overwrite=TRUE)
#8. stack Jul and claculate mean and export
d7<-stack(Tiff_list[182:212])
abs7<-calc(d7, fun=abs)
mean7<-calc(abs7,na.rm=TRUE, fun=mean)
writeRaster(mean7, filename="July_mean.tif", format='GTiff',overwrite=TRUE)
#9. stack Aug and claculate mean and export
d8<-stack(Tiff_list[213:243])
abs8<-calc(d8, fun=abs)
mean8<-calc(abs8,na.rm=TRUE, fun=mean)
writeRaster(mean8, filename="Aug_mean.tif", format='GTiff',overwrite=TRUE)
#10. stack Sep and claculate mean and export
d9<-stack(Tiff_list[244:273])
abs9<-calc(d9, fun=abs)
mean9<-calc(abs9,na.rm=TRUE, fun=mean)
writeRaster(mean9, filename="Sep_mean.tif", format='GTiff',overwrite=TRUE)
#11. stack Oct and claculate mean and export
d10<-stack(Tiff_list[274:304])
abs10<-calc(d10, fun=abs)
mean10<-calc(abs10,na.rm=TRUE, fun=mean)
writeRaster(mean10, filename="Oct_mean.tif", format='GTiff',overwrite=TRUE)
#12. stack Nov and claculate mean and export
d11<-stack(Tiff_list[305:334])
abs11<-calc(d11, fun=abs)
mean11<-calc(abs11,na.rm=TRUE, fun=mean)
writeRaster(mean11, filename="Nov_mean.tif", format='GTiff',overwrite=TRUE)
#13. stack Dec and claculate mean and export
```

```
d12<-stack(Tiff_list[335:365])
abs12<-calc(d12, fun=abs)
mean12<-calc(abs12,na.rm=TRUE, fun=mean)
writeRaster(mean12, filename="Dec_mean.tif", format='GTiff',overwrite=TRUE)


#IndexMatching trimester dates and UVAI index
#****************************
#Import Date List
library(readxl)
year <- read_excel("0809dateindex.xlsx", col_types = c("numeric",
                                                      "date"))
View(year)
#Import 2009 Mother
library(readxl)
TriDate <- read_excel("2009TrimesterDate.xlsx",
                      col_types = c("numeric", "numeric","numeric","date", "date",
                                    "date", "date", "date", "date"))
View(TriDate)
#Create new column of ID for 3 trimesters' start and end dates based on x2007 indx
for (i in seq_along(TriDate$`1T Start`)){
  TriDate$T1startID[i]<-match(TriDate$`1T Start`[i],year$Date)
  TriDate$T1endID[i]<-match(TriDate$`1T End`[i],year$Date)
  TriDate$T2startID[i]<-match(TriDate$`2T Start`[i],year$Date)
  TriDate$T2endID[i]<-match(TriDate$`2T End`[i],year$Date)
  TriDate$T3startID[i]<-match(TriDate$`3T Start`[i],year$Date)
  TriDate$T3endID[i]<-match(TriDate$`3T End`[i],year$Date)
}

#Export Table
```

```
write.table(TriDate,file = "2009TrimesterDateIndex.csv", sep = ",",quote = FALSE, row.names = TRUE)


#***************************************Back to Image
#Reread all tif images(cleaned)
Tiff_dir2<-'D:/Qiong Air Data/OMI UVindex L3/Mother UVAI/0809tif/'
Tiff_list2<-list.files(Tiff_dir2,full.names=T, recursive=T)
View(Tiff_list2)


#Import Trimester Date Excel,2009 TrimesterDateINdex need extra work to ensure the missing dates are not lies on the trimester bouders. When missing dates lies on the trimester bolder, if beginning date is broken image date, increase one day as beginning day; If ending date  is image broken day, decrease one day as ending day.
library(readxl)
TriDateindex <- read_excel("2009TrimesterDateIndex2.xlsx",
                    col_types = c("numeric","numeric", "numeric","numeric","date", "date",
                          "date",                    "date",                    "date",
"date","numeric","numeric","numeric","numeric","numeric","numeric"))
View(TriDateindex)


TriDateindex$T1Mean<-NA##Create empty factor
TriDateindex$T2Mean<-NA
TriDateindex$T3Mean<-NA


#Find mean for each mother based on mother's residence *********
for (j in seq_along(TriDateindex$`ID`)){
  long<-TriDateindex$LONG[j]
  lat<-TriDateindex$LAT[j]
  ID<-data.frame(long,lat)
  coordinates(ID)<-~long+lat
  T1<-stack(Tiff_list2[TriDateindex$T1startID[j]:TriDateindex$T1endID[j]])
```

```
  absT1<-calc(T1, fun=abs)
  meanT1<-calc(absT1,fun=mean,na.rm=TRUE)
  TriDateindex$T1Mean[j]<-extract(meanT1,ID)
  T2<-stack(Tiff_list2[TriDateindex$T2startID[j]:TriDateindex$T2endID[j]])
  absT2<-calc(T2, fun=abs)
  meanT2<-calc(absT2,fun=mean,na.rm=TRUE)
  TriDateindex$T2Mean[j]<-extract(meanT2,ID)
  T3<-stack(Tiff_list2[TriDateindex$T3startID[j]:TriDateindex$T3endID[j]])
  absT3<-calc(T3, fun=abs)
  meanT3<-calc(absT3,fun=mean,na.rm=TRUE)
  TriDateindex$T3Mean[j]<-extract(meanT3,ID)
}

write.table(TriDateindex,file = "AOTTriDate2009averaged2.csv", sep = ",",quote = FALSE, row.names = TRUE)
```

APPENDIX C: ICD-10 Diagnosis Codes

Table 5.30. ICD-10 Diagnosis Codes.

Index	ICD10	Code Description	Frequency	Category
1	O69.1	Labor and delivery complicated by cord around neck, with compression	1107	7
2	O99.0	Anemia complicating pregnancy, childbirth and the puerperium	810	3
3	O33.9	Maternal care for disproportion, unspecified. Cephalopelvic disproportion NOS, Fetopelvic disproportion NOS	592	2
4	O41.0	Oligohydramnios	502	2
5	O42.9	Premature rupture of membranes, unspecified	486	4
6	O23.9	Other and unspecified genitourinary tract infection in pregnancy	464	3
7	O34.2	Maternal care due to uterine scar from previous surgery	382	1
8	O80.0	spontaneous vertex delivery	298	4
9	O36.3	Maternal care for signs of fetal hypoxia	269	6
10	O13	Gestational (Pregnancy-induced) hypertension	254	2
11	N76.1	subactue and chronic vaginitis	219	3
12	O32.1	Maternal care for breech presentation	161	2
13	O98.4	Viral hepatitis complicating pregnancy, childbirth and the puerperium	138	3
14	O64.0	Obstructed labour due to incomplete rotation of fetal head	119	4
15	O99.5	Diseases of the respiratory system complicating pregnancy, childbirth and the puerperium	113	3
16	O99.1	Other diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism complicating pregnancy, childbirth and the puerperium	87	3
17	E77.8	Other disorders of glycoprotein metabolism	76	3
18	O82.0	Delivery by elective caesarean section	73	4
19	O34.1	maternal care for tumour of corpus uteri	65	1
20	O63.0	Prolonged first stage of labour	65	4
21	Z35.2	Supervision of pregnancy with other poor reproductive obstetric history	64	1
22	O26.6	Liver disorders in pregnancy, childbirth and the puerperium	59	1
23	O99.4	Disease of the circulatory system complicating pregnancy, childbirth and the puerperium	56	1

Table 5.30. (cont'd).

Index	ICD10	Code Description	Frequency	Category
24	O36.5	Maternal care for poor fetal growth	54	6
25	O24.4	Diabetes mellitus arising in pregnancy	49	2
26	O99.2	Endocrine, nutritional and metabolic diseases complicating pregnancy, childbirth and the puerperium	47	3
27	Z76.2	Health supervision and care of other healthy infant and child	47	8
28	P07.1	Other low birth weight	46	8
29	O26.7	Subluxation of symphysis in gregnancy, childbirth and the puerperium	44	2
30	Z30.2	Sterilization	39	5
31	P23.9	Congenital pneumonia, unspecified	38	8
32	O44.0	Placental praevia specified as without haemorrhage	34	2
33	O72	Postpartum haemorrhage	33	5
34	P07.3	Other preterm infants	33	8
35	P12.0	Cephalhaematoma due to birth injury	31	8
36	O99.6	Diseases of the digestive system complicating pregnancy, childbirth and the puerperium	29	3
37	P91.6	Hypoxic ischaemic encephalopathy of newborn	29	7
38	O48	Prolonged pregnancy	26	2
39	O36.0	Maternal care for rhesus isoimmunization	23	2
40	O43.8	Other placental disorders	22	2
41	O34.8	Maternal care for other abnormalities of pelvic organs	20	1
42	P12.8	Other birth injuries to scalp	20	7
43	O41.8	Other specified disorders of amniotic fluid and membranes	19	2
44	O98.8	Other maternal infectious and parasitic diseases complicating pregnancy, childbirth and the puerperium	19	3
45	N83.8	Other noninflammatory disorders of ovary, fallopian tube and broad ligament	18	1
46	O26.8	Other specified pregnancy related conditions	17	3
47	P24.1	Neonatal aspiration of amniotic fluid and mucus	17	7
48	Z35.5	Supervision of elderly primigravida	17	1
49	O45.9	premature separation of placenta, unspecified	15	2
50	O69.8	Labour and delivery complicated by other cord complications	15	7
51	P28.8	Other specified respiratory conditions of newborn	15	8

Table 5.30. (cont'd).

Index	ICD10	Code Description	Frequency	Category
52	O36.6	Maternal care for excessive getal growth	14	6
53	O62.0	Primary inadequate contractions	14	4
54	O34.0	Maternal care for congenital malformation of uterus	12	1
55	Z35.9	supervision of high-risk pregnancy,unspecified	12	2
56	O73.0	Retained placenta without haemorrhage	10	5
57	O99.3	Mental disorders and diseases of the nervous system complicating pregnancy, childbirth and the puerperium	10	1
58	O34.4	Maternal care for other abnormalities of cervix	9	1
59	M79.8	Other specified soft tissue disorders	8	5
60	O36.1	Maternal care for other isoimmunization	8	2
61	O98.3	Other infections with a predominantly sexual mode of transmission complicating pregnancy, childbirth and the puerperium	8	1
62	Q65.8	Congenital hip dysplasia	8	8
63	P83.8	Other specified conditions of integument specific to fetus and newborn	7	8
64	Z35.4	Supervision of pregnancy with grand multiparity	7	2
65	O32.6	Maternal care for compound presentation	6	2
66	O33.1	Maternal care for disproportion due to generally contracted pelvis	6	1
67	O35.8	Maternal care for other (suspected) fetal abnormality and damage	6	6
68	O40	Polyhydramnios	6	2
69	O41.1	Infection of amniotic sac and membranes, Amnionitis, Chroioamnionitis, Membranitis, Placentitis	6	2
70	O43.1	Malformation of placenta	6	2
71	P00.3	Fetus and newborn affected by other maternal circulatory and respiratory diseases	6	8
72	P29.1	Neonatal cardiac dysrhythmia	6	8
73	Q62.0	Congenital hydronephrosis	6	8
74	P94.2	Congenital hypotonia	5	8
75	A53.9	Syphilis,unspecified	4	1
76	N73.9	Female pelvic inflammatory disease, unspecified	4	1
77	O63.1	Prolonged second stage (of labour)	4	4
78	O71.1	Rupture of uterus during labour	4	4
79	P21.9	Birth asphyxia, unspecified	4	7

Table 5.30. (cont'd).

Index	ICD10	Code Description	Frequency	Category
80	P39.1	Neonatal conjunctivitis and dacryocystitis	4	8
81	P94.1	Congenital Hypertonia	4	8
82	Q53.1	Undescended testicle,unilateral	4	8
83	E87.2	Acidosis	3	3
84	I45.1	Other and unspecified righ boundle-branch block	3	1
85	I45.6	Pre-excitation syndrome	3	1
86	I80.9	Phlebitis and thrombophlebitis of unspecified site	3	1
87	K64	Haemorrhoids and perianal venous thrombosis	3	2
88	N43.3	Hydrocele, unspecified	3	8
89	N87.9	Dysplasia of cervix uteri, unspecified	3	1
90	N89.8	Other specified noninflammatory disorders of vagina	3	5
91	O10	Pre-existing hypertension complicating pregnancy, childbirth and the puerperium	3	1
92	O34.6	Maternal Care for abnormality of vagina	3	2
93	O62.1	Secondary uterine inertia	3	4
94	O70.1	Second degree perineal laceration during delivery	3	4
95	O86.8	Other specified puerperal infections	3	5
96	O99.8	Other specified diseases and conditions complicating pregnancy, childbirth and the puerperium	3	1
97	P21.1	Mild and moderate birth asphyxia	3	7
98	P24.9	Neonatal aspiration syndrome, unspecified	3	7
99	P71.4	Transitory neonatal hypoparathyroidism	3	8
100	Q21.0	Ventricular septal defect	3	1
101	R01.1	Cardiac murmur, unspecified	3	8
102	R57.1	Hypovolaemic shock	3	4
103	D69.4	Congenital thrombocytopenia	2	8
104	E16.2	Hypoglycaemia, unspecified	2	3
105	E79.0	Hyperuricaemia without signs of inflammatory arthritis and tophaceous disease	2	1
106	H91.3	Deaf mutism, not elsewhere classified	2	1
107	I49.9	Cardiac arrhythmia, unspecified	2	8
108	I50.0	whole heart failure	2	8
109	I50.9	Heart failure, unspecified	2	8
110	J18.0	Bronchopneumonia, unspecified organism	2	3
111	M51.2	Lumbar intervertebral disc hernia	2	1
112	N80.0	Endometriosis of uterus	2	1

Table 5.30. (cont'd).

Index	ICD10	Code Description	Frequency	Category
113	N88.8	Other specified noninflammatory disorders of cervix uteri	2	3
114	O24.3	Pre-existing diabetes mellitus, unspecified	2	1
115	O63.9	long labour, unspecified	2	4
116	O68.1	Labour and delivery complicated by meconium in amniotic fluid	2	7
117	O69.2	Labour and delivery complicated by other cord entanglement, with compression	2	7
118	O75.8	Other specified complications of labour and delivery	2	5
119	P02.6	Fetus and newborn affected by other and unspecified conditions of umbilical cord	2	6
120	P10.9	Unspecified intracranial laceration and haemorrhage due to birth injury	2	7
121	P55	Haemolytic disease of fetus and newborn	2	2
122	P70.4	Other neonatal hypoglycaemia	2	8
123	P96.8	Other specified conditions originating in the perinatal period	2	8
124	Q62.3	Other obstructive defects of renal pelvis and ureter	2	8
125	R16.1	Splenomegaly, not elsewhere classified	2	1
126	Z90.4	Acquired absence of other parts of digestive tract	2	1
127	A49.3	Mycoplasma infection, unspecified site	1	3
128	E28.2	Polycystic ovarian syndrome	1	1
129	E83.5	Disorders of calcium metabolism	1	1
130	F41.2	Mixed anxiety and depressive disorder	1	3
131	G93.6	Cerebral oedema	1	3
132	H33.5	Other retinal detachments	1	8
133	I50.1	Left ventricular failure	1	2
134	I51.4	Myocarditis, unspecified	1	3
135	K11.2	Sialoadenitis	1	3
136	K66.8	Other specified disorders of peritoneum	1	8
137	K85.9	Acute pancreatitis, unspecified	1	2
138	L03.9	Cellulitis, unspecified	1	1
139	M41.9	Scoliosis, unspecified	1	1
140	N28.8	Other specified disorders of kidney and ureter	1	8
141	N70.1	Chronic salpingitis and oophoritis	1	1
142	N71.9	Inflammatory disease of uterus, unspecified	1	3
143	N85.6	Intrauterine synechiae	1	1

Table 5.30. (cont'd).

Index	ICD10	Code Description	Frequency	Category
144	N85.8	Other specified noninflammatory disorders of uterus	1	2
145	N94.8	Other specified conditions associated with female genital organs and menstrual cycle	1	3
146	O10.2	Pre-existing hypertensive renal disease complicating pregnancy, childbirth and the puerperium	1	1
147	O22.0	Varicose veins of lower extremity in pregnancy	1	2
148	O22.1	Genital varices in pregnancy	1	2
149	O23.5	Infections of the genital tract in pregnancy	1	2
150	O26.4	Herpes gestationis	1	2
151	O26.9	Pregnancy-related conditions, unspecified	1	1
152	O32.2	Maternal care for transverse and oblique lie	1	4
153	O34.5	Maternal care for other abnormalities of gravid uterus	1	1
154	O34.7	Maternal care for abnormality of vulva and perineum	1	3
155	O35.0	Maternal care for (suspected) central nervous system malformation in fetus	1	8
156	O41.9	Disorder amniotic fluid and mmembranes, unspecified	1	8
157	O47.9	False labour, unspecified	1	2
158	O62.2	Other uterine inertia	1	4
159	O66.0	Obstructed labour due to shoulder dystocia	1	4
160	O69.9	Labour and delivery complicated by cord complication, unspecified	1	4
161	O88.2	Obstetric pulmonary embolism	1	6
162	O98.5	Other viral diseases complicating pregnancy, childbirth and the puerperium	1	1
163	O99.7	Diseases of the skin and subcutaneous tissue complicating pregnancy, childbirth and the puerperium	1	2
164	P00.2	Fetus and newborn affected by maternal infectious and parasitic diseases	1	1
165	P02.2	Fetus and newborn affected by other and unspecified morphological and functional	1	6
166	P03.1	Fetus and newborn affected by other malpresentation, malposition and disproportion during labour and delivery	1	7
167	P07.0	Extremely low birth weight	1	8
168	P15.8	Other specified birth injuries	1	7
169	P21.0	Severe birth asphyxia	1	7

Table 5.30. (cont'd).

Index	ICD10	Code Description	Frequency	Category
170	P22.1	Transient tachypnoea of newborn	1	8
171	P28.9	Respiratory condition of newborn, unspecified	1	8
172	P29.3	Persistent fetal circulation	1	8
173	P36.8	Other bacterial sepsis of newborn	1	6
174	P39.2	Intra-amniotic infection of fetus, not elsewhere classified	1	6
175	P54.0	Neonatal haematemesis	1	8
176	P55.1	ABO isoimmunization of fetus and newborn	1	6
177	P58.9	Neonatal jaundice due to excessive haemolysis, unspecified	1	6
178	P76.1	Transitory ileus of newborn	1	6
179	P80.9	Hypothermia of newborn, unspecified	1	8
180	P83.3	Other and unspecified oedema specific to fetus and newborn	1	8
181	P83.5	Congenital Hydrocele	1	6
182	P96.3	Wide cranial sutures of newborn	1	6
183	Q03.1	Atresia of foramina of Magendie and Luschka	1	6
184	Q05	Spina bifida	1	6
185	Q21.1	Atrial septal defect	1	6
186	Q25.0	Patent ductus arteriosus	1	6
187	Q42.3	Congenital absence, atresia and stenosis of anus without fistula	1	6
188	Q43.2	Other congenital functional disorders of colon	1	6
189	Q44.7	Other congenital malformation of liver	1	6
190	Q53.2	Undescended testicle, bilateral	1	8
191	Q53.9	Undescended testicle, unspecified	1	8
192	Q55.6	Other congenital malformations of penis	1	6
193	Q66.3	Other congenital varus deformities of feet	1	6
194	Q66.6	Other congenital valgus deformities of feet	1	6
195	Q69.9	Polydactyly, unspecified	1	6
196	Q82.5	Congenital non-neoplastic naevus	1	6
197	Q90.9	Down syndrome, unspecified	1	6
198	R09.1	Pleurisy	1	6
199	R68.1	Excessive crying of infant	1	8
200	S06.0	Concussion	1	7
201	T14.9	Injury, unspecified	1	3
202	T21.0	Burn of unspecified degree of trunk	1	1

Table 5.30. (cont'd).

Index	ICD10	Code Description	Frequency	Category
203	Z35.7	Supervision of high-risk pregnancy due to social problems	1	1
204	Z86.0	Personal history of other neoplasms	1	1
205	Z90.7	Acquired absence of genital organ(s)	1	1
206	Z91.6	Personal history of other physical trauma	1	1

APPENDIX D: Variance Inflation Factor (VIF) for All Independent Variables

Table 5.31. Variance Inflation Factor (VIF) for All Independent Variables.

Variables	VIF
UVAIT1Mean	2.624
UVAIT2Mean	1.099
UVAIT3Mean	2.579
Age	4.436
HospitalDa	1.357
Gest1_day	1.287
F1stprenexa	1.184
Totalprene	1.174
BPHigh	4.216
BPLow	3.699
Urban	1.288
Occupation	1.179
Marriage	1.065
PregnancyH	1.819
Parity	2.034
Nutrition	1.123
Gender	1.059
TpDeliver	1.214
MethDelive	1.722
Deformity	1.011
Amfluid	1.158
Pre_M	1.377
Preg_M	1.592
Pre_Preg_M	1.202
Delivery_M	1.323
Post_Deliv_M	1.055
Preg_B	1.100
Deliv_B	1.089
Post_Deliv_B	1.081
O69.1	1.113
O99.0	1.109
O33.9	1.103
O41.0	1.109
O42.9	1.106
O23.9	1.082
O34.2	1.172

Table 5.31. (cont'd).

Variables	VIF
O80.0	1.385
O36.3	1.057
O13	1.099
N76.1	1.050
O32.1	1.047
O98.4	1.032
O64.0	1.078
O99.5	1.044
O99.1	1.032
E77.8	1.076
O82.0	1.093
O34.1	1.049
O63.0	1.093
Z35.2	1.041
O26.6	1.060
O99.4	1.039
O36.5	1.130
O24.4	1.044
O99.2	1.068
Z76.2	1.069
P07.1	1.106
O26.7	1.042
Z30.2	1.092
P23.9	1.211
O44.0	1.050
O72	1.048
P07.3	1.053
P12.0	1.108
O99.6	1.051
P91.6	1.237
O48	1.010
O36.0	1.017
O43.8	1.016
O34.8	1.018
P12.8	1.033
O41.8	1.033
O98.8	1.030

Table 5.31. (cont'd).

Variables	VIF
N83.8	1.061
O26.8	1.035
P24.1	1.060
Z35.5	1.042
O45.9	1.039
O69.8	1.058
P28.8	1.035
O36.6	1.093
O62.0	1.039
O34.0	1.020
Z35.9	1.057
O73.0	1.034
O99.3	1.015
Z35.4	1.030
O35.8	1.026
P29.1	1.030
O10	1.028
O24.3	1.090
Others	1.078

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