ESSAYS ON THE ENVIRONMENTAL IMPACT ON CHILD HEALTH: THE CASE OF SRI LANKA

A Dissertation

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By

Rambandage Dhanushka Ravilal Perera

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Abstract

This dissertation investigates the impact of environmental shocks on child health, focusing on natural and artificial actions in the environment. The first chapter examines the heterogeneous impact of rainfall shocks experienced in utero on the health outcomes of newborn babies in Sri Lanka. The Demographic and Health Surveys (DHS) conducted in 2006 and 2016, and rainfall data from approximately 140 rainfall stations from 1970-2016 are combined to estimate regional level fixed-effect model. The results indicate that; (1) the increase of rainfall from the historical rain during the first trimester increases the birth weight of children, and this impact is concentrated among poor children in rural and plantation (estate) sectors. (2) Rainfall shocks in the third-trimester decrease the birth weight of children in the urban sector, particularly among boys.

The second chapter examines the effect of air pollution on children's respiratory health (age under 0-6 years) living in seven highly populated districts (Colombo, Gampaha, Kaluthara, Galle, Rathnapura, Kurunegala, and Kandy) in Sri Lanka. We utilized household data from the Demographic and Health Survey (DHS) in 2016 and air pollution data; a monthly average of 24 hours SO_2 (Sulfur Dioxide) emission records from 67 stations which were monitored by the NBRO (National Building Research Organization). This study has considered the WHO recommended air pollution interim targets (2005);

most studies have relatively less focused. We used GIS techniques to interpolate pollution data and estimated the effects of ambient SO_2 pollution using the regional level fixed-effects model. Our main results show that (1) among the poor children living 10km radius of air pollution measurement stations, ambient SO_2 pollution is associated with a higher likelihood of respiratory disorders. (2) This relationship is concentrated only among poor households, measured by the DHS wealth index. The findings of this dissertation suggested the importance of targeting the pregnant mothers living in rural and plantation sectors and the mothers in the third trimester of pregnancy in the urban sector when implementing the nutrient supplement and diseases prevention programs in Sri Lanka. Also, this study highlights the reviewing of existing policies on air pollution, limiting the SO_2 emissions to meet the WHO standards. Overall, this study highlights the importance of targeting disadvantaged groups such as households living in rural/estate sectors and poor households in an urban setting.

Keywords: *Birth weight, rainfall shocks, ambient* SO_2 *pollution, vulnerable groups*

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To beloved my mother, Kamala Loolpola

and my father, Amarananda Perera.

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Chapter 1

Introduction

1.1.Introduction

The third goal of the 2030 Agenda for Sustainable Development is to “ensure healthy lives and promote well-being for all ages” describes the importance of prioritizing maternal and child health globally; because gestational and childhood periods in life are the highly vulnerable stages for environmental consequences. For instance, in 2015, 5.9 million children age under five died globally. Apart from them, 26% of deaths are recorded due to environmental-related hazards (WHO,2017). Therefore, identifying environmental risk and policy actions to mitigate the adverse effect of environmental consequences is vital to achieving sustainable goals 2030.

There is growing attention among academics on exposure to environmental shocks in early childhood on various health outcomes. The research interest in this area has been popularized based on the fetal origin hypothesis introduced by Dvavid J. Berker, British epidemiologist that describes the early stages are the most critical stages of life that determine the future health conditions of humans (Almond and Currie, 2011). Thus, this study focuses on short-term health outcomes (i.e, birthweight) in early life response to the environmental consequences in the developing context.

Rainfall is a vital weather element that affects humans in several ways. First, adequate rain impacts agriculture production and brings positive outcomes. (Maccini & Young, 2009). Second, during extreme rainfall conditions, some communities experience negative results. For instance, children who live in diverse geographical regions are vulnerable to vector-borne, water-borne, and air-borne diseases during the rainy periods (Rocha & Sares, 2015). Similarly, environmental changes due to human activities bring several effects to human beings. For instance, every 9 out of 10 persons breathe polluted air globally; thus, nearly 7 million deaths worldwide in 2018 (WHO,2019).

Under this context, studies related to the effects of environmental shocks on health are urgently needed. Therefore, this dissertation presents fundamental policy debates on prioritizing child health, particularly in developing settings.

1.2.Objectives and contributions of the study

This dissertation address two environmental issues that potentially contribute to child health, referring to the development context. Therefore, the main objective of this dissertation is to identify vulnerable groups who are highly sensitive to environmental consequences. In order to achieve this primary objective, this dissertation specifies several secondary objectives associated with two main empirical chapters. In particular, the objectives of the first empirical study are (1) to identify critical stages in utero which are highly sensitive to environmental shocks, (2) To assess the heterogeneity in the impact of rainfall shocks across the various socio-economic conditions. Finally, the second empirical study of this dissertation aims to identify vulnerable groups exposed to urban air pollution under the developing context.

This dissertation provides several contributions to the existing literature. The first empirical study contributes to the existing literature in several ways. First, few studies have focused on rainfall shocks out of the various types of environmental-related shocks. Apart from them, the effect of rainfall shocks in utero on short-term health outcomes (i.e., birth weight) is relatively less focused. However, estimating the effect of shocks in each stage in utero is essential; because each stage has a unique role for fetus development. In addition, the second empirical chapter mainly considered one of the harmful gaseous pollutants SO_2 and its WHO recommended levels (interim targets 2) for the analysis. Because SO_2 is a mostly harmful gaseous pollutant that leads to respiratory disorders, ranging from hospital admission to mortality. In addition, this study examines the health benefits of meeting the WHO's interim targets introduced in 2005. Therefore, this methodological approach brings new contributions to the existing air pollution studies.

1.3.Organization of the dissertation

This dissertation is organized as follows; Chapter 2 provides empirical evidence on the effect of rainfall shocks in utero on the initial child health outcomes of children under five. In particular, this chapter examines the heterogeneity in the impact of rainfall shocks across various socio-economic groups in Sri Lanka. Chapter 3 explores the effect of urban pollution risk on child respiratory health issues in Sri Lanka. This study examines the pollution effect across various economic groups, referring to seven populated cities in Sri Lanka. Finally, Chapter 4 concludes the main findings and the policy implications of this dissertation.

Chapter 2

Assessing the heterogeneity in the impact of rainfall shocks in utero on child health in Sri Lanka (2006 -2016)

2.1. Introduction

The changes in climate conditions bring significant challenges for socio-economic development. Considering that most low-income families in developing countries are dependent on agriculture, their livelihood is more likely to be affected by climate change. In that context, vulnerable households living in rural areas, especially children, experience potential welfare losses. Thus, the impact of weather-related shocks on human capital development has been a growing consideration in economic and health science studies. However, the impact of rainfall shocks in utero on human health outcomes is relatively less focused. We investigated this relationship across various geographical and socio-economic groups in Sri Lanka to fill this research gap.

Investigating the effects of rainfall shocks on health outcomes is extremely important in several ways. First, a moderate increase of rainfall shocks increases agriculture productivity (Andalon et al.,(2016). As a result, these shocks lead to increased food availability in the market and nutritional intake. Secondly, rainfall negatively affects health outcomes. For instance, children are particularly vulnerable to vector-borne, water-borne, and air-borne diseases during the rainfall (Akachi, Goodman & Parker, 2009). Thirdly, these adverse health outcomes in early life prevail long term and indirectly influence their education and socio-economic developments in the long run (Almond and Currie, 2011).

In this context, the previous literature generally addressed the effect of rainfall shocks on long or medium-term human capital development (i.e. HAZ, education achievements), and they less likely focused on initial health conditions at birth. However, low birth weight incidences in developing countries are associated with maternal malnutrition (Pathirana et al.,2017). Likewise, investigating the effect of rainfall shocks during the different stages in utero is essential. For instance, first-trimester rainfall shock contributes to the fetus's fast growth and organ development during the initial stages of gestation; because the maternal diet contributes development and differentiation of various organs of the fetus during the first trimester (Rifas-Shiman et al.,(2006). Therefore, by highlighting the importance of early life health, this study addresses issues such as (1) how do rainfall shocks in different stages in utero experience in utero influence birth weight? (2) How does heterogeneity in rainfall impact influenced health outcomes across the various socio-economic groups? Thus, this study lines with the literature on the impact of exogenous shocks on human capital development, mainly in developing contexts.[1]

This study uses two sets of data for the analysis. (1) Household data from the nationally representative Demographic and Health Surveys (DHS) conducted in 2006 and 2016. We used birth weight records in DHS as the primary outcome variable of this study; because birth weight is a prevailing predictor of initial health that biologically links with other health outcomes (i.e., illnesses) (Wilcox, 2001). (2) Rainfall data from 140 meteorological stations located across different geographical locations for 1970-2016. To better understand the impact of shocks, we constructed three different explanatory variables for each trimester in the gestation. We estimated our results by the use of OLS (Ordinary Least Squire) with fixed effects. The results revealed that (1) the increase of rainfall from the historical rain during the first trimester increases the birth weight of

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[1] For example, Maccini & Young (2009); Rocha & Soares (2013); Cornwell & Inder (2015)

children in rural and plantation sectors (2) Rainfall shocks in the third Trimester decrease the birth weight of children in the urban sector, particularly among boys.

Previous literature generally used the effect of rainfall shocks during the overall gestation period, and they were less focused on trimesters in utero (i.e., Cornwell & Inder, 2015; Maccini & Yang, 2009). However, numerous biomedical studies have indicated that consideration of different phases in utero is essential. For instance, first-trimester growth has a significant association with health outcomes at birth (Mook-Kanamori et al., 2010; Smith et al., 1998). In addition, existing studies have relatively less focused on the heterogeneity in weather-related consequences across various socio-economic groups. Therefore, to fill these empirical gaps, (1) this study considers the critical phases in a utero and their relative importance for human capital development. (2) Also, this study examines the effect of rainfall for several groups, which are fragmented based on socio-economic characteristics such as sectors, gender, and wealth structure. The heterogeneity analysis is crucial; because households in developing countries are substantially isolated from the various socio-economic characteristics. For instance, in Sri Lanka, DHS's in 2006 and 2016 have indicated that the human capital development indicators are explicitly different across these characteristics[2]. Thus, understanding these characteristics helps to identify if any disadvantaged group is affected more than others in catastrophic events, and it is a vital aspect of the policymaking process.

This chapter is organized as follows: Section 2.2 presents the literature review on climate-related studies published mainly in developing countries. Section 2.3 provides the background information in Sri Lanka and describes the link between rainfall and

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[2] For instance, the average birth weight of each district in Sri Lanka is shown in Figure 2.4

health. Section 2.4 presents the methodology used for the estimation. Section 2.5 describes the empirical strategy used in this study. Section 2.6 describes results and discussion. Section 2.7 describes the robustness check. Finally, section 2.8 concludes the study.

2.2. Literature review

Several studies have indicated that the effect of shocks in utero on various health and socio-economic outcomes. First, nutritional shocks in utero during the Ramadan fasting period were widely considered in the previous literature (Almond & Mazumder,2011; Chen,2014; Majid,2015 & Schoeps,2018). For instance, Majid (2015) has revealed that Indonesian pregnant mothers who experienced Ramadan fasting showed an adverse outcome for their children, and the impacts persist from childhood to adulthood. These nutritional shocks lead to a decrease in the cognitive and math scores significantly during childhood. In addition, shocks led to decreased working hours and increased self-employment incidences during adulthood. Secondly, several pieces of literature have indicated that exposure to conflict during pregnancy brings adverse health outcomes for their offspring (Bundervoet & Fransen,2018; Dagnelie et al.,2018 & Valente,2015;). The studies in this framework argued that direct physical acts of violence, such as the limitation of access to healthcare, the devastation of infrastructure, and income losses, leads to maternal stresses, and these conditions negatively affect their children (Valente,2015). Thirdly, several studies have examined how exposure to famine in utero brings various adverse health outcomes, highlighting maternal nutrition's effect on fetus development. For example, Almond et al. (2010) have examined that experience in Chinese famine (1956-1964) during the gestation period result in a negative socio-economic outcome such as illiterate incidences and high physical disabilities.

Out of the above categories of studies, relatively few studies have examined the impact of various weather shocks in utero on health outcomes. First, the effect of temperature shocks in utero on the adverse health outcomes was examined, matching the timing of exposure in each Trimester (Deschenes, 2009 & Andalon et al.,2016). For instance, Andalon et al. (2016) indicated that temperature shocks during 1999-2008 in Colombia lower the gestation period; particularly shocks during the first and second trimesters reduce the gestational length. Moreover, exposure to high-temperature shock during the third trimester results in low birth weight. Secondly, shocks that come from various environmental phenomena such as the El Nino are examined in some studies. For instance, Rosales (2018) has examined the impact of severe flood shocks in utero during the El Nino period (1997-1998) in Ecuador on children's various health and cognitive outcomes. In particular, severe flood shock exposure in the first and third trimesters negatively affects cognitive skills and children's height, respectively.

In contrast to the growing number of weather shock-related studies, few studies focus on rainfall shocks. Maccini and Young (2009) have considered the rainfall shocks a year before the birth year, the birth year itself, and one year after the birth, separately. They mainly found that having a higher rainfall than the historical average in the first year of age results in higher educational attainments among adult females living in rural Indonesia. However, they found no evidence of the effect of rainfall shocks in one to three years before the birth year. On the other hand, another Indonesian study was conducted by Cornwell and Inder (2015), which has revealed that the positive rainfall shocks during the gestation period decrease HAZ of children living in urban areas. Likewise, Rocha and Sares (2015) have examined the effect of water scarcity in utero on health outcomes at birth in Brazil. Their result suggests that negative rainfall shocks (i.e., drought) lower the birth weight and heighten mortality rates, and the effects are severe during the second trimester of gestation. In this context, this study has focused on the shocks in utero because nine months in gestation are the most crucial period in a life that shapes the future health status of humans (Bundervoet & Fransen,2018; Almond & Currie,2011).

In order to identify the causal relationship between rainfall shocks and health outcomes, existing literature has explained several channels. The first channel is through the disease environment. For example, rainfall changes environmental conditions in a developing context and contributes to a lack of safe drinking water (Rocha & Sares,2015). Also, these changes lead to the occurrence of vector-borne (i.e., Malaria, Dengue) and water-borne diseases (i.e., Cholera, leptospirosis, Typhoid fever) (Rabassa, Skoufias & Jacoby,2012). The second channel is through food intake and agricultural production. Rural economies in developing countries mainly depend on rain-fed agriculture. Thus, rainfall influences rural households' income and nutrition intake (Rocha & Soares, 2015; Thiwari et al., 2017). Finally, the third mechanism is through the labor supply decisions of mothers. For instance, rainfall increased the opportunity cost of parental time and increased mothers' labor supply, and these conditions negatively impact child health outcomes (Thai & Myrskyla,2012). In particular, this channel explains the relationship between labor demand during the rainfall period and parental time consumption on breastfeeding.

Overall, Maccini and Yonng (2009), Rocha and Soares (2015), and Cornwell and Inder (2015); have used rainfall shocks based on the changes of rainfall from the historic rainfall. Indeed, positive rainfall shocks connect to positive outcomes, particularly among developing countries (Maccini & Yonng, 2009). However, these studies focused only on the shocks in the entire gestation period. Thus, we estimated the relative importance of critical stages in utero concerning rainfall shocks; because each stage in the gestational period has a unique role in fetus development[3]. Secondly, the previous literature generally addressed the effect of rainfall shocks on long or medium-term human capital development (i.e. HAZ, education achievements), and they less likely focused on initial health conditions at birth. Therefore, we used birth weight to fill this empirical gap because it is a reasonable proxy to examine the initial health condition (Hoynes, 2016). In addition, we specifically considered birth weight as our primary outcome in this study; because we already know about the effect of rainfall shocks on the long-term human capital development outcomes.

2.3. Background

Sri Lanka is an island that covers 65,610 square kilometers of land area, and it is located in the Indian Ocean where situated nearby equator extends longitudes from 79°41' to 81°53' and latitudes from 5°55' to 9°50' (Melmgren et al., 2003). Sri Lanka is exposed to two types of monsoon rainfalls (i.e., South-West Monsoon, North-East Monsoon) and two inter-monsoon rainfalls (i.e., First and Second Inter Monsoons). South-West and North-East monsoon periods are considered the main rainfall periods and occur from May to September and December to February, respectively. Inter-monsoon periods occur in between the monsoon periods. For instance, the first inter-monsoon occurs from March to April, and the second monsoon period occurs from October to November (Zubair, 2002). In this context, agricultural activities in Sri Lanka are conducted parallel to rainfall seasons. For instance, the rice crop is the staple food in Sri Lanka, and it is cultivated in

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[3] i.e., The first trimester in the gestational period is considered the rapid development stage, which develops the fetus's organs and structure. The second trimester is considered most of the brain’s development stage, and the third trimester is the maturing stage of the fetus.

two farming seasons; "Maha" and "Yala." Thus, Maha and Yala are matching to North-East and South-West monsoon periods, respectively. Thus, rice farming communities are highly dependent on the rainfall pattern in Sri Lanka (Zubair, 2002).

During the last 50 years, rainfall reception was changed significantly. For instance, 21 rainfall measurement stations showed an increasing rainfall trend while the other 11 stations showed a decreasing trend over 50 years in Sri Lanka (Karunathilaka et al., 2017). Furthermore, Nissanka and Sangakkara (2005) have indicated that the variance of rainfall distribution during the second Inter-Monsoon Season and the North-East Monsoon was increased; however, South-West Monsoon remained unchanged from 1961 to 1990. Based on the disaster information in Sri Lanka, rainfall in Sri Lanka has adversely changed and led to flood conditions across different areas. For instance, several districts were flooded heavily in 2010 and 2014 due to extreme rainfall conditions (IFRC&RCS, 2010; WHO, 2014). Also, rainfall-related health hazards were increased in Sri Lanka during the past few years. For instance, in 2002, dengue fever was the third most notifiable disease in Sri Lanka, and presently it became the most notifiable disease during the past few years. Over 35,000 dengue victims were recorded in 2009, and the majority of them came from the wet zone, whereas a relatively higher rainfall associated area in Sri Lanka, shown in Figure 2.1 (Sirisena & Noordeen, 2014). In this context, Sri Lanka was considered the second-largest affected country from extreme weather events in 2017 based on the Climate Risk Index (CRI) introduced by the Germanwatch climatic institute (Eckstein et al., 2018).

Over the last decade, in Sri Lanka, low birth weight (<2500g) deliveries are a substantial issue that has not been settled yet over the last decade. For instance, in 2012, the total low birth weight records were 55,557, and it was 16.3% of total live births

(Pathirana et al.,2017). Moreover, the DHS 2016 has revealed that the low birth weight incidences under-five age children are 17%, varied across sectors; i.e., the estate and rural sectors, showed 25% and 16.6% low birth weight, respectively (Department of Census & Statistics [DCS], 2016). The low birth weight incidences in developing countries are more likely associated with maternal malnutrition (Pathirana et al.,2017). Also, maternal malnutrition links with poverty that impacts human capital development (Vorster, 2010). In Sri Lanka, nearly 25% of the population who live in the estate and rural sectors is below the poverty line. Based on the previous studies in Sri Lanka, poverty trends are subject to weather characteristics such as rainfall. For example, the population below the poverty line in Sri Lanka was increased from 26% to 29% from 1990/91 to 1995/96, while the average rainfall in most parts of the country was recorded below the average (Aturupane & Deolalikar, 2005). Thus the analysis below investigates possible heterogeneous effects of rainfall shocks across three sectors (i.e., urban, rural, and estate) in Sri Lanka.

2.4.3. Conceptual framework:

This study is based on a variant of the agriculture household model. In particular. first, we use the utility function shown in equation 2.1a.

$$U = u(H, X, Xl) \qquad \text{(eq.2.1a)}$$

Equation 2.1a describes the utility of household (U); comprises the health (H), purchased commodity (X), and the leasure time (Xl). Secondly, we used the agricultural production function, shown in equation 2.1b.

$$Q = f(A, L, K, Sh) \qquad \text{(eq.2.1b)}$$

Equation 2.1b explains that agricultural output (Q) is the function of the fixed inputs (i.e., Land; A, Capital; K), variable inputs (i.e. Labor; L), and Environmental factors; Sh. More importantly, Environmental factors (Sh) represent the physical and natural conditions that substantially affect production output in rural economics. For instance, fair rain provides enough moisture for the crops that result in high productivity gains. On the other hand, rain brings negative results through the disease effect.

The relationship between health inputs and the initial health conditions is shown in the health production function equation 2.1c (Grossman, 1972)[4].

$$H = f(i, Df(sh), L_h, \eta) \qquad \text{(eq.2.1c)}$$

Based on equation 2.1c, the initial health outcomes (H) at birth is described by as a function of health inputs (i), time spent on healthcare (L_h), disease conditions $(Df(sh))$ as a function of environmental shocks (sh), and the unobserved characteristics (η) (i.e., household unobserved characteristics) experienced during the gestational period.

Households are subject to budget constraints; first, the budget constraint shown in equations 2.1d

$$\ddot{Y} = P_a Q - W(L - F) = P_i i + P_x X \qquad \text{(eq.2.1d)}$$

Equation 2.1d describes household income from farming activities ($\ddot{Y}$) that equals the difference between the revenue received from the production and labor costs. The revenue is the total agricultural production (Q) when sold at a price; P_a. The cost for labor is the total wage paid (W) to the number of general labors (L) excluding family laborers (F). In that context, households spend their income ($\ddot{Y}$) to purchase commodities (X) and health inputs (i) at prices P_x and P_i, respectively.

Secondly, we used the time constraints, shown in equation 2.1e.

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[4] Health production function was used by several authors as the basic conceptual framework of their study; i.e. Maccini & Young (2009), Ahmed, H., (2015), Cornwell & Inder (2015), and Tiwari et al.,(2016).

$$L_h + F + Xl = T \qquad \text{(eq.2.1e)}$$

Equation 2.1e shows the total time endowment (T) and its composition. Where (L_h) is the time spent on health care, (F); working time, and (Xl); leisure time.

When substituting the time constraint into budget constraint yields equation 2.1f.

$$\ddot{Y} = P_a Q - W(L - T + Xl + L_h) = P_i i + P_x X \qquad \text{(eq.2.1f)}$$

Let the optimum levels of healthcare investment (i^*) and the time spent on health care (L_h^*) to be:

$$i^* = i^*(Df(sh), \eta, P_a, W, P_i) \qquad \text{(eq 2.1.g)}$$

$$L_h^* = L_h^*(Df(sh), \eta, P_a, W, P_i) \qquad \text{(eq 2.1.h)}$$

Where i^* and L_h^* are depending on all the exogenous variables $Df(sh), \eta, P_a, W, P_i$.

Thus, the reduced form theoretical equation of equation 2.1f is explained as follows:

$$H^* = f(i^*, Df(sh), L_h^*, \eta) \qquad \text{(eq.2.1i)}$$

Where the optimized health capital at birth (H^*) is explained as a function of optimized health investment and the optimized time spent on the health care and all the other exogenous variables $(i.e., Df(sh), \eta)$.

Therefore, the reduced form health equation can also be derived by replacing i with i^*, and L_h with L_h^*; because both 2.1.g and 2.1.h contain the same set of exogenous variables shown in equation 2.1j.

$$H^* = H^*(Df(sh), \eta, P_a, W, P_i) \qquad \text{(eq 2.1.j)}$$

2.4. Methodology

2.4.1. Data

To construct rainfall shock variables, first, we collected average monthly rainfall data from approximately 140 rain gauge stations for 1970-2016. In Sri Lanka, mainly three government institutions collect the rainfall: The Department of Meteorology, the

Department of Irrigation, and the Department of Agriculture (UNESCO, 2006). Apart from them, we collected rainfall data from the Department of Meteorology for this study representing at least five rain gauge stations per district[5]. The rainfall stations used in this study are shown in Figure 2.2.

Secondly, we collected health data from repeated cross-sectional surveys: Demographic and Health Surveys (DHS)- 2006/2016. DHS data provides comprehensive health records of maternal characteristics and relevant health information of infants (i.e., birth weight). Mainly, we used the birth weight of infants born within five years at the interview time of DHS as the outcome variable of this study[6]. In addition, we selected appropriate co-variates from the DHS to control any variance in birth weight. In particular, we selected child, mother, household, and regional characteristics shown in Table 2.1.

The sampling procedure of DHS is based on a two-stage stratified sampling design. The first stage of sample design selects approximately 2500 enumeration clusters based on the population census in each district. The second stage of selection practices systematic sampling that identifies a fixed number of households[7] within each cluster. The DHS in 2016 was the fifth latest DHS survey, representing 28,720 households for all 25 districts in Sri Lanka. DHS in 2006 was the fourth DHS round which represents 21,600 households. The 2006 DHS has excluded the Northern province due to the conflict between Sri Lankan army and LTTE[8]. Therefore, we excluded the households in the

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[5] The Department of Meteorology records the additional rainfall data collected from other institutes; therefore, their data covers all the rainfall stations in the country.

[6] For instance, DHS 2016 provides the birth weight of children under five years of age born from 2011 to 2016.

[7] 10 and 12 housing units were selected from each DHS cluster in 2006 and 2016 DHS, respectively.

[8] LTTE- Liberation Tigers in Tamil Eelam

northern province for 2016 DHS, and we pooled the rest of the households in both DHS surveys for our analysis (DHS clusters are shown in Figure 2.3). The location of households in DHSs was matched by using the centroid GPS coordinates of "Grama Niladari" [GN] divisions[9] which are the smallest administrative units in Sri Lanka. The usual technique of linking the GPS coordinates of households into rainfall value is matching the centroid point of sample clusters into the closest rainfall measurement station (Thiwari et al., 2017). However, due to the lack of GPS coverage of the DHS sampling clusters, we matched the centroid point of the GN division with the interpolated rainfall data collected from 140 rainfall stations from 1970 to 2016 (Please see the note for the cleaning of data in Appendix I). Second, this study has identified the timing of the childbirth and the amount of rainfall that he/she experienced during the utero period.

2.4.2. Summary statistics

Table 2.1 shows the variables used in this study, including information on child, mother, household, and region characteristics for both surveys, 2006 and 2016.

<Table 2.1: Summary statistics>

Panel A shows the basic outcome variable of this study. The average birth weight of the selected sample is 2,897 grams, and 80.2% of children show healthy weight based on the WHO standards[10]. However, the distribution of birth weight across the districts is varied from the mean, shown in Figure 2.4. The main explanatory variables used in this study are shown in Panel B. In particular, we separately developed rainfall shock variables

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[9] In Sri Lanka, there are four administrative levels; province level, district level, divisional secretariat level and “Grama Niladari” (GN) level. The GN is the smallest administrative unit, and our sample represented 2,259 GN divisions out of 14,022 total GN divisions in Sri Lanka.

[10] If the birth weight of a newborn child is less than 2500 grams, it is considered as the low birth weight (WHO,2006)

for each trimester, describes in section 2.5.2. For child characteristics, we considered the sex and multiple birth status of children aged below five years. The data exhibit 51 % of boys, and 49% of girls represented our sample. Moreover, we found that 1% of births are multiple births. For mother characteristics, the birth history of mothers aged 15-49 years, education level, ethnicity, and religion were considered. We found that almost 91% of mothers have completed their primary education, and most mothers are Sinhalese – Buddhists. For instance, 69.1% of Sinhalese and 74% of Buddhist mothers represent our sample. For household characteristics, first, we considered sanitary facilities of households; drinking and cooking water sources. For instance, 79% and 78% of households have piped water for drinking and cooking, respectively. In addition, 94% of households have improved toilet facilities. Also, we considered household wealth characteristics; 89% of households have electricity, 72% of households have a radio, 85% of households have television, 70% of households have mobile phones, 48% of households have a refrigerator, 26% of households are used electricity as their main fuel source, 32% of households have owned agriculture land. Finally, we developed dummy variables to represent poor and rich households based on wealth index scores[11]. We divided the wealth index scores into five quintiles. Intuitively, households who received 1 and 2 quintiles represented the bottom 40% of wealth quintiles, and households who received 3, 4, and 5 quintiles represented the upper 60% of wealth quintiles. On this basis, we identified 39.1% and 60.9% of relatively poor and wealthy households, respectively. However, the household characteristics used to construct the wealth index could not

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[11] We develop wealth index based on the step by step guide explained by Fry et al., (2014). For this purpose, we selected 21 household characteristics and we used Principle Component Analysis (PCA).

represent the characteristics during the mother's gestation period. Therefore, we assumed that the above household property characteristics existed during the gestation period.

For regional characteristics, we considered the location of households. Furthermore, we considered the altitude of the household location to control any regional differences in our specifications. However, we observed that the altitude of household locations is missed in the DHS data; thus, we used the centroid point of the GN division as the household altitude, and we measured it using ArcGIS. The mean altitude is 209 meters, and most households live in the low country (below 300m). Finally, we constructed sector dummies for urban, rural, and estate sectors. We observed that 74% of households represented the rural sector. Other households represented urban and estate sectors; those are 17% and 7%, respectively.

2.5. Empirical strategy

2.5.1. Econometric models

Based on the equation 2.1j described in Section 2.4.3, we use the following econometric model to estimate the impact of rainfall shocks experienced by a child in each trimester on the birthweight. Equation 2.2 shows both observed and exogenous variables captured from equation 2.1.j.

$$BW_{ijt} = \beta_0 + \beta_1 Tr1_{ij} + \beta_2 Tr2_{ij} + \beta_3 Tr3_{ij} + \beta_4 X1_{ij} + \beta_5 X2_{ij} + \beta_6 X3_{ij} + \varphi_D + \alpha_S + y_b + \delta_m + \varepsilon_{ijdsbm} \qquad \text{(eq.2.2)}$$

In particular, H^* described in the equation 2.1j in section 2.4.3 is captured by the (BW_{ijt}), which is the primary outcome variable of this study (i.e., birth weight). It describes the birth weight of the newborn child (i) in the GN division (j) in the birth year (t). Likewise, the shock experienced in utero (sh) explained in equation 2.1j in section 2.4.3 is captured by key explanatory variables used in this study; $Tr1_{ij}$, $Tr2_{ij}$, and $Tr3_{ij}$ are the rainfall shocks variables in first, second and third trimesters, respectively. The definition of shocks variables is described in section 2.5.2. $X1_{ij}$ is a vector of control variables for the child. $X2_{ij}$ is the vector of control variables for mother characteristics. $X3_{ij}$ is the vector of control variables for household and community characteristics. The composition of vectors $X1_{ij}$, $X2_{ij}$ and $X3_{ij}$ are described in the summary statistics in Table 2.1. In addition, the model includes district fixed effects; φ_D, survey year fixed effects; α_S, birth year fixed effect;y_b and birth month fixed effects; δ_m.

District fixed effects include time-invariant unobserved characteristics which impact maternal health. For instance, remote districts are subject to fewer healthcare facilities, and pregnant mothers likely have poor health conditions. In addition, government healthcare investment and agro-climatic conditions are different across districts. Moreover, the amount of rainfall received is varied across the district in Sri Lanka. Therefore, we used the district fixed effect to control the rainfall variation across districts, which gives us the precise estimation of the impact of rainfall shocks[12]. More importantly, we assumed that district fixed effects capture other environmental factors (i.e., air pollution, temperature), the prices ($P_a \; and \; P_i$) and wage rate (w) described in section 2.4.3; because these characteristics are unlikely to change across the DS divisions in this study.

Survey year and birth year fixed effects include any time-variant unobserved characteristics during the study period. The birth month fixed effect captures birth month-

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[12] However, we compute the rainfall shock variable at most disaggregated administrative levels (GN Division); thus, our estimation is likely precise though we exclude the district fixed effect.

specific unobserved characteristics. i.e., seasonality patterns in utero conditions. However, the unobserved characteristics described in equation 2.1J in section 2.4.3 could impact the estimations. For instance, some unobserved household behavioral characteristics on health unlikely capture in this model; i.e., some households are more concerned about their health, and some are not. Finally, ε_{ijdsbm} represents the idiosyncratic standard error clustered at the GN division level, and this variable will correct any correlated conditions in utero within the GN division over time.

2.5.2. Rainfall shock variables

In the agricultural context, a moderate increase of rainfall shocks contributes to increasing agriculture productivity[13]. In addition, these types of shocks lead to an increase in food availability in the market. Thus, the nutritional status of mothers who experienced positive shocks is likely to be better than the mothers who experienced adverse shocks during their pregnancy period. In order to see if this is the case, we develop the following three rainfall shock variables as basic explanatory variables of this study[14]. In particular, rainfall shocks experienced by a child in utero during his/her first, second, and third trimesters were calculated by the use of equations 2.2, 2.3, and 2.4, respectively.

$$Tr1_{ij} = \frac{\sum_{m-6}^{m-8}(R_{ijt_1} - \bar{R}_{ij})}{\sigma^{\bar{R}_{ij}}} \qquad \text{(eq.2.3)}$$

$$Tr2_{ij} = \frac{\sum_{m-3}^{m-5}(R_{ijt_2} - \bar{R}_{ij})}{\sigma^{\bar{R}_{ij}}} \qquad \text{(eq.2.4)}$$

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[13] Andalon et al.,(2016) have indicated that the moderate increase of rainfall leads to increase in agriculture production in tropical countries such as Colombia

[14] In contrast, Maccini & Young (2009) and Cornwell & Inder (2015) have considered the rainfall shocks exposure during the total pregnancy period, and they were relatively less focused on the trimestrial shocks. In this study, we found no relationship between shocks during the total gestation period and the initial health outcomes of infants. Thus, this study highlighted the importance of shocks during the trimesters following the Deschenes (2009) and Andalon et al. (2016).

$$Tr3_{ij} = \frac{\sum_{m}^{m-2}(R_{ijt_3} - \bar{R}_{ij})}{\sigma^{\bar{R}_{ij}}} \qquad \text{(eq.2.5)}$$

$Tr1_{ij}$, $Tr2_{ij}$ and $Tr3_{ij}$ are the rainfall shocks experienced by mother (i) in GN division (j) during the first, second and third trimesters, respectively. R_{ijt_1},R_{ijt_2} and R_{ijt_3}, are aggregate rainfall during the respective trimester based on the birth month (m) of each mother (i). $\bar{R}_{ij}$ is the corresponding average historical rainfall in the individual-specific trimester from 1970 to 2000, which varies by child born to each mother (i) in the GN division (j). $\sigma^{\bar{R}_{ij}}$ is the standard deviation of rainfall in the individual-specific trimester for 1970-2000 corresponding to each child of mother (i) in the GN division (j). We find that calculated rainfall shock variables in each trimester are similar in 2006 DHS and 2016 DHS as shown in Figures 2.5, 2.6, and 2.7. Hence, we used pooled rainfall shocks of both 2006 and 2016 surveys for econometric analysis.

<Figure 2.5: Rainfall shock in trimester 1 in 2006 and 2016>

<Figure 2.6: Rainfall shock in trimester 2 in 2006 and 2016>

<Figure 2.7: Rainfall shock in trimester 3 in 2006 and 2016>

In addition, we developed additional six rainfall shock variables to identify the positive and negative rainfall shock separately (i.e., floods and droughts) extreamly positive and negative rainfall shock are defined as the dummy variables that are equal to 1 if the standardized rainfall is greater or equal to 2 and lesser or equal to 2, respectively. The summary statistics of these variables is described in Table 2.1.

2.6.Results and discussion

2.6.1. Effect of moderate rainfall shocks on birth weight

Table 2.2 shows the results of the main specification, equation 2.2. The first column shows the results, including district-level fixed effects, survey year fixed effect, birth year fixed effect, birth month fixed effect, and columns 2-4 exhibit the results, including different sets of controls such as child, mother, household, and regional characteristics. The results in each column (from columns one to four) in Table 2.2 remain consistent. Column 5 exhibits the result, including the mother fixed effect, indicating that the significance is dropped due to losing the variation within the sample. Therefore, we dropped the mother fixed effect for the rest of the analysis. Our primary interest in the specification is shown in column 4, with all controls. In particular, rainfall shocks in the first trimester in utero showed a significant positive effect on birth weight. For instance, an increase of rainfall shocks in the first trimester by one standard deviation leads to increased birth weight by 15 grams[15], which is a 0.5% of increase from the average birth weight (i.e., 2.8kg). Our results are consistent with Rocha and Soares (2015) finding that pregnant mothers exposed to rainfall shocks during the first and second trimesters have affected their babies' birth weight in Brazil[16]. The possible explanation for the relationship between the birth weight gains and the first-trimester rainfall shock is that on the fetus's fast growth and organ development during the initial stages of gestation; because the maternal diet contributes development and differentiation of various organs of the fetus during the first trimester (Rifas-Shiman et al.,(2006).

<Table 2.2: Impact of rainfall shocks in utero on birth weight>

2.6.2. Effect of extreme rainfall shocks on birth weight

In addition to the effect of linear rainfall shocks analysis, we examined the impact of extreme rainfall shocks on the initial health outcomes of infants. For this purpose, we

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[15] In order to check the changes from one standard deviation (SD), we multiplied the co-efficient from respective SD in the shock variable; because the shock variables represent the standardized values.

[16]. However, Rocha and Soares (2015) have used a slightly different mechanism to develop rainfall shock variables. For instance, they have used log deviation between rainfall shocks in utero and the historical rainfall.

used six rainfall shock dummy variables described in Table 2.1, Panel B as the basic explanatory variables. The results are shown in Table 2.3. The first column in Table 2.3 describes the impact of overall extreme shocks on the birth weight of infants. In particular, extreme positive shocks during the first trimester positively affect birth weight, significant at 10% level. These results are consistent with the results in the continuous specification described in Table 2.2. On the other hand, extreme negative shocks in the first trimester negatively impact birth weight, which is significant at a 5% level. Therefore, the overall results suggested that an increase of rainfall above moderate level benefits infants' initial health outcomes. This analysis assumed that the extreme rainfall shocks change from the above +2 or below -2 from the standardized rainfall shocks in the continuous specification.

2.6.3. Heterogeneity in the impact of moderate rainfall shocks on birth weight

Next, we assess the heterogeneity in the impact of rainfall shocks in utero on birth weight. First, we estimated the effect of rainfall shocks by sectors (i.e., urban, rural, and estate); because families living in rural and estates are more likely depends on rain-fed agriculture. Secondly, we examined the heterogeneity in the impact of rainfall shocks among the gender to identify gender bias. This is of interest as a substantial amount of literature has considered the household resource allocation across the gender during the post-natal period[17]. However, household resource allocation during the prenatal period is relatively less focused except for few studies[18]. Furthermore, in Sri Lanka, most parents

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[17] Kim Y.S. (2010) and Tiwari et al (2013)

[18] For example, Bharadwaj & Lakdawala (2013) have found that a significant behavioral change among mothers who pregnant with boys relative to mothers who pregnant with girls; because mothers who pregnant with boys are more likely to have tetanus vaccination relative to mothers who pregnant with girls in India

know the sex of their babies before birth[19]; therefore, this specification provides inference on the prenatal preference on the gender during pre-natal period in Sri Lanka. Finally, we examined the effect of rainfall shock among various income groups to understand how health outcomes are changed among different income groups respond to rainfall shocks. We find that the sample from the estate sector accounts for 7.3%. Therefore, we combined the household in the estate and rural sectors. Thus, the reference sectors are rural and estate. The results are shown in Table 2.4.

<Table 2.4: Impact of rainfall shocks in utero on birth weight by sectors>

In Table 2.4, Panel A column 1 shows that the rainfall shocks in the first trimester positively influence birth weight for households in the rural and estate sectors. For instance, an increase of rainfall shocks during the first trimester by one standard deviation leads to increased birth weight by 15 grams for rural and estate sectors. Thus, the results suggested that the rural and estate sectors positively respond to the increase of rainfall relative to the historical norm, which is consistent with the Athurupane and Deolalikar (2005). Indeed, a decent fall of rain is suitable for agricultural production and food availability, which is more likely to reflect children's health outcomes.

In contrast, Table 2.4 Panel B column 1 shows the negative impact of third-trimester rainfall shocks in the urban sector. For instance, a one standard deviation increase of shocks decreases birth weight by 19 grams in the urban sector and is significant at 5 percent. It is a 0.6% decrease from the average birth weight limit. Intuitively, this might be due to the negative consequences of rainfall shocks due to the alteration of environmental conditions in the urban sector. Based on the explanation of

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[19] Most of Sri Lankan pregnant mothers identified sex of their babies during the ultrasound scanning process before the childbirth (Babyspace(n.d.))

Cornwell and Inder (2015), rain in urban areas more likely brings poor health for pregnant mothers. They explained that the dengue fever in Indonesian urban areas increased during the heavy rain; thus, pregnant mothers infected from diseases experienced poor health, negatively impacting the fetus's development. Therefore, the disease channel in the urban sector more likely brings negative consequences from the positive rainfall shock.

<Table 2.5: Impact of rainfall shocks in utero on birth weight, by gender>

Table 2.5 shows the impact of rainfall shocks in utero on birth weight across the gender. Column 1 describes the overall results, and Columns 2 and 3 show the results separately for urban, rural/estate sectors separately. Based on panels A and B in column 1, mothers exposed to rainfall shock during the first trimester showed significant growth of their babies' birth weight irrespective of sex. For instance, increasing one standard deviation in the first trimester increases birth weight by 16 and 14 grams, respectively, for girls and boys. These results suggested that boys and girls in the overall sample have been treated equally by parents in Sri Lanka.

In contrast, panel B column 2 shows a significant negative relationship between rainfall shock exposure in the third trimester and birth weight for boys in the urban sector. For instance, an increase of rainfall shocks by one standard deviation in the third trimester leads to decreased birth weight for urban sector boys by 36 grams[20]. In addition, health science publications have indicated that maternal exposure to diseases during the third trimester is relatively higher than in the second and third trimesters (March of dimes,

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[20] These results are consistent with the Table 2.3 panel B: Mothers who exposed to rainfall shocks in third trimester showed a significant negative association with birth weight of their babies in the urban sector. Intuitively, these results are mainly contributed by the negative co-efficient of boys in the urban sector.

2021). For instance, lungs capacity during the third trimester is reduced due to the growth of the fetus. Thus, the lungs attempt to absorb more oxygen, and the mothers' belly puts pressure on the lungs, and these conditions result in shortness of breath and maternal stress. As a result, pregnant mothers are more likely infected with flu-like diseases during the third trimester[21]. Moreover, biomedical literature has indicated that the male fetus is physiologically weaker than the female fetus; therefore, the male fetus is highly vulnerable to risk, death, or damage (Kraemer, S., 2000).

Finally, column 3 shows the impact of rainfall shocks in utero on birth weight separately for rural and urban samples. In particular, rural and estate samples show a significant positive relationship between first-trimester rainfall shocks and the birth weight of both genders. However, the impact of third-trimester rain is significantly positive for boys in rural/estate sectors. For instance, an increase of rainfall, shock by one standard deviation in the third trimester, significantly influences birth weight by 16 grams for boys[22]. Thus, it can be that the parents who have unborn boys are more likely to spend more when it rains more. Therefore, parents living in rural/estate sectors in Sri Lanka are more likely biased on household resource allocation across gender groups. Indeed, our results are consistent with gender-related studies in India; Bharadwi and Lakdawala (2013); mothers with male fetuses receive more prenatal care than mothers with female fetuses in India.

For heterogeneity assessment across wealth structure, we developed a dummy based on the wealth index score. In particular, we assign 'one' if the households represented the bottom 40% of the wealthy population. Moreover, we used the interaction

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[21] Please see; https://www.marchofdimes.org/complications/influenza-and-pregnancy.aspx

[22] It is 0.55% increase from the average birth weight.

of the bottom 40% dummy with rainfall shock variables. Thus, the reference group is households that represented the upper 60% of the wealthy population. Intuitively, this specification provides evidence on how heterogeneity in the rainfall shocks in utero impacts newborn babies across the differential wealth status of households[23]. The results are shown in Table 2.6.

< Table 2.6: Impact of rainfall shocks in utero on birth weight, by wealth structure>

Table 2.6 shows the impact of rainfall shocks in utero on birth weight across the wealth structure of households. Column 1 shows the effect of rainfall shocks across the wealth structure for the complete sample. Columns 2 and 3 show the results for sectors; (1) urban sector (2) rural and estate sectors. Based on panel B column 1, relatively poor households are sensitive to rainfall shocks. For instance, an increase of rainfall by one standard deviation during the first trimester increases birth weight by 30 grams. Column 2 shows the impact of rainfall shocks in utero on birth weight based on wealth structure for the urban sector. The results suggested that rainfall shocks in the urban sector are less likely to impact the wealthy groups; because the urban sector is relatively less sensitive to agricultural production and related income generation activities.

In addition, panel B column 3 shows a significant positive relationship between rainfall shock in the first trimester and birth weight for relatively poor households. For instance, rainfall shocks in the first-trimester increase birth weight by 33 grams in rural/estate sectors. This result can also be explained by using the nutritional channel of rural and estate sector households. Intuitively, the poor household in the rural and estate

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[23] As an alternative to wealth structure of households, we tried to construct dummy by considering household head’s occupation in order to identify the households who engage in agriculture activities. However, we observed that code description in microdata is missed in 2006DHS.

sectors work in the agriculture sector, and they are more likely to receive benefits from the moderately positive rainfall shocks due to the increase of agriculture production[24]. However, relatively wealthy households in rural and estate sectors are less sensitive to rainfall shocks.

2.6.4. Heterogeneity in the impact of extreme rainfall shocks on birth weight

In addition to moderate rainfall shocks' heterogeneity analysis, we examined the heterogeneity in the impact of extreme rainfall on initial health outcomes of infants. For this purpose, we used six rainfall shock dummy variables described in Table 2.1 Panel B as the basic explanatory variables. The results are shown in Table 2.7. The first and second columns show the results separately for urban and rural/estate sectors, respectively. For the urban sector, the first and third trimesters are sensitive to extreme shocks. For instance, both extremely positive and negative shocks during the first and third trimesters increase significant birth weight among infants. These results suggest that the urban sector's disease channel is relatively weak when the rainfall turns to extreme levels. For the rural/estate sector, we found extreme negative shocks during the first trimester significantly reduced birth weight. These results further explained the results in Table 2.4 Column 3; because the rural/estate sectors are dependent on agriculture, and drought conditions bring negative health results through the loss of income and nutrient availability.

2.7. Robustness check

In this section, we discuss the possible threat to our estimated results. First, we test the selective conception; because parents can decide the timing of conception by

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[24] Andalon et al.,(2016)

avoiding environmental conditions. Therefore, we check whether there is any significant association between rainfall shock outside the gestation period and the birth weight. In particular, we conducted a placebo test by constructing a rainfall shock variable for three months before the conceiving month (i.e., Trimester 0). For that purpose, we used similar types of rainfall shock variables described in equations from 2.3 to 2.5. The results obtained from the benchmark specification (eq.2.2) are shown in Table 2.8.

<Table 2.8: Impact of rainfall shocks outside the critical period on birth weight>

Table 2.8 column 1 shows the results, including fixed effects. From columns 2 to 4, we added other control variables. More importantly, we could not find any significant impact outside the pregnancy period; thus, these findings suggested that the rainfall shock does not determine parent's decision on conception on their babies.

Our second apprehension is selective migration. For example, if a mother migrated to other areas to get rid of the adverse shocks during the gestation period, the actual estimates could be attenuated towards zero; therefore, the results could be underestimated. Similarly, if a mother migrated to an adverse area searching for work, the results could be overestimated. In addition, we used this robustness check to address the measurement errors of the rainfall shock variables used in this study. For instance, if a mother migrates during the gestation period, the actual rainfall shocks could be miscalculated. Therefore, the estimates can be attenuated towards zero. In that context, we used the migration details of the mother in DHS, and we could identify the number of respondents who migrated during the pregnancy period. In particular, we restricted our sample to non-migrants and estimated the results using equation 2.2. The results are shown in Table 2.9.

< Table 2.9: Impact of rainfall shocks on birth weight for non-migrant during the critical period.>

According to Table 2.9, column 4, fewer observations are dropped due to the selective migration. For instance, Table 2.2 column 4 shows, 12,395 observations and Table 2.9 column 4 shows, 10,276 observations. Therefore, the proportion of migrated respondents is approximately 17%. However, the basic results in Table 2.2 remained unchanged for the non-migrated sample shown in table 2.9. Therefore, our results are not biased from the selective migration of parents.

Finally, we test for selective attrition. In particular, we estimated the recorded miscarriages, stillbirth, and abortion cases in both DHS rounds. We identified the mothers who self-recorded miscarriage, stillbirth, and abortion cases during the last five years are 9.7%, which is relatively low from the global records.[25] Explicitly, the recorded miscarriages, stillbirth, and abortion cases in 2006 DHS are 7.5%, 0.4%, and 0.5%, respectively. However, the above cases are not shown separately in 2016 DHS. Therefore, the fraction of the above cases is more likely lower relative to the global scale. Therefore, the impact of selective attrition might be less likely to impact our estimates.

In addition, the main estimates could be affected by the maternal mortality that not be observed from the selected data. This study is limited to identifying the number of maternal deaths during pregnancy; thus, our results could be biased. However, Sri Lanka recorded the lowest maternal mortality rate in the south Asian region; thus, the bias due to maternal mortality could less likely affect the estimated results. For instance, in 2017

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[25] For instance, Gallos et al. (2017) have indicated that 15 -20% of pregnancies in the globe end up with miscarriages, and 25% of pregnant mothers have faced a miscarriage in their lifetime.

maternal mortality ratio per 100,000 live births in Sri Lanka is 36, and it is the lowest in South Asia[26].

2.8. Summary and conclusion

This study provides evidence of the effect of rainfall shock in utero on the health outcomes of newborn babies in Sri Lanka. Unlike previous studies in this area, we could estimate the effect of rainfall shocks exposure in utero on short-term health outcomes, particularly birth weight. We find that rainfall shocks in utero have positively and negatively influenced birth weight. The results suggest that the rainfall shock in rural and estate sectors positively impacted child health, but not for the urban sector. In addition, this study found heterogeneity in the impact of rainfall shocks on birth weight across the gender; We found that the rural/estate sectors showed a significant positive relationship between third-trimester shocks and the birth weight of boys. Conversely, results indicate a significant negative relationship between third-trimester shocks and birth weight for boys in the urban sector.

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[26] Please see https://www.statista.com/statistics/639534/asia-pacific-maternal-mortality-ratio-by-country/

Chapter 3

Assessing the heterogeneity in the impact of urban air pollution on child respiratory health in Sri Lanka.

3.1.Introduction

Air pollution is becoming a severe threat to human life (World Health Organization [WHO], 2006). Every 9 out of 10 persons breathe highly polluted air, and approximately 7 million deaths occurred worldwide in 2018 due to air pollution. Apart from them, 4.2 million deaths occur annually due to outdoor air pollution (WHO, 2019). More importantly, the effects of air pollution on child health are critical; globally, 93% of children live in polluted environments; the pollutants levels are recorded above the WHO Air Quality Guidelines (AQGs) (WHO, 2018). Indeed, air pollution has become a prioritized global issue, and it was addressed essentially by United Nations 2030 agenda for sustainable development[27] (WHO, 2016).

Air pollution in Sri Lanka is a growing issue due to the extraordinary increase in vehicle population and traffic congestion. For instance, the number of cars in Sri Lanka was increased by 300% from 2000 to 2018. Moreover, the population of motorcycles and three-wheelers were increased by 290% and 380%, respectively, for the period 2003-2008 (Illeperuma, 2020). As a result, air quality in major cities in Sri Lanka has been affected critically due to the increase of vehicle population rapidly: Indeed, Colombo is the commercial capital in the western province, and approximately 60% of emissions in Colombo are coming from vehicular emissions (Nandasena, Wickramasinghe & Sathiakumar, 2010; Premasiri et al., 2015). Also, the air pollution level in Colombo was

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[27] SDG indicator 3.9.1: Mortality rate attributed to household and ambient air pollution (goal3), SDG indicator 11.6.2: Annual mean levels of fine particulate matter in cities (goal11), SDG indicator 7.1.2: Proportion of population with primary reliance on clean fuels and technologies for the sustainable energy goal (goal3).

recorded at a higher level relative to other south Asian cities. For instance, the maximum PM_{10}[28] level in Colombo was recorded at 110µg/m^3, and it was higher than average air pollution measurements in Dhaka (Bangladesh); 105.5µg/m^3, Islamabad (Pakistan); 88.4µg/m^3, Trombay (India); 82µg/m^3 for the period 2002-2005 (Hopke et al.,2008). In this context, urban air pollution in Sri Lanka became a severe issue to human life (Galhamuwa, Perera & Bandara,2016). For this reason, we examine the effect of urban air pollution on children's respiratory illnesses; concerning the World Health Organization [WHO]s' interim targets of air pollution, which is relatively less focused by existing literature.

Based on the growing volume of various air pollutants in developed and developing countries, WHO has introduced AQGs in 2005, targeting four primary pollutants in the air; PM (Particular Matter), NO_2 (Nitrogen Dioxide), SO_2 (Sulfur Dioxide), and (O_3) Ozone (WHO, 2006)[29]. However, these pollutants in many countries exceeded the WHO recommended levels, and it is not realistic to achieve the recommended levels; thus, WHO has introduced interim targets[30] for each pollutant to gradually improve air quality for member countries (Chen & Kan,2008). In particular, we

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[28] Particular matter (PM); diameter is less than 10µm

[29] $PM_{2.5}$:10µg/m^3 for annual mean and 25µg/m^3 for 24 hours mean
PM_{10}:20µg/m^3 for annual mean and 50µg/m^3 for 24 hours mean
NO_2:40µg/m^3 for annual mean and 200µg/m^3 for 1 hour mean
SO_2:20µg/m^3 for 24 hours mean and 500µg/m^3 for 10 minutes mean
O_3:100 µg/m^3 for 8 hours, daily maximum

[30] 24 hours interim targets (IT) for $PM_{2.5}$: IT1 = 75µg/m^3, IT2 = 50µg/m^3 and IT3 = 37.5µg/m^3
Annual interim targets (IT) for $PM_{2.5}$: IT1 = 35µg/m^3, IT2 = 25µg/m^3 and IT3 = 15µg/m^3
24 hours interim targets (IT) for PM_{10}: IT1 = 150µg/m^3, IT2 = 100 µg/m^3 and IT3 = 75 µg/m^3
Annual interim targets (IT) for PM_{10}: IT1 = 70µg/m^3, IT2 = 50 µg/m^3 and IT3 = 30 µg/m^3
24 hours interim targets (IT) for SO_2: IT1 = 125µg/m^3, IT2 = 50 µg/m^3
Daily maxim 8 hours mean interim target (IT) for O_3: IT1=160 µg/m^3

investigate the potential health benefits of meeting the WHO interim air pollution targets, which is relatively less focused in current literature. More specifically, this study examines whether and which socio-economic groups are affected by the exposure to SO_2, which is one of the important pollutants.

This study utilizes mainly two sets of data for this analysis: Household data from the DHS (Demographic and Health Survey) in 2016 and a monthly averaged of 24 hours SO_2 (Sulfur Dioxide) emission records from 67 stations. We used the time and regional fixed-effects model to examine the possible causality between air pollution and child respiratory health; because the exposure of households to air pollution is usually non-random for various reasons (i.e., economic activities, income distribution). We tested our results in several ways, including the IV (Instrumental Variable) approach that uses the altitude of household locations as an IV.

The main estimates of this study have revealed that impoverished children living in potentially polluted areas are vulnerable to respiratory health problems relative to wealthy children. For instance, children who expose to SO_2 concentrations above the WHO interim target (2) ($50\mu g/m^3$) show an increase of the incidence of coughing by 19 and 10 percentage points significantly for households who are in the bottom 20% (poorest) and 40% (Poor) of the wealth groups, respectively. However, we could not find a significant association between ambient SO_2 pollution and respiratory disorder for relatively wealthy households living within 10km and 5km radius-areas of air pollution measurement stations.

In contrast to the growing number of air pollution studies in epidemiological and economic backgrounds, this study has attempted to address several research gaps. First, numerous air pollution studies are relatively less focused on WHO’s interim targets on air pollution. Thus, we considered the interim target (2) for ambient SO_2 emission, bringing a new contribution to the air pollution literature. Secondly, this study focuses on the most harmful gaseous pollutant, SO_2, that brings respiratory health issues among children living in various wealth conditions, and the effect of SO_2 on respiratory health is reactively under-documented in the economic literature. Finally, to our best knowledge, this is the first air pollution-related study for Sri Lanka that covers mostly populated six districts.

This chapter is arranged as follows: Section 3.2 describes the literature review on air pollution-related studies published in developed and developing contexts. Section 3.3 reviews the Sri Lankan condition of air pollution and related consequences. Section 3.4 describes the data and methodology of the study. Section 3.5 describes the empirical strategy. Section 3.6 shows the results and discussion. Section 3.7 explains the robustness check, and lastly, section 3.6 concludes the study.

3.2.Literature review

Pollutants in the air come from numerous forms, with many mixtures that result in adverse human health conditions. These pollutants can be divided mainly into two categories; particular matter (PM) and gaseous pollutants. PM is considered air particles, and these are further classified based on the diameter: coarse (diameter is less than 10μm; PM_{10}), fine (diameter is less than 2.5μm; $PM_{2.5}$), and ultrafine (diameter is less than 0.1μm; $PM_{0.1}$). The gaseous pollutants are SO_2 (Sulfur Dioxide), NO_2 (Nitrogen Dioxide), CO (Carbon Monoxide), O_3 (Ozone), and some organic compounds such as benzene (Mannucci & Franchini, 2017). Among these gaseous pollutants, SO_2 and O_3 are the most important pollutants concerning human health and acute effects. Explicitly, SO_2 has apparent effects on patients with asthma, and its impact ranges from hospital admission to mortality (Manahan,1997). Moreover, SO_2 affects the human respiratory system uniquely. For instance, the effect of exposure to ambient SO_2 leads to irritation and mucus secretion within the human respiratory system (Manahan, 2006). Also, biomedical literature has indicated that the early stages in life are most vulnerable to pollutants; because of their rapid growth and immature metabolic mechanisms (Sunyer,2008). However, despite the importance of SO_2 for respiratory health, few studies examine this pollutant's effect on respiratory health outcomes, particularly for children.

Based on the growing volume of air pollutants in developed and developing countries, WHO has initiated a global consultation to limit the pollutants. In particular, WHO has introduced Air Quality Guidelines (AQGs) in 2005 targeting PM, NO_2, SO_2, and O_3 (WHO,2006). However, the current pollutant levels of member countries are much higher than the suggested AQGs; therefore, WHO has introduced interim targets for each pollutant to improve air quality gradually for member countries (Chen & Kan,2008). In that context, several studies have used AQGs as their benchmarks for their estimation (Krzyzanowski & Cohen, 2008). First, Moreno et al. (2007) have examined that to what extent the European countries could achieve the WHOs' AQGs. They found that the PM level at traffic monitoring stations in many European cities exceeds the WHOs' AQGs by 50-100%, and they emphasized that over 250,000 infant deaths are recorded in Europe due to the inhalation of PM in 2000. Secondly, Shi et al. (2018) have investigated the potential health advantages when regulating PM based on the WHOs' AQGs in Southeast and South Asia for 1999-2014. In particular, they indicated four scenarios describing how AQGs contribute to infants' health[31]. However, the above literature has less focused on

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[31] For instance, (1) scenario 1 shows that controlling $PM_{2.5}$ at $10\mu g/m^3$ level reduces premature

WHOs' interim targets of gaseous pollutants (SO_2, NO_2, etc.), which are likely to be more relevant for developing countries. For instance, in Sri Lanka, 24 hours mean SO_2 concentration is 42 μg/m^3 (Shown in Table 3.1), which is higher than the WHO AQGs' (20μg/m^3), but lower the interim target 2 (50μg/m^3). Indeed, no study has focused on the effects of SO_2 pollution on health when the pollution level exceeds the WHOs' interim targets to our best knowledge. This study fills this empirical gap considering the WHOs' interim targets for SO_2.

In epidemiological literature, the various types of pollutants are widely used to examine air pollution's effect on mortality and morbidity (Buka, Koranteng & Osornio-Vargas, 2006). For instance, Xu, Yu, Jing, and Xu (2000) have investigated the relationship between mortality and air pollutants, SO_2, and TSP (Total Suspended Particulates) in Shenyang industrial city in China, and they found that the deaths due to pulmonary and cardiovascular diseases were increased due to the high level of air pollutants. Also, the causes of death due to cardiovascular and pulmonary diseases are highly co-related to ambient TSP and SO_2 pollution, respectively. More importantly, Glinianaia et al. (2004) have examined the effect of prenatal exposure to particulate pollution on infant mortality. They found that this effect becomes strong among subgroups such as infants. In addition, several epidemiological studies have highlighted the short-term effects of air pollution on human health. For instance, Sunyer et al. (2003) have examined the association between daily air pollution records of SO_2 and daily

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deaths by 69.3%. (2) scenario two shows that reducing $PM_{2.5}$ at IT-3 level (15μg/m^3) decreases premature deaths by 49.1%. (3) scenario three finds that the reduction of $PM_{2.5}$ at IT-2 level (25μg/m^3) results in a decrease in premature deaths by 25.4 and (4) finally scenario four shows that the $PM_{2.5}$ at IT-1 level (35μg/m^3) decrease of premature deaths by 12.8% based on the mortality records for 1999-2004.

hospital admissions in seven major populated areas in Europe. The result indicates that the impact of SO_2 is significant for children, not for adults, relative to the effect of NO_2.

Economists have also examined ambient air pollution's impact on health outcomes (i.e., Day & Grafton, 2003; Jayachandran,2009; Garg, 2011, Luechinger, 2014; Takahashi & Hibiki, 2020), and they examined its heterogeneity. For example, Jayachandran (2009) has studied the impact of polluted air due to the forest fires on infant mortality under the palm oil industry program in Indonesia in 1997. The main result indicates that the effect of pollutants is higher in poor areas relative to wealthy areas in Indonesia, and the pollution effect is higher in females than males. Another Asian study conducted by Garg (2011) has found that reducing particular matter (PM_{10}) in air leads to decreased mortality and morbidity in New Delhi after introducing emission control policies in India, and health benefits are significant for poor people. A recent study conducted by Kurata, Takahashi, and Hibiki (2020) has examined prenatal and postnatal exposure to particular matter ($PM_{2.5}$) on child health in Bangladesh. This study examined indoor and outdoor air pollution effects simultaneously on child growth standards (i.e., stunning) and respiratory illness by gender. Their main results indicated a significant positive relationship between indoor air pollution and respiratory disease, only for girls. Furthermore, they found that prenatal exposure to outdoor air pollution troubles boys' growth, but not for girls; however, it has a negative growth effect for both genders.

3.3.Background

Air pollution in Sri Lanka is a growing issue due to the extraordinary increase in vehicle population and motor traffic congestion (Illeperuma, 2020). Based on the Department of Motor Traffic statistics in Sri Lanka (DMTSL), the total number of vehicles is increased by 50% from 2007 to 2016, shown in Figure 3.1. In addition, figure

3.1 shows that the number of motor cars, motor tricycles, motorcycles, and buses increased between 2007 and 2016 by 46%, 65%, 52%, and 20%, respectively (DMTSL, 2015; DMTSL, 2016).

<Figure 3.1: Vehicle population for 2007-2017 in Sri Lanka>

This increased vehicular emissions and worsened air pollution in major cities in Sri Lanka. For instance, in Colombo's commercial capital, approximately 60% of total emission is generated from vehicular emissions (Nandasena, Wickramasinghe & Sathiakumar, 2010; Premasiri et al., 2015). In addition, concentrations of SO_2, $NO_{2,}$ and Ozone in the central capital (Kandy) exceeded the air quality standards by 41%, 14%, and 28%, respectively, due to the vehicular emissions from 2001 to 2005 (Illeperuma, 2020). These two major polluted districts and the other five populated districts (Gampaha, Kaluthara, Galle, Kurunegala, and Rathnapura) are included in our study.

Colombo's air pollution level was recorded relatively higher during past years, even in contrast to several cities in South Asia. For instance, the maximum PM_{10}[32] level in Colombo was recorded at $110\mu g/m^{3,}$ which was higher than average air pollution measurements in Dhaka (Bangladesh); $105.5\mu g/m^3$, Islamabad (Pakistan); $88.4\mu g/m^3$, Trombay (India); $82\mu g/m^3$ for the period 2002-2005 (Hopke et al.,2008). Also, International Association for Medical Assistance to Travelers (IAMAT) has indicated that air pollution in Sri Lanka is harmful to human life; because the annual mean concentration of $PM_{2.5}$ is exceeded the WHO guidelines[33] (IAMAT,2020).

In order to cope with the growing air pollution level, the Sri Lankan government has introduced several emission control policies. i.e., introducing low sulfur diesel in

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[32] Particular matter (PM); diameter is less than $10\mu m$

[33] The country mean concentration of $PM_{2.5}$ is $11\mu g/m^3$ and this rate is higher than the WHO recommended limits of $10\mu g/m^3$

2003, prohibiting the importation of two-stroke three-wheelers in 2008, and introducing compulsory emission tests for vehicles in 2008. Thus, there can be considered critical steps towards controlling vehicular emissions. More importantly, the government of Sri Lanka has introduced air quality standards, which had been set up under the National Environment regulations in 1994, and the standards were amended based on the 2005 WHO air quality guidelines (Nandasena, Wickremasinghe & Sathiakumar, 2010).

In this context, several studies in Sri Lanka have discussed the relationship between urban air pollution and respiratory health. Thishan and Coowanitwong (2008) have found that PM_{10} concentration in the Colombo city area has a robust relationship with three respiratory diseases among children; pneumonia, bronchiolitis, and emphysema, based on the health records of two national hospitals[34] in Colombo. In addition, they found that recorded asthma cases in two national hospitals in 2005 are attributed to high PM_{10} concentration in the Colombo city area. Another study done by Nandasena et al. (2012) has found a significant association between ambient NO_2 and the respiratory health of school children (age 7-10 years) living in an urban and semi-urban setting. More importantly, the prevalence of "persistent coughing" is higher among children living in urban areas than in semi-urban areas. However, no air pollution study in Sri Lanka covers mostly populated six districts to our best knowledge.

3.4.Methodology

3.4.1. Data sets

First, to measure the air quality, we collected monthly averaged 24-hour mean SO_2 readings from 67 air quality measurement centers scattered in highly air polluted areas in Sri Lanka, shown in Figure 3.2. These measurement centers are located in highly

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[34] The National Hospital of Sri Lanka (NHSL) and Lady Ridgeway Hospital (LRH)

contaminated urban areas in seven districts (Colombo, Gampaha, Kaluthara, Galle, Rathnapura, Kurunegala, and Kandy). In addition, NBRO has installed air pollution measurement centers through potentially air polluted spots such as heavy traffic highways under the vehicular emission control project in 2012 (NBRO, 2020). These measurement centers read the air quality by measuring the primary air pollutants such as SO_2, NO_2, and $PM_{2.5}$. We used only the monthly averaged 24 hours SO_2 readings for the primary analysis; because NO_2 concentration has shown a minimum variation within our selected sample areas, and $PM_{2.5}$ has shown missing values during the DHS survey period due to the lack of $PM_{2.5}$ measurement coverage. Afterward, we interpolated[35] the monthly averaged SO_2 using ArcGIS to extract the SO_2 values for the DHS cluster[36] indicated in the DHS sample.

<Figure. 3.2: Air quality measurement centers >

Secondly, this study's household data were obtained from the DHS-V (Demographic and Health Survey, Round V), which was conducted by the Department of Census and Statistics conducted in 2016. DHS is a nationally representative survey; describes unique health-related information of children 0-6 years old. The sampling procedure of DHS-V is based on a two-stage stratified sampling design. The first stage of sample design selects approximately 2500 enumeration clusters based on the population census in 25 districts. The second stage of selection practices systematic sampling that identifies 10-12 households within each cluster. The DHS in 2016 has covered 28,720

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[35] Please see note no.2 in Appendix I.

[36] Initially, we could not find the location (Latitude & Longitude) of clusters in the DHS 2016; however, we identified the central location of the smallest administrative unit (GN division) of each cluster by use of separate data which was obtained from the Department of Surveys in Sri Lanka. In particular, we identified the location of DHS clusters. During this process, we match the location of GN division corresponding to each cluster in the 2016 DHS.

housing units, and 27,455 units were successfully interviewed (Department of Census and Statistics [DCS], 2016). We selected two samples using ArcGIS based on the proximity from the household locations to air pollution measurement centers to ensure the accuracy of the pollution measures. In particular, we selected households living within a 5km and 10km radius of the air pollution measurement centers, shown in Figure 3.3[37]. We named those samples as 5km and 10km samples, containing 841 and 1675 children, respectively. The category of children in both samples is 0-6 years old, and they were interviewed from May to December in 2016.

<Figure 3.3: Selected DHS clusters from both 5km and 10km samples >

Finally, we collected rainfall data from the Department of Meteorology; rainfall is an essential confounding factor that alters the disease environment and affects a child's health. For instance, during the rainy periods, children in developing countries are more likely to suffer from water-borne diseases such as Cholera, leptospirosis, and typhoid fever during the rainy periods (Rocha & Sares, 2015). Therefore, we collected rainfall data from nearly 140 rainfall stations monitored by the Department of Meteorology corresponding to DHS 2016.

3.4.2.Summary statistics

Summary statistics of key variables are described in Table 3.1[38].

<Table 3.1: Summary statistics>

Panel A shows the outcome variable. For this variable, we used a dummy variable which takes the value one if a child had a cough with illness during the last two weeks before the interview. The average cough incidences within the 10km sample are 20%;

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[37] For instance, Atari et al., (2008) and Kurata et al., (2020) have used similar techniques and they developed buffer zones and matched these zones with household’s data sets.

[38] Summery statistics for 5km sample are exhibit in Table A2.1 in Appendix 2

hence, approximately one child out of five children suffered from cough two weeks before the interview. In addition, we considered the other respiratory disorders, such as asthma, and we identified any household member who showed asthma symptoms during the past 12 months. The results indicate that the average asthma incidence of the 10km sample is 17%.

Table 3.1, Panel B shows the primary independent variable, which takes value “one” if the ambient SO_2 concentration exceeds $50\mu g/m^3$ based on the WHO (2006) interim target 2. Indeed, 10% of households are exposed to SO_2 pollution on average during the survey period from May to December 2016. This level is higher for the 5km sample at 17% (Table A2.1 in Appendix 2). Also, we consider the other types of pollutants that potentially impact human respiratory disorders. In particular, we used monthly averaged 24 hour NO_2 (Nitrogen Dioxide) readings to estimate its mutual effect with SO_2 on respiratory disorders. For that purpose, we used continuous variables of NO_2 and a dummy variable based on the WHO’s annual NO_2 mean (i.e., “one” if the NO2 reading is exceeded the 40 μg/m3).

Descriptively, Figure 3.4 shows a non-parametric estimate for the relationship between the share of cough incidences recorded two weeks before the interview and the mean ambient SO_2 in a DHS cluster. The vertical line at the SO_2 being $50\mu g/m^3$ indicates the WHO Interim Target 2. Panel A shows the relationship, including the observations with extreme SO_2 pollution levels ($<=25\ \mu g/m^3$and $>=65\ \mu g/m^3$), while Panel B shows the relationship excluding those with extreme values. It suggests no relationship between the incidence of coughing and the SO_2 level as long as SO_2 pollution does not exceed the WHO interim target 2. When it exceeds the threshold, SO_2 pollution and respiratory health problems become positively correlated.

<Figure 3.4: The association between the share of coughing incidences >

Furthermore, this relationship is found only for relatively poor households in terms of the DHS wealth index, which is explained in detail below (Figure 3.5). It shows that the effect of meeting the WHO IT2 for the relatively poor (Panel A) is clear, while that for the rest of the group (Panel B) is not pronounced.

Panels C-H in Table 3.1 shows the other covariates used in this study. Panel C shows the child's characteristics, birth weight, gender, and age in months. Panel D shows the mother characteristics; total living children at home, mother's age, religion, ethnicity, and education qualifications. More specifically, most mothers are Buddhists and Sinhalese; 71% and 79% respectively. In addition, nearly half of the mothers completed an Advanced Level (AL) or qualified with a degree. For instance, 45% and 48% of mothers completed higher education in 5km and 10km samples, respectively. Panel E shows the indoor pollution indicators which are influenced by intrahousehold activities. We used these indicators to examine whether the estimated impact of SO_2 concentration is partly driven by indoor pollution correlated with the SO_2 contamination. In particular, we considered five dummy variables indicating households; (1) that used wood as their fuel source, (2) that cook inside the house, (3) where cooking smoke comes into the house, (4) where any member in the household has smoked, and (5) where a household member has smoked inside the house. Panel F shows the household wealth characteristics, wealth index scores, and wealth quintiles. We developed variables in Panel F to compare the living standards; because the DHS inadequately provides information relates to households' income. The original data in the DHS 2016 did not provide the wealth index; therefore, we developed a wealth index using households' property characteristics, which are similar to characteristics used by other DHS programs[39]. For this process, we followed a statistical method: Principal Component Analysis (PCA) that determined the aggregate measures of the wealth of households. We categorized households into four groups; the below 20%, the below 40%, the below 60%, and the below 80%. For instance, households in the first quintile represent the bottom 20% in terms of wealth index; households in the first and second quintiles represent the bottom 40%. Panel G shows the regional-specific and weather characteristics such as altitude and rainfall. Finally, Panel H shows the 20 property characteristics owned by each household, and we used these characteristics under the wealth indicator analysis described in section 3.5.2.

3.5.Empirical strategy

3.5.1. Basic specification

In order to estimate the overall association between ambient SO_2 pollution and respiratory health, we used the following fixed-effect models.

$$Cough_{ijg} = \beta_0 + \beta_1 D_{SO2(gm)} + \beta_2 X_{1(ijg)} + \beta_3 X_{2(ijg)} + \beta_4 X_{3(jg)} + \beta_5 X_{4(g)} + \eta_m + \theta_d + \epsilon_{ijgmd} \qquad \text{eq.3.1}$$

$Cough_{ijg}$ is a dummy variable, and it takes "one" if a child (i) in a household (j), GN division (g) had a cough. $D_{SO2(gm)}$ is a dummy variable it takes "one" if the SO_2 concentration is greater than 50μg/m^3 in GN division (g) in the surveyed month (m). Given the higher cough incidence in areas with the SO_2 concentration above this level, the dummy specification is likely to capture the impact of meeting the WHO IT2 flexibly. $X_{1(ijg)}$ is the child-specific controls of a child (i). $X_{2(ijg)}$ and $X_{3(jg)}$ are the mother

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[39] The selection of characteristics of DHS is relatively straightforward to construct the wealth index, and usually choose household assets, utility services, and country-specific items (Rustein & Johnson,2004)

and household specific control variables, respectively, for child (i). $X_{4(g)}$ is the weather-related controls such as rainfall experienced by child (i). The η_m is the fixed-effects for the surveyed month (m), capturing the time-variant characteristics. The θ_d is the fixed-effect for DS division [40]which captures the time-invariant features of DS division such as healthcare facilities. ϵ_{ijgmd} is the idiosyncratic error term, clustered at GN division.

3.5.2. Specification for the heterogeneity analysis

Moreover, we used the following specification to estimate the heterogeneity in the impact of air pollution across different wealth groups.

$$\begin{aligned} Cough_{ijg} = \beta_0 + \beta_1 \mathrm{D}_{\mathrm{SO2(gm)}} + \beta_2 \mathrm{below20\%}_j + \beta_3 \mathrm{D}_{\mathrm{SO2(gm)}} * \mathrm{below20\%}_j + \\ \beta_4 \mathrm{below40\%}_j + \beta_5 \mathrm{D}_{\mathrm{SO2(gm)}} * \mathrm{below40\%}_j + \\ \beta_6 \mathrm{below60\%}_j + \beta_7 \mathrm{D}_{\mathrm{SO2(gm)}} * \mathrm{below60\%}_j + \\ \beta_8 \mathrm{below80\%}_j + \beta_9 \mathrm{D}_{\mathrm{SO2(gm)}} * \mathrm{below80\%}_j + \\ \beta_{10} X_{1(ijg)} + \beta_{11} X_{2(ijg)} + \beta_{12} X_{3(jg)} + \beta_{13} X_{4(g)} + \eta_m + \theta_d + \epsilon_{ijgmd} \end{aligned}$$

eq.3.2

For equation 3.2, we additionally used several dummy variables such as the $\mathrm{below20\%}_j$, the $\mathrm{below40\%}_j$, the $\mathrm{below60\%}_j$, the $\mathrm{below80\%}_j$ and their interactions with the SO_2 pollution dummy. In particular, we estimated the coefficient for the reference group (i.e. if $\mathrm{D}_{\mathrm{SO2(g)}}$ =0) based on the β_1, and for rest groups (i.e. if $\mathrm{D}_{\mathrm{SO2(g)}}$ =1) by adding the β_1 into the respective co-efficient of interaction terms; $\beta_3, \beta_5, \beta_7$ and β_9.

3.5.3. Specification for testing the correlation between outdoor and indoor pollution

Households are more likely to be affected by ambient air pollution and indoor air pollution simultaneously (Lan et al.,2012; Liu et al.,2013 & Kurata et al.,2020). Therefore, we examined whether indoor pollution characteristics are co-related with the SO_2 dummy

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[40] Divisional Secretariat (DS) is the aggregate level of villages known as the GN (Grama Niladari) divisions, the smallest administrative unit of Sri Lanka.

variable. The econometric model is shown in equation 3.3.

$$Y_{jg} = \beta_0 + \beta_1 \mathrm{D}_{\mathrm{SO2(g)}} + \beta_2 X_{1(ibjg)} + \beta_3 X_{2(jg)} + \beta_4 X_{3(jg)} + \beta_5 X_{4(g)} + \eta_m + \theta_d + \epsilon_{ibjgmd} \quad \text{-eq. 3.3}$$

Where, Y_{jg} is indoor pollutant characteristics of household (j), GN division (g). We identified five indoor pollution characteristics that affect the indoor air quality of households; (1) 1 if a household uses woods as the main fuel source and 0 other sources (i.e.electricity, gas) (2) 1 if cooking is done inside the house or 0 otherwise. (3) 1 if cooking smoke comes into the house and 0 otherwise. (4) 1 if any household member smokes tobacco or 0 otherwise. (5) 1 if smoking is allowed inside the house and 0 otherwise. All other variables are similar to equation 3.1.

3.5.4. IV specification

Based on the previous literature, the potential endogeneity issues of air pollution are addressed using the IV approach (Chen & Kan, 2008; He et al.,2016, and Kurata et al., 2020). Indeed, it is doubtful to assume that air pollution is randomly assigned across the study area for several reasons. First, households living in low economic settings receive relatively low nutrients; therefore, their health could be weak. As a result, the estimation could be biased upward. On the other hand, households who receive a high income have good health conditions though living in a polluted location. Therefore, results could be biased downwards. Finally, the pollution variable of this study is derived from the interpolation techniques based on the ArcGIS software; thus, models specified above are likely to suffer from measurement errors such as ignorance of non-linear features of air pollution distribution. Therefore, our estimations could be affected by the attenuation bias.

To deal with these potential endogeneity issues, we apply the Instrumental Variable (IV) analysis using the altitude of household location as the IV for the air pollution dummy. We assumed that this altitude of the household location impacts child respiratory health only through the ambient SO_2 concentration, and it does not directly impact the child's health[41]. The first stage estimation of IV is shown in equation 3.4.

$$\mathrm{D}_{\mathrm{SO2(g)}} = \beta_0 + \beta_1 Alt_g + \beta_4 X_{1(ijg)} + \beta_5 X_{2(jg)} + \beta_6 X_{3(jg)} + \beta_7 X_{4(g)} + \eta_m + \theta_d + \epsilon_{ibjgmd} \qquad \text{eq.3.4.}$$

Where $\mathrm{D}_{\mathrm{SO2(g)}}$ is the dummy variables similar to equation 1. Alt_g is the altitude of the GN division (g). All other variables are similar to equation 3.1

3.6. Results

3.6.1. Result based on the linear specification

First and foremost, we examined the general relationship between the air pollution variable and the cough incidences of children using the linear specification for the pollution variable. In particular, we utilized equations 3.1 and 3.2, replacing the continuous SO_2 instead of the SO_2 dummy variable. The results are shown in Table 3.2.

<Table 3.2: SO_2 pollution effects (Continuous) on cough for 10km sample>

Based on Table 3.2 Panel A column 1, the relationship between cough and the ambient SO_2 is negative and insignificant. Also, we found insignificant results for each wealth group in panel B. However, in Panel B columns 2 and 3, we found a positive relationship

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[41] Several studies have used wind speed as an IV to address the possible endogeneity issues of air pollution (i.e., Gu et al., 2019; Zhang et al., 2020). However, we received a weak F-test value for first-stage regression when using wind speed, possibly due to the low sample size of this estimation. Therefore, we select altitude as our second-best solution to select as an IV for this estimation.

for the bottom 20% and 40% groups, and it is consistent with our main estimation shown in Table 3.3 described in section 3.6.2. These results, together with the non-linear relationship between the cough incidence and the level of SO_2 (Figure 3.4), suggested that linear specification does not fit the data very well. Thus, we investigate the dummy specification (equations 3.1 and 3.2) next.

3.6.2. Main results

Tables 3.3 shows the results obtained from the dummy specification. The results are shown for the 10km sample only, as the results are substantially similar for the 5km sample, shown in Table A2.2 in Appendix 2.

<Table 3.3: SO_2 pollution effects on cough for 10km sample>

Table 3.3, column 1 shows the overall association between ambient SO_2 pollution and children's respiratory health, obtained from equation 3.1. Column 1 indicates results excluding the interactions of wealth dummies with the SO_2 pollution dummy. Based on the un-interacted results of column 1, the overall association is positive and insignificant. Columns 2 to 7 show the results based on different forms of equation 3.2, and column 8 shows the complete version of equation 3.2. More importantly, Panel A, columns 2 to 5, shows the pollution effect for the reference group. Panel B, columns 2 to 5, indicates the additional coefficients for the rest group. (i.e., the summation of the coefficient of D_{SO2} and its interaction with the respective wealth dummy). For instance, in column 2, the effect of SO_2 pollution for the reference group (below 20%=0) labels the coefficient of D_{SO2}, and the estimated SO_2 pollution effect for the rest group (below 20%=1) indicates the total of D_{SO2} and its interaction with below 20% (i.e., D_{SO2} * below 20%). Therefore, the pollution effect on the children represented in the bottom 20% (poor) is 19 percentage

points, and it is significant at 1% level (Shown in Panel B Column 2). Also, the coefficient for the reference group (below 20%=0) shown in Panel A indicates that the relatively wealthy children are not sensitive to the effect of SO_2 pollution. Likewise, Panel B, Column 3, shows the effect of ambient SO_2 for the second most inferior group (i.e., the below 40%). For instance, children exposed to high SO_2 pollution ($>50\mu g/m^3$) lead to increased respiratory illnesses by 10 percentage points, significant at 10%. However, this association is weaker for the bottom 60% and bottom 80% groups shown in columns 4 and 5 in Panel B, respectively. Therefore, the effect of SO_2 pollution is more likely reduced among rich children.

Table 3.3, Column 6 shows the effect of SO_2 pollution, including below 20% and 40% groups. Likewise, column 7 shows the SO_2 effect, including three groups; below 20%, 40, and 60%, and lastly, column 8 shows the SO_2 effect for all groups, including below 20%,40%, 60%, and 80% groups. In addition, Panel B, columns 6-8, shows the estimated effect of SO_2 on the below 20% of groups and intermediate groups (i.e., between 20-40%, 40-60%, and 60-80%). Based on Panel B column 6, the estimated SO_2 pollution effect for the group below 20% is the sum of the first co-efficient (D_{SO2}), and its interactions of wealth dummies (I,e., D_{SO2} * below 20%, and D_{SO2} * below 40%). Likewise, in Panel B, columns 7 to 8 show the pollution effect below 20% (the summation of the first coefficient and the respective interactions). On this basis, Panel B Columns 6-8 shows the effect of SO_2 pollution among the below 20% group is consistent with the results in Panel B Column 2; because the p-value (<0.05) in columns 6,7 and 8 is significant for the bottom 20% group. In addition, the effect of SO_2 across the intermediate groups is insignificant; because the estimated P-values for groups; 20-40%, 40-60%, and 60-80% shown in Panel B, columns 6-8 are higher than the 0.05. Therefore, poor households show respiratory health problems when ambient air pollution exceeds the threshold; however, the wealthy groups are less likely to affect ambient air pollution. These results are consistent with Grag (2011), who found a similar relationship using PM_{10}, and he found that poor households are more likely to be exposed to ambient air pollution than medium and high-income groups in India. The possible explanation is, poor households attribute low income; thus, they have less attention to the environment that can affect their health status in many developing countries (He et al., 2016).

In addition, the results for the 5km sample are also likely unchanged with the 10km sample shown in Appendix Table A2.2. In particular, Panel A, column 1 indicates that the overall relationship between ambient SO_2 pollution and respiratory health is insignificant, including all the controls. This result is consistent with the 10km sample; however, the direction of association is negative and biased downward. This bias could be due to the increase of measurement errors relative to the 10km sample. However, in Panel B column 2, the estimated SO_2 pollution effect for the poor children is more likely similar to the 10km sample and significant at 5% level.

3.6.4. Analysis for testing the correlation between outdoor and indoor pollution

In this analysis, the results of equation 3.3 are shown in Table 3.4 for both samples.

<Table 3.4: Relationship between SO_2 and indoor air pollution characteristics>

The results in Table 3.4 show that the indoor pollution levels are not significantly different between areas below and above the WHO’s recommended level of SO_2. These results suggested that indoor pollutants do not spuriously drive the main results described in section 3.6.2.

3.7.Robustness check:

This section explains several robustness checks for our estimates. First, we used an

Instrumental Variable (IV) approach to address the possible endogeneity concerns in our OLS estimation discussed in Section 3.6.2. Secondly, we check the results controlling other pollutants (i.e., Nitrogen Dioxide; NO_2). Thirdly, we checked our results for selective migration, restricting the sample for non-migrants. Fourthly, we tested the validity of our estimation by controlling the initial health condition of children. Finally, we examined the effect of ambient air pollution on other serious types of respiratory health issues (i.e., asthma) at the household level.

3.7.1.IV estimation

The first stage regression in IV estimation is shown in Table 3.5.

<Table 3.5: First stage estimation >

Table 3.5 indicates that higher altitudes significantly lower air pollution, consistent with Ha (2017). For instance, column 6 shows that an increase of altitude by 100 meters[42] leads to lowering SO_2 pollution effect by three percentage points, which is significant at 1%. This analysis uses the same set of controls and fixed effects in the OLS estimation described in section 3.6.2. In particular, column 1 shows the effect of altitude on the SO_2 pollution excluding all the controls and fixed effects. Columns 2 to 4 show the results, including controls, one by one. Indeed, we control the potential confounding factors associated with child, mother, and household characteristics from columns 2 to 4. In addition, columns 6 to 7 show the results, including fixed effects. F statistics are different based on the changes of control and fixed effect from columns 1 to 7. It ranges between 3.8 and 26.6, partly due to the small sample size and the set of control variables. It fell

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[42] The altitude is recorded in meters; thus, the regression coefficient was too small to interpret. For interpretation purposes, we divided altitude by 100.

below ten when the DS division[43] fixed effect is included. This could be due to the low variation of ambient SO_2 pollution within DS divisions.

The results for second-stage regression are shown in Table 3.6, and these findings are consistent with Table 3.3.

<Table 3.6 Second stage estimation >

From columns 1 to 6, as more control variables adding to the specification, the relationship is unchanged. More importantly, column 6 shows the estimates, including controls, except the DS division fixed effect. The results indicate that an increase of SO_2 pollution above the threshold leads to an increase in the incidence of coughing by 54 percentage points, and it is significant at 5%. Therefore our IV estimates are consistent with the OLS estimates that described in Table 3.3. In addition, the OLS estimates in Table 3.3 Column 1 shows an insignificant relationship between SO_2 pollution and children's respiratory health, indicating that the OLS estimates used in this study are underestimated. Therefore, we possibly conclude that the results of our study are more reliable based on empirical strategy.

3.7.2. Robustness against controlling for NO_2 concentration

In this analysis, we considered the potentially important other air pollutants that contribute to respiratory disorders. For example, we used Nitrogen Dioxide (NO_2) concentration to identify its mutual effect with SO_2 pollution. However, we found a limitation of the NO_2 data sample that possibly impacts our estimation; because NO_2 variation is relatively low in contrast to SO_2 pollution. For this analysis, we constructed continuous and dummy variables based on the interpolated NO_2 readings. In order to

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[43] DS divisions are the sub administrative units of districts

construct the NO_2 dummy variable, we selected WHOs' recommended annual mean, which is 40 $\mu g/m^3$ (i.e., "one" if the NO_2 reading is greater than the recommended annual mean). Finally, the effect of both pollutants on respiratory health is estimated by continuous and the dummy specifications of equation 3.1. The results are shown in Table 3.7.

<Table 3. 7: Robustness against controlling for NO_2 concentration>

Panels A and B in Table 3.7 show the estimates obtained from continuous and dummy specifications, respectively. The results in panels A and B are insignificant; thus, the mutual effect of other gaseous pollutants is less likely associated with this study.

3.7.3.Test for selective migration

This section concerns another possible bias related to selective migration. If wealthy households migrate to potentially low air polluted areas from polluted areas before the survey period, the estimates could be underestimated. Therefore, we excluded the children who migrated before the survey period. As a result, 326 observations (19%) are dropped from the baseline 10km sample. The results shown in Table 3.8 indicate that the main conclusion is unchanged. For example, the magnitude of the coefficient for the bottom 20% is likely unchanged among the non-migrants. Therefore, results suggested that our results are robust and not confound with the selective migration. However, the significance of the bottom 40% group is dropped in this estimation due to the potential attenuation bias.

<Table 3.8: SO_2 pollution effect on cough for 10km sample (for non-migrants)>

3.7.4. Robustness against controlling for birth weight

Finally, we considered the omitted variables bias to test the validity of the estimation. The common practice to test the omitted variable bias is to examine coefficient changes after incorporating observed variables into the specification (Oster, 2019). Therefore, we controlled the birth weight; because it is considered a proxy for examining health conditions (Hoynes, 2016). In addition, our results could be biased downward; if healthier children live in a polluted area or vise versa. Thus, controlling the birth weight is a vital practice in this setting. We observed several missing birth weight records in our samples; therefore, we dropped 153 observations from the 10km sample. The results obtained from equation 3.2 are shown in Table 3.9.

<Table 3.9: SO_2 pollution effect on cough for 10km sample (including birth weight controls)>

Table 3.9 suggests that the effect of SO_2 pollution on child health is likely unchanged with Table 3.3. For instance, Panel B column 2 indicates that the increase of SO_2 pollution above the threshold leads to an increase of coughing by 21 percentage points, and it is significant at a 5% level for the bottom 20% group. This result is consistent with the first set of coefficients indicated in Panel B columns 6 to 8, and P-values are less than 0.05. Therefore, overall, our results are less likely to confound by omitted variable bias.

3.7.5. Effect of air pollution on other respiratory disorders (for 10km sample)

In this analysis, we examine other respiratory disorders that result from ambient air pollution. Because our primary outcome variable, coughing incidences could be caused by various factors such as diseases. Therefore, we identified the number of asthma cases recorded in each household during the last 12 months when the DHS survey was conducted. In particular, we use continuous and dummy specifications based on the WHO’s interim target 2.

<Table 3. 10: Effect of air pollution on asthma for 10km sample>

The results are shown in Table 3.10. Mainly, panels A and B show the estimates obtained from continuous and dummy specifications, respectively. The overall results show a weaker association between air pollutants and asthma cases. In addition, the coefficient of NO_2 dummy in Panel B is significant at the 10% level; however, the direction is negative. Similarly, we found a weaker association for the heterogeneity analysis for asthma cases relative to cause incidences among children. Therefore, the effect of air pollution on cough incidences of early ages is more substantial relative to self-reported asthma cases in this study.

3.8.Summary and conclusion

Ambient air pollution has become a severe threat to human life. This study examined the effect of urban ambient air pollution on respiratory health in Sri Lanka, mainly focusing on the early ages. In particular, we used ambient SO_2 concentration and its WHO's recommended levels (interim targets 2). To our best knowledge, this is the first study using SO_2 interim target in the air pollution literature. This study finds that children living in poor households are more vulnerable to ambient air pollution than wealthy households and found no association between ambient and indoor pollution. Moreover, this study has investigated the mutual effects of air pollutants on cough incidences and the effect of air pollution on other types of respiratory disorders such as asthma. The results found no significant co-relation.

Finally, this study has attempted to address several risks for the estimation, such as endogeneity concerns, selective migration, and children's health conditions, by conducting several robustness checks.

Chapter 4

Conclusion

4.1. Summary and findings

This dissertation provides empirical evidence on the impact of environmental shocks on human capital development, focusing on developing context. In particular, this dissertation presents two separate studies related to the effect of natural and artificial shocks in the environment on child health in Sri Lanka. The first empirical chapter explains the effect of rainfall shocks experienced in utero on birth weight using nationally representative Demographic and Health Surveys (2006/2016) and the rainfall data. The second empirical chapter explains the effect of urban air pollution on child respiratory health using Demographic and Health Survey-2016 and the Sulfur Dioxide (SO_2) emissions data. Both main chapters of this dissertation consider the heterogeneity in the impact of environmental shocks across various socio-economic groups in Sri Lanka.

The results in the first empirical chapter revealed that the increase of rainfall from the historical rainfall during the gestational period has mixed effects on birth outcomes dependent on the context. The first empirical chapter results indicate that the increase in rainfall shock during the first trimester increases the birth weight of children living in rural/plantation sectors. In addition, rainfall shocks experienced in the third trimester decrease the birth weight of children living in the urban sector.

The results in the second analytical chapter indicate that the children living within 10km radius of the air pollution measurement centers showed a significant association between ambient SO_2 pollution and incidence of coughing. Also, the results further explain that this relationship is concentrated only among the poor household, measured by the DHS wealth index.

4.2. Policy implications and directions for future research

The first empirical study provides several policy implications. More specifically, this study identified several groups sensitive to rainfall shocks (i.e., poor households in the rural and estate sectors). Therefore, it is crucial to identify those groups and protect them from environmental shocks through effective policy interventions. In particular, this study recommended; (1) restructuring the existing nutrient supplement programs targeting pregnant mothers in the rural and estate sectors. For instance, Sri Lanka currently has a pre-natal nutrient supplement program for all pregnant mothers named the *Thriposha* program, which governs the Medical Officers of Health (MOH) centers. This program provides two packets (750g) of nutrient supplements per month for pregnant mothers (Sri Lanka Thriposha LTD, 2020). Based on the findings of this study, we suggest increasing the provision of the number of nutrient supplement packets for sensitive pregnant mothers living in rural/estate settings after a re-assessment of nutrient needs during their pregnancy period. (2) Introduction of awareness programs during the third trimester of pregnant mothers in the urban sector explaining the associated adverse effect of rainfall. Because rainfall brings diseases such as dengue fever in an urban setting, if a pregnant mother is infected with a disease during the third trimester, this would negatively affect their babies' birth weight. (3) Targeting the mothers with male fetuses in an urban setting and providing awareness to protect them from diseases. Indeed, our results suggested a negative relationship between third-trimestral rainfall shocks and the birth weight of boys in the urban setting, and we explain the mechanism through the disease channel. Thus, if parents are more aware of male fetuses' sensitivity for diseases during the third trimester, they can pay special attention during the adverse conditions to protect them from water-related diseases.

The second empirical chapter has highlighted the prioritizing of child health issues in Sri Lanka's urban setting. Therefore, targeting the children living in poor livelihood settings is more important to protect them from adverse environmental consequences such as air pollution. In this context, this study has attempted to review the present Air Quality Guidelines in Sri Lanka under the condition which the growing number of emission sources; thus, we highlighted the importance of government interventions for achieving the WHO interim targets introduced in 2005 as a feasible solution by regulating the emissions. For instance, currently, the Sri Lankan government regulates the emissions of vehicles through an annual testing program. However, this strategy is not succeeded in meeting the air quality standards. Therefore, the government needs to implement a frequent emission testing program with less than a year (i.e., Bi-annual vehicle testing program) for potentially high emission old vehicles. Also, the findings of the second empirical chapter highlighted the importance of sound awareness of air quality through an alert system. For instance, this chapter proposed introducing a mobile application to check the real-time air pollution in potentially high polluted city areas. In particular, households living in an urban setting can prepare for the air pollution risk by minimizing their exposure to air pollution during peak hours. In addition, the improvement of the capacity of low-income groups to cope with air pollution is essential. These interventions can be done along with the existing poverty alleviation programs such as ”Samurdhi” by providing healthcare advice for needy households living in polluted areas.

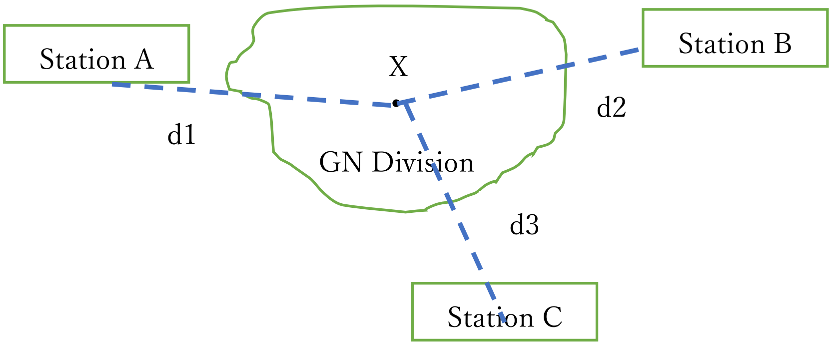
The findings of the second empirical study suggest several proposals for future research. This chapter selected gaseous pollutants due to the limitation of data. Therefore, it is vital to investigate the impact of multiple air pollutants (i.e., particulate matter) simultaneously on various health outcomes rather than selecting one or two pollutants at a selected period. Thus, these types of future research can understand the comparative effect of air pollutants on human health.

Appendix 1

1. Note for cleaning of data:

In this study, we prepared standardized rainfall shock variables for each trimester in utero. During this process, we observed that the birthdates of babies were randomly fallen in months. For instance, some of the birth dates were fallen early in the month, and some were late. Thus, to improve the accuracy of the rainfall shock variable, we obtained the average rainfall of the birth month and the previous month if the interview has been conducted before the 15th of the month. Furthermore, we obtained birth month rainfall if the baby was born 15th or later; i.e., if a baby was born on the 6th of October 2006, we considered the average rainfall in August and October as the birth month's rainfall. Moreover, if the baby was born on the 20th of October 2006, we calculated the rainfall in October 2006 as the birth month rainfall. We imported GIS coordinates of each rainfall station to Arc-GIS in this process, and average monthly rainfall for missing areas was estimated using IDW (Inverse Distance Weighting) interpolation techniques.

IDW is a popular technique for calculating the rainfall in missing areas from the observed rainfall measurement stations. First, the values of observed rainfall stations are given unique weight according to the proximity from the centroid location of the DHS cluster. For example, the following diagram demonstrates the calculated amount of rainfall of a GN division (X) based on the known rainfall amount of rainfall measurement stations; A, B and B. The distance from the centroid of GN division to rainfall stations A, B, and C are d1, d2, and d3, respectively.



$$\text{Value of unknown point } X = (\frac{X}{d_1^2} + \frac{X}{d_2^2} + \frac{X}{d_1^2})/(\frac{1}{d_1^2} + \frac{1}{d_2^2} \frac{1}{d_3^2})$$

After that, the rainfall values were extracted into DHS clusters separately using the extraction function of ArcGIS. Each DHS cluster represents 10-12 households, and they received a common rainfall amount, which is identical to a DHS cluster. On this basis, rainfall shock variables in each trimester were calculated.

2. Note for the interpolation and extraction of air pollution data:

The joining of household and air pollution data is an essential practice of this study. First, we estimated the SO_2 values for the rest of the areas where air pollution measurement centers were not installed. For this purpose, we used the Inverse Distance Weighting (IDW) method; because IDW can adequately reflect the missing areas from the measured ambient SO_2 pollution (Atari et al., 2008) (Please find the explanation for the IDW described in note no.1 in Appendix I). Secondly, the clusters in DHS 2016 were added to the interpolated SO_2 estimates, and we identified the households within 5km and 10km radius of the air pollution measurement centers. During this process, we matched the survey month and the corresponding SO_2 pollution levels. Finally, the interpolated SO_2 values are extracted to the DHS clusters, and we assigned a unique SO_2 value for each cluster.

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Tables

Table 2. 1: Summary statistics

Variables	Obs	Mean	Std. Dev.
A. Outcome variables			
Birth Weight (g)	12,444	2897.499	480.145
B. Rainfall shock variables			
Standerdised Rainfall in 1st Trimester	12,444	0.067	1.806
Standerdised Rainfall in 2nd Trimester	12,444	-0.050	1.694
Standerdised Rainfall in 3rd Trimester	12,444	0.024	1.692
Extream positive shocks in 1st Trimester	12,444	0.147	0.354
Extream positive shocks in 2st Trimester	12,444	0.124	0.329
Extream positive shocks in 3st Trimester	12,444	0.131	0.337
Extream negative shocks in 1st Trimester	12,444	0.104	0.305
Extream negative shocks in 2st Trimester	12,444	0.109	0.312
Extream negative shocks in 3st Trimester	12,444	0.102	0.302
C. Child characteristics			
Sex(1-Male/0-Female)	12,444	0.510	0.49
1 if the baby has multiple births (twins or triplets)	12,444	0.017	0.128
D. Mother characteristics			
Total living children at home	12,444	2.051	1.002
Age (years)	12,441	31.406	5.999
1 if mother experienced miscarriage, abortion or still birth	12,441	0.162	0.369
1 if no primary education	12,444	0.095	0.293
Religion (1 if Buddhist)	12,443	0.691	0.462
Ethnicity (1 if Sinhalese)	12,443	0.740	0.439
E. Household characteristics			
1 if used piped drinking water	12,444	0.794	0.404
1 if used piped water for cooking	12,444	0.789	0.408
1 if used improved toilet facilities	12,425	0.945	0.229
1 if the household has electricity	12,439	0.899	0.302
1 if the household has a radio	12,440	0.728	0.445
1 if the household has a television	12,442	0.853	0.354
1 if the household has a mobile phone	12,430	0.703	0.457

1 if the household has a refrigerator	12,438	0.490	0.500
1 if household used electricity as main fuel type	12,444	0.265	0.441
1 if the household owns the land for agriculture	12,440	0.321	0.467
1 if households fall in the bottom 40% of the wealth index	12,444	0.609	0.488
1 if households fall in upper 60% of wealth index	12,444	0.391	0.488
F. Regional characteristics			
1 if household in the urban sector	12,444	0.177	0.382
1 if household in the rural sector	12,444	0.749	0.433
1 if household in the estate sector	12,444	0.073	0.261
The altitude of household location (meters)	12,444	209.087	360.595

Table 2. 2: Impact of rainfall shocks in utero on birth weight

	(1)	**(2)**	**(3)**	**(4)**	**(5)**
VARIABLES	**Birth weight**	**Birth weight**	**Birth weight**	**Birth weight**	**Birth weight**
Trimester 1	7.031**	8.161***	8.264***	8.326***	7.661
	(2.963)	(2.737)	(2.697)	(2.677)	(5.922)
Trimester 2	1.394	0.114	-0.0367	0.684	-1.935
	(3.052)	(2.853)	(2.839)	(2.805)	(6.390)
Trimester 3	-0.500	-0.320	-0.288	-0.261	-0.515
	(2.979)	(2.740)	(2.715)	(2.682)	(5.924)
Constant	2,912***	2,917***	2,602***	2,863***	2,146***
	(47.84)	(43.92)	(52.68)	(56.40)	(247.8)
Observations	12,444	12,444	12,439	12,395	12,395
R-squared	0.025	0.057	0.074	0.091	0.076
District fixed effect	Yes	Yes	Yes	Yes	No
Survey year fixed effects	Yes	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes	Yes
Birth month fixed effect	Yes	Yes	Yes	Yes	Yes
Child characteristics	No	Yes	Yes	Yes	Yes
Mother characteristics	No	No	Yes	Yes	Yes
Household characteristics	No	No	No	Yes	Yes
Mother fixed effect	No	No	No	No	Yes

Notes: This is based on the author's calculations. For this analysis, we used the 2006 DHS and 2016 DHS samples collectively. Standard errors are shown in the brackets and clustered at GN ("Grama Niladari") level. *** Significant at 1 percent, ** Significant at 5 percent, * Significant at 10 percent.

Table 2. 3: Impact of extreme rainfall shocks in utero on birth weight

	(1)
VARIABLES	**Birth weight**
Trimester 1 (Extreme positive)	23.22*
	(12.59)
Trimester 2 (Extream positive)	-6.183
	(13.32)
Trimester 3 (Extream positive)	9.829
	(13.07)
Trimester 1 (Extream negative)	-31.88**
	(14.42)
Trimester 2 (Extream negative)	5.267
	(14.72)
Trimester 3 (Extream negative)	-4.100
	(14.58)
Constant	2,863***
	(57.42)
Observations	12,395
R-squared	0.091

Notes: This table is based on the author's calculation. For this analysis, we pooled the samples of the 2006 DHS and 2016 DHS. Standard errors are shown in brackets and clustered at the GN level. The main explanatory variables in this analysis are the extreme rainfall shock variables (floods/ droughts). In addition, we used several fixed effects; district fixed effect, survey year fixed effect, birth year fixed effect, and birth month fixed effect. Control variables include child-specific controls, mother-Specific controls, and households with regional controls. ** Significant at 1 percent, **Significant at 5 percent, *significant at 10 percent.

Table 2. 4: Impact of rainfall shocks in utero on birth weight by sectors

VARIABLES	**(1)** **Birth Weight**
Panel A	
Trimester 1	8.414***
	(2.870)
Trimester 2	-1.281
	(3.037)
Trimester 3	2.192
	(2.968)
Urban	1.876
	(14.01)
Urban * trimester 1	-1.292
	(6.121)
Urban * trimester 2	10.58
	(6.694)
Urban * trimester 3	-13.50**
	(6.259)
Constant	2,861***
	(56.55)
Observations	12,395
R-squared	0.091
Panel B	
Trimester 1 (Urban)	7.122
	(5.773)
Trimester 2 (Urban)	9.299
	(6.221)
Trimester 3 (Urban)	-11.34**
	(5.629)

Notes: This table is based on the author's calculation. For this analysis, we combined the samples of the 2006 DHS and 2016 DHS. Standard errors are shown in brackets and clustered at the GN level. Panel A shows the results, including rainfall shock variables and their interactions with sector dummies. In addition, this table used fixed effects, district fixed effect, survey year fixed effect, birth year fixed effect, and birth month fixed effect. Control variables include child-specific controls, mother-specific controls, and households with regional-specific controls. Panel B shows the estimated co-efficient for rural & estate sectors. *** Significant at 1 percent, ** significant at 5 percent * Significant at 10 percent.

Table 2. 5: Impact of rainfall shocks in utero on birth weight, by gender

VARIABLES	**(1)** **Birth weight**	**(2)** **Birth weight in Urban**	**(3)** **Birth weight in Rural &Estate**
Panel A			
Trimester 1	8.469**	11.18	7.971**
	(3.617)	(9.198)	(3.935)
Trimester 2	-0.481	12.47	-3.519
	(3.686)	(8.953)	(4.124)
Trimester 3	-5.116	-2.989	-5.025
	(3.693)	(9.034)	(4.071)
Boys	36.97***	36.86*	37.18***
	(8.280)	(20.53)	(9.047)
Boys * trimester 1	-0.120	-6.784	1.034
	(4.671)	(11.81)	(5.047)
Boys * trimester 2	2.215	-12.29	5.050
	(4.951)	(12.33)	(5.511)
Boys * trimester 3	9.789*	-18.72	15.55***
	(5.040)	(12.06)	(5.598)
Constant	2,827***	2,737***	2,842***
	(56.35)	(139.2)	(62.52)
Observations	12,395	2,199	10,196
R-squared	0.091	0.092	0.092
Panel B: Calculated estimates for boys			
Trimester 1 (Boys)	8.589**	4.400	9.005**
	(3.490)	(8.330)	(3.833)
Trimester 2 (Boys)	1.734	0.18	1.531
	(3.796)	(9.369)	(4.160)
Trimester 3 (Boys)	4.673	-21.70***	10.52**
	(3.670)	(8.232)	(4.142)

Notes: This table is based on the author's calculation. For this analysis, we combined the samples of the 2006 DHS and 2016 DHS. Standard errors are shown in brackets and clustered at the GN level. Panel A shows the results, including rainfall shock variables and their interactions with gender dummies. In addition, this table used fixed effects, district fixed effect, survey year fixed effect, birth year fixed effect and birth month fixed effect. Control variables include child-specific controls, mother-specific controls, and households with regional-specific controls. Panel B shows the estimated co-efficient for rural & estate sectors. *** Significant at 1 percent, ** significant at 5 percent * Significant at 10 percent.

Table 2. 6: Impact of rainfall shocks in utero on birth weight, by wealth structure

	(1)	(2)	(3)
VARIABLES	**Birth Weight**	**Birth Weight in urban sector**	**Birth Weight in rural & estate sector**
Panel A			
Trimester 1	6.515*	9.122	5.226
	(3.403)	(7.053)	(3.887)
Trimester 2	4.775	6.992	2.867
	(3.603)	(8.024)	(4.076)
Trimester 3	-1.000	-7.027	1.029
	(3.406)	(6.960)	(3.934)
Bottom 40%	-30.97**	-7.806	-31.78**
	(13.97)	(32.57)	(15.56)
Bottom 40%*Trimester 1	10.54**	-7.522	13.30***
	(4.630)	(13.06)	(5.033)
Bottom 40%*Trimester 2	-4.193	-8.632	-2.005
	(5.306)	(15.32)	(5.734)
Bottom 40%*Trimester 3	6.446	-27.02**	9.078
	(5.283)	(12.88)	(5.833)
Constant	2,858***	2,730***	2,887***
	(54.17)	(134.9)	(59.80)
Observations	12,395	2,199	10,196
R-squared	0.083	0.085	0.083
Panel B: Calculated estimates for poors			
Trimester 1 (bottom 40%)	17.06***	1.600	18.52***
	(3.967)	(12.33)	(4.177)
Trimester 2 (bottom 40%)	0.582	-1.640	0.862
	(4.395)	(13.89)	(4.625)
Trimester 3 (bottom 40%)	5.447	-34.05***	10.11**
	(4.295)	(11.82)	(4.575)

Notes: This table is based on the author's calculation. For this analysis, we pooled the samples of the 2006 DHS and 2016 DHS. Standard errors are shown in brackets and clustered at the GN level. Panel A shows the results, including rainfall shock variables and their interactions with the bottom 40% of the wealthy (poor) dummy. In addition, we used several fixed effects; district fixed effect, survey year fixed effect, birth year fixed effect, and birth month fixed effect. Control variables include child-specific controls, mother-Specific controls, and households with regional controls. Panel B shows the calculated estimates for the poor population. *** Significant at 1 percent, **Significant at 5 percent, *significant at 10 percent.

Table 2. 7:Impact of extreme rainfall shocks in utero on birth weight, by sectors

	(1)	**(2)**
VARIABLES	**Birth weight in Urban Sector**	**Birth weight in Rural/Estate Sectors**
Trimester 1 (Extream positive)	48.68*	17.44
	(29.33)	(13.94)
Trimester 2 (Extream positive)	13.82	-11.37
	(32.33)	(14.64)
Trimester 3 (Extream positive)	-18.94	15.36
	(29.97)	(14.54)
Trimester 1 (Extream negative)	17.85	-39.19**
	(36.46)	(15.63)
Trimester 2 (Extream negative)	36.19	-0.280
	(33.96)	(16.17)
Trimester 3 (Extream negative)	65.95*	-22.52
	(34.55)	(16.16)
Constant	2,788***	2,886***
	(139.6)	(63.76)
Observations	2,199	10,196
R-squared	0.090	0.091

Notes: This table is based on the author's calculation. For this analysis, we pooled the samples of the 2006 DHS and 2016 DHS. Standard errors are shown in brackets and clustered at the GN level. The main explanatory variables in this analysis are the extreme rainfall shock variables (floods/ droughts). In addition, we used several fixed effects; district fixed effect, survey year fixed effect, birth year fixed effect, and birth month fixed effect. Control variables include child-specific controls, mother-Specific controls, and households with regional controls. ** Significant at 1 percent, **Significant at 5 percent, *significant at 10 percent.

Table 2. 8: Impact of rainfall shocks outside the critical period on birth weight

VARIABLES	(1) Birth Weight	(2) Birth Weight	(3) Birth Weight	(4) Birth Weight
Trimester 0	1.779	1.123	0.831	0.406
	(2.658)	(2.601)	(2.584)	(2.557)
Trimester 1	6.731**	7.970***	8.123***	8.257***
	(2.824)	(2.765)	(2.731)	(2.716)
Trimester 2	1.017	0.387	0.166	0.783
	(2.988)	(2.914)	(2.898)	(2.864)
Trimester 3	0.131	-0.251	-0.237	-0.236
	(2.894)	(2.743)	(2.717)	(2.683)
Constant	2,888***	2,916***	2,601***	2,863***
	(44.87)	(43.91)	(52.69)	(56.41)
Observations	12,444	12,444	12,439	12,395
R-squared	0.024	0.057	0.074	0.091
District fixed effect	Yes	Yes	Yes	Yes
Survey year fixed effects	Yes	Yes	Yes	Yes
Birth month fixed effect	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
Child characteristics	No	Yes	Yes	Yes
Mother characteristics	No	No	Yes	Yes
Household characteristics	No	No	No	Yes

Notes: This table is based on the author's calculation. For this analysis, we added additional rainfall shock variables; outside the critical period of pregnant mothers. *** Significant at 1 percent, ** significant at 5 percent, significant at 10 percent.

Table 2. 9:Impact of rainfall shocks on birth weight for non-migrants

VARIABLES	**(1) Birth Weight**	**(2) Birth Weight**	**(3) Birth Weight**	**(4) Birth Weight**
Trimester 1	7.922**	8.416***	8.646***	8.817***
	(3.255)	(2.991)	(2.950)	(2.932)
Trimester 2	1.985	0.428	0.190	1.146
	(3.332)	(3.083)	(3.075)	(3.042)
Trimester 3	0.606	0.879	0.879	0.869
	(3.297)	(3.025)	(2.999)	(2.956)
Constant	2,905***	2,911***	2,617***	2,858***
	(54.83)	(50.20)	(59.74)	(64.15)
Observations	10,320	10,320	10,316	10,276
R-squared	0.026	0.062	0.077	0.092
District fixed effect	Yes	Yes	Yes	Yes
Survey year fixed effects	Yes	Yes	Yes	Yes
Birth year fixed effect	Yes	Yes	Yes	Yes
Birth month fixed effect	Yes	Yes	Yes	Yes
Child characteristics	No	Yes	Yes	Yes
Mother characteristics	No	No	Yes	Yes
Household characteristics	No	No	No	Yes

Notes: This table is based on the author's calculation. For this analysis, restricted the sample only for non-migrants during the critical period. *** Significant at 1 percent ** significant at 5 percent * significant at 10 percent.

Table 3. 1: Summary statistics (for 10km sample)

Variables	**Obs**	**Mean**	**Std. Dev.**
A. Outcome variables			
1 if a child had an illness with a cough at any time two weeks before the interview	1,675	0.204	0.403
1 if any household member suffers from asthma	1,598	0.178	0.382
B. Independent variables			
SO2(µg/m3)	1,677	42.541	6.383
1 if SO2 reading is greater than 50 (µg/m3)	1,677	0.100	0.300
NO2(µg/m3)	1,599	27.709	4.279
1 if NO2 reading is greater than 40 (µg/m3)	1,599	0.01	0.099
C. Child characteristics			
Birth weight (g)	1,523	2946.651	465.346
Sex(1-Male/0-Female)	1,677	0.519	0.499
Age(Months)	1,677	36.528	20.116
D. Mother characteristics			
Total living children at home	1,677	1.960	0.876
Age (years)	1,677	32.353	5.553
Religion (1 if Buddhist)	1,677	0.713	0.452
Ethnicity (1 if Sinhalese)	1,677	0.790	0.406
Mother education:			
1 if only completed grade 10	1,677	0.103	0.304
1 if only passed OL (Ordinary Level)	1,677	0.438	0.496
1 if only passed AL (Advanced Level) or qualified a degree	1,677	0.457	0.498
E. Indoor polluted characteristics			
1 if household used wood as main fuel type	1,677	0.418	0.493
1 if cook inside the house	1,677	0.893	0.308
1 if cooking smoke comes inside the house	1,677	0.193	0.395
1 if any household member has smoked	1,666	0.369	0.482
1 if any household member smoke inside the house	1,677	0.139	0.346
F. Household wealth characteristics			
Household wealth score	1,677	-0.00029	1.829
1 if households fall in the bottom 20% of the wealth index	1,677	0.202	0.402
1 if households fall in the bottom 40% of the wealth index	1,677	0.403	0.490
1 if households fall in the bottom 60% of the wealth index	1,677	0.596	0.490
1 if households fall in the bottom 80% of the wealth index	1,677	0.800	0.399
G. Regional characteristics			
The altitude of household location (meters)	1,677	113.392	193.093
Rainfall (mm)	1,677	253.435	246.748

H. Additional household property characteristics			
1 if household used gas & electricity as main fuel type	1,677	0.581	0.493
1 if household floor has terrazzo/tiles/granite	1,677	0.280	0.449
1 if household roof has tiles	1,677	0.239	0.427
1 if a household wall has bricks	1,677	0.392	0.488
1 if household has a radio	1,677	0.704	0.456
1 if household has a television	1,677	0.930	0.254
1 if household has a land telephone	1,677	0.345	0.475
1 if household has a refrigerator	1,677	0.740	0.438
1 if household has a computer	1,677	0.320	0.466
1 if a household has a washing machine	1,677	0.401	0.490
1 if household has a rice cooker	1,677	0.763	0.424
1 if household has a bicycle	1,677	0.237	0.425
1 if a household has a motorbike	1,677	0.435	0.495
1 if household has a trishaw	1,677	0.236	0.424
1 if household has motor car	1,677	0.206	0.405
1 if household owned a agriculture land	1,677	0.190	0.392
1 if household uses tap water for cooking	1,677	0.595	0.491
1 if household uses tap water for drinking	1,677	0.590	0.491
1 if household used flushed to a piped sewer system	1,677	0.088	0.283
1 if a household member owns house	1,677	0.782	0.412

Table 3. 2: SO_2 pollution effects (Continuous) on cough for 10km sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**cough**	**cough below 20%**	**cough below 40%**	**cough below 60%**	**cough below 80%**	**cough below 20&40**	**cough below 20 40&60**	**cough below 20, 40,60&80**
Panel A								
SO2	-0.001	-0.002	-0.002	0.001	0.002	-0.002	0.001	0.002
	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.003)
below20%		-0.214				-0.183	-0.184	-0.192
		(0.180)				(0.220)	(0.220)	(0.223)
below20% * SO2		0.004				0.003	0.003	0.003
		(0.004)				(0.005)	(0.005)	(0.005)
below40%			-0.087			-0.014	-0.239	-0.243
			(0.128)			(0.155)	(0.170)	(0.171)
below40% * SO2			0.0026			0.001	0.006	0.006
			(0.002)			(0.003)	(0.003)	(0.003)
below60%				0.139			0.350**	0.279
				(0.144)			(0.177)	(0.194)
below60%*SO2				-0.002			-0.008**	-0.006
				(0.003)			(0.003)	(0.004)
below80%					0.176			0.123
					(0.174)			(0.210)
below80%*SO2					-0.004			-0.003
					(0.004)			(0.004)
Constant	-0.047	-0.027	-0.021	-0.130	-0.181	-0.0369	-0.154	-0.206
	(0.174)	(0.177)	(0.181)	(0.195)	(0.222)	(0.182)	(0.198)	(0.226)
Observations	1,677	1,677	1,677	1,677	1,677	1,677	1,677	1,677
R-squared	0.119	0.120	0.119	0.119	0.119	0.120	0.122	0.123
Panel B								
Co-efficient for bottom 20 %		0.002				0.0019	0.0101	0.0111
		(0.003)				[0.5833]	[0.589]	[0.588]
Co-efficient for bottom 40 %			0.0003					
			(0.002)					
Co-efficient for bottom 60 %				-0.002				
				(0.002)				
Co-efficient for bottom 80 %					-0.002			
					(0.001)			
Co-efficient between 20-40%						-0.016	-0.2385	-0.2409
						[0.682]	[0.1382]	[0.1226]
Co-efficient between 40-60%							-0.0077	-0.0009
							[0.0127]	[0.4159]
Co-efficient between 60-80%								-0.0009

[0.7574]

Note: This table is based on the author's calculation. Standard errors are shown in parenthesis and clustered at the GN level, and P-Values are shown in brackets. We used several fixed effects, district fixed effect and survey year fixed effect, and a set of variables to control child-specific, mother-specific, household-specific, and weather characteristics. ***Significant at 1 percent, **significant at 5 percent, * significant at 10 percent

Table 3. 3: SO_2 pollution effects on cough for 10km sample

Variables	**(1) cough**	**(2) cough below 20%**	**(3) cough below 40%**	**(4) cough below 60%**	**(5) cough below 80%**	**(6) cough below 20&40**	**(7) cough below 20 40&60**	**(8) cough below 20, 40,60&80**
Panel A								
D_SO2	0.028	-0.010	-0.021	0.005	-0.004	-0.020	0.003	-0.008
	(0.0496)	(0.0527)	(0.0576)	(0.0652)	(0.105)	(0.0578)	(0.0651)	(0.105)
below20%		-0.049				-0.054	-0.056	-0.074
		(0.0398)				(0.0409)	(0.0426)	(0.0463)
below20% * D_SO2		0.199***				0.174*	0.172*	0.172*
		(0.0730)				(0.0950)	(0.0952)	(0.0950)
below40%			0.039			0.052	0.048	0.036
			(0.0347)			(0.0354)	(0.0360)	(0.0395)
below40% * D_SO2			0.120*			0.033	0.086	0.084
			(0.0617)			(0.0804)	(0.0896)	(0.0895)
below60%				0.004			-0.0001	-0.006
				(0.0370)			(0.0391)	(0.0398)
below60%*D_SO2				0.038			-0.074	-0.085
				(0.0591)			(0.0693)	(0.0721)
below80%					-0.034			-0.040
					(0.0392)			(0.0482)
below80%*D_SO2					0.039			0.024
					(0.0971)			(0.110)
Constant	0.088	0.076	0.072	0.083	0.109	0.0468	0.056	0.088
	(0.196)	(0.195)	(0.197)	(0.195)	(0.195)	(0.197)	(0.197)	(0.200)
Observations	1,675	1,675	1,675	1,675	1,675	1,675	1,675	1,675
R-squared	0.183	0.187	0.186	0.184	0.184	0.188	0.188	0.189
Panel B								
Co-efficient for bottom 20 %		0.189***				0.186	0.186	0.186
		(0.0719)				[0.0092]	[0.0094]	[0.009]
Co-efficient for bottom 40 %			0.098*					
			(0.0572)					
Co-efficient for bottom 60 %				0.044				
				(0.0518)				
Co-efficient for bottom 80 %					0.035			
					(0.0487)			
Co-efficient between 20-40%						0.013	0.089	0.076
						[0.8683]	[0.3974]	[0.5705]

Co-efficient between 40-60%	-0.071	-0.094
	[0.2902]	[0.4685]
Co-efficient between 60-80%		0.016
		[0.8175]

Notes: This table is based on the author's calculation. Standard errors are shown in parenthesis and clustered at the GN level, and P-Values are shown in brackets. We used several fixed effects, district fixed effect and survey year fixed effect, and a set of variables to control child-specific, mother-specific, household-specific, and weather characteristics. ***Significant at 1 percent, **significant at 5 percent, * significant at 10 percent.

Table 3. 4: Relationship between SO_2 *and indoor air pollution characteristics*

	10km					**5km**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
VARIABLES	**fuel type**	**cook inside**	**smoke comes inside**	**smoke inside**	**member smoke**	**fuel type**	**cook inside**	**smoke comes inside**	**smoke inside**	**member smoke**
D_SO2	-0.007	-0.023	0.027	0.017	-0.011	-0.023	-0.004	0.044	0.021	-0.064
	(0.049)	(0.035)	(0.053)	(0.041)	(0.059)	(0.054)	(0.034)	(0.063)	(0.050)	(0.081)
Constant	0.079	0.961***	-0.021	0.549***	0.419	0.081	0.926***	-0.215	0.385	0.713**
	(0.198)	(0.152)	(0.214)	(0.203)	(0.299)	(0.282)	(0.165)	(0.218)	(0.317)	(0.354)
Observations	1,677	1,677	1,677	1,677	1,666	842	842	842	842	836
R-squared	0.466	0.221	0.214	0.163	0.198	0.501	0.315	0.312	0.259	0.283
Survey month fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DS division fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Child characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mother characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household wealth characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Cluster standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3. 5: First stage estimation

VARIABLES	(1) SO2	(2) SO2	(3) SO2	(4) SO2	(5) SO2	(6) SO2	(7) SO2
Altitude_	-0.016***	-0.016***	-0.0182***	-0.018***	-0.022***	-0.031***	-0.060*
	(0.005)	(0.004)	(0.00515)	(0.005)	(0.005)	(0.006)	(0.030)
Constant	0.119***	0.020	-0.132	-0.132	-0.0730	0.232*	0.122
	(0.019)	(0.014)	(0.098)	(0.097)	(0.104)	(0.135)	(0.169)
F-Statistics	12.753	12.204	14.042	14.034	16.746	26.674	3.815
Observations	1,677	1,677	1,677	1,677	1,677	1,677	1,677
R-squared	0.012	0.050	0.087	0.087	0.096	0.169	0.510
Child characteristics	No	Yes	Yes	Yes	Yes	Yes	Yes
Mother characteristics	No	No	Yes	Yes	Yes	Yes	Yes
Household wealth characteristics	No	No	No	Yes	Yes	Yes	Yes
Rainfall Controls	No	No	No	No	Yes	Yes	Yes
Survey month fixed effect	No	No	No	No	No	Yes	Yes
DS division fixed effect	No	No	No	No	No	No	Yes

Cluster standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3. 6: Second stage estimation

VARIABLES	**(1)** **Cough**	**(2)** **Cough**	**(3)** **Cough**	**(4)** **Cough**	**(5)** **Cough**	**(6)** **Cough**	**(7)** **Cough**
D_SO2	1.339***	1.286***	1.069***	1.102***	0.951***	0.541**	0.664
	(0.474)	(0.470)	(0.373)	(0.377)	(0.317)	(0.225)	(0.475)
Constant	0.0707*	-0.0006	0.0097	0.0077	-0.0560	-0.311**	0.0295
	(0.0400)	(0.0132)	(0.130)	(0.132)	(0.125)	(0.132)	(0.226)
Observations	1,675	1,675	1,675	1,675	1,675	1,675	1,675
Child characteristics	No	Yes	Yes	Yes	Yes	Yes	Yes
Mother characteristics	No	No	Yes	Yes	Yes	Yes	Yes
Household wealth characteristics	No	No	No	Yes	Yes	Yes	Yes
Rainfall Controls	No	No	No	No	Yes	Yes	Yes
Survey month fixed effect	No	No	No	No	No	Yes	Yes
DS division fixed effect	No	No	No	No	No	No	Yes

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

Table 3. 7: Robustness against controlling for NO$_2$ concentration

Panel A		**Panel B**	
	(1)		**(1)**
VARIABLES	**cough**	**VARIABLES**	**cough**
SO2	-0.001	D_SO2	0.0249
	(0.002)		(0.056)
NO2	0.0026	D_NO2	0.0469
	(0.004)		(0.093)
Constant	-0.238	Constant	-0.209
	(0.212)		(0.152)
Observations	1,596	Observations	1,596
R-squared	0.165	R-squared	0.165
Child characteristics	Yes	Child characteristics	Yes
Mother characteristics	Yes	Mother characteristics	Yes
Household characteristics	Yes	Household characteristics	Yes
Rainfall controls	Yes	Rainfall controls	Yes
Survey month fixed effect	Yes	Survey month fixed effect	Yes
District fixed effect	Yes	District fixed effect	Yes

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

Table 3. 8: SO_2 pollution effect on cough for 10km sample (for non-migrants)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**cough**	**cough below 20%**	**cough below 40%**	**cough below 60%**	**cough below 80%**	**cough below 20&40**	**cough below 20 40&60**	**cough below 20, 40,60&80**
Panel A								
D_SO2	0.044	0.007	0.012	0.051	0.077	0.011	0.044	0.073
	(0.054)	(0.058)	(0.062)	(0.069)	(0.111)	(0.062)	(0.069)	(0.111)
below20%		-0.011				-0.018	-0.022	-0.040
		(0.043)				(0.044)	(0.046)	(0.052)
below20% * D_SO2		0.179**				0.194*	0.193*	0.193*
		(0.090)				(0.113)	(0.113)	(0.113)
below40%			0.035			0.044	0.039	0.026
			(0.039)			(0.0401)	(0.040)	(0.045)
below40% * D_SO2			0.072			-0.021	0.046	0.045
			(0.081)			(0.103)	(0.111)	(0.112)
below60%				-0.011			-0.002	-0.012
				(0.042)			(0.044)	(0.045)
below60%*D_SO2				-0.011			-0.098	-0.085
				(0.070)			(0.076)	(0.081)
below80%					-0.040			-0.035
					(0.0437)			(0.055)
below80%*D_SO2					-0.0349			-0.039
					(0.108)			(0.127)
Constant	0.246	0.248	0.228	0.254	0.273	0.219	0.232	0.264
	(0.222)	(0.222)	(0.223)	(0.223)	(0.221)	(0.224)	(0.225)	(0.226)
Observations	1,349	1,349	1,349	1,349	1,349	1,349	1,349	1,349
R-squared	0.217	0.219	0.218	0.217	0.217	0.220	0.221	0.221
Panel B								
Co-efficient for bottom 20 %		0.186**				0.184	0.184	0.187
		(0.089)				[0.039]	[0.039]	[0.036]
Co-efficient for bottom 40 %			0.0843					
			(0.0743)					
Co-efficient for bottom 60 %				0.0398				
				(0.060)				
Co-efficient for bottom 80 %					0.0424			
					(0.055)			
Co-efficient between 20-40%						-0.01	0.089	0.118
						[0.918]	[0.469]	[0.457]

Co-efficient between 40-60%	-0.054	-0.012
	[0.457]	[0.932]
Co-efficient between 60-80%		0.033
		[0.680]

Notes: This table is based on the author's calculation. Standard errors are shown in parenthesis and clustered at the GN level, and P-Values are shown in brackets. We used several fixed effects; district fixed effect and survey year fixed effect. Control variables include child-specific controls, mother-specific controls, household-specific controls, and weather controls. ***Significant at 1 percent, **significant at 5 percent, * significant at 10 percent.

Table 3. 9: SO$_2$ pollution effect on cough for 10km sample (including birth weight controls)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**cough**	**cough below 20%**	**cough below 40%**	**cough below 60%**	**cough below 80%**	**cough below 20&40**	**cough below 20 40&60**	**cough below 20, 40,60&80**
Panel A								
D_SO2	0.046	0.008	-0.0028	0.027	0.023	-0.0007	0.0260	0.0188
	(0.051)	(0.053)	(0.059)	(0.067)	(0.110)	(0.059)	(0.067)	(0.110)
below20%		-0.049				-0.054	-0.0569	-0.0781
		(0.042)				(0.044)	(0.045)	(0.049)
below20% * D_SO2		0.203***				0.181*	0.179*	0.179*
		(0.076)				(0.101)	(0.101)	(0.101)
below40%			0.0411			0.0541	0.0492	0.0353
			(0.0386)			(0.039)	(0.040)	(0.043)
below40% * D_SO2			0.119*			0.0283	0.0919	0.0902
			(0.0656)			(0.086)	(0.096)	(0.096)
below60%				0.0042			0.0011	-0.0062
				(0.040)			(0.043)	(0.043)
below60%*D_SO2				0.0335			-0.0890	-0.0980
				(0.062)			(0.073)	(0.076)
below80%					-0.038			-0.0458
					(0.043)			(0.053)
below80%*D_SO2					0.0298			0.0185
					(0.103)			(0.117)
Constant	0.0395	0.0398	0.0204	0.0343	0.0598	0.0045	0.0144	0.0497
	(0.248)	(0.247)	(0.250)	(0.248)	(0.247)	(0.250)	(0.249)	(0.251)
Observations	1,522	1,522	1,522	1,522	1,522	1,522	1,522	1,522
R-squared	0.177	0.180	0.179	0.177	0.177	0.181	0.182	0.182
Panel B								
Co-efficient for bottom 20 %		0.211***				0.209	0.208	0.209
		(0.0760)				[0.006]	[0.0062]	[0.006]
Co-efficient for bottom 40 %			0.116*					
			(0.060)					
Co-efficient for bottom 60 %				0.060				
				(0.053)				
Co-efficient for bottom 80 %					0.052			
					(0.050)			
Co-efficient between 20-40%						0.028	0.118	0.109
						[0.730]	[0.288]	[0.438]
Co-efficient between 40-60%							-0.063	-0.079

	[0.373]	[0.562]
Co-efficient between 60-80%		0.0373
		[0.603]

Table 3. 10: Effect of air pollution on asthma for 10km sample

Panel A		Panel B	
	(1)		**(1)**
VARIABLES	**Asthma**	**VARIABLES**	**Asthma**
SO2	0.00487	D_SO2	0.0474
	(0.00321)		(0.0607)
NO2	-0.00265	D_NO2	-0.146*
	(0.00441)		(0.0820)
Constant	-0.0666	Constant	0.0500
	(0.199)		(0.110)
Observations	1,598	Observations	1,598
R-squared	0.030	R-squared	0.029
Child characteristics	No	Child characteristics	No
Mother characteristics	No	Mother characteristics	No
Household characteristics	Yes	Household characteristics	Yes
Rainfall controls	Yes	Rainfall controls	Yes
Survey month fixed effect	Yes	Survey month fixed effect	Yes
District fixed effect	Yes	District fixed effect	Yes

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

Appendix 2

Appendix Table A2. 1:Summary statistics for 5km sample

Variables	Obs	Mean	Std. Dev.
A. Outcome variables			
1 if a child had an illness with a cough at any time in the last two weeks	841	0.231	0.422
B. Independent variables			
SO2(µg/m3)	842	42.608	7.016
1 if SO2 reading is greater than 50 (µg/m3)	842	0.171	0.377
C. Child characteristics			
Birth weight (g)	776	2962.468	440.235
Sex(1-Male/0-Female)	842	0.511	0.500
Age (Months)	842	35.882	20.304
D. Mother characteristics			
Total living children at home	842	1.982	0.893
Age (years)	842	32.365	5.602
Religion (1 if Buddhist)	842	0.641	0.480
Ethnicity (1 if Sinhalese)	842	0.704	0.457
Mother education:			
1 if only completed grade 10	842	0.108	0.311
1 if only passed OL	842	0.407	0.492
1 if only passed AL or qualified a degree	842	0.485	0.500
E. Indoor polluted characteristics			
1 if household used wood as main fuel type	842	0.312	0.464
1 if cook inside the house	842	0.930	0.255
1 if cooking smoke comes inside the house	842	0.192	0.394
1 if any household member is smoked	836	0.359	0.480
1 if any household member smoke inside the house	842	0.115	0.319
F. Household wealth characteristics			
Household wealth score	842	0.042	1.795
1 if households fall in the bottom 20% of wealth index	842	0.188	0.391
1 if households fall in the bottom 40% of wealth index	842	0.392	0.488
1 if households fall in the bottom 60% of wealth index	842	0.596	0.491
1 if households fall in the bottom 80% of wealth index	842	0.796	0.403
G. Regional characteristics			
The altitude of household location (meters)	842	88.143	172.530
Rainfall (mm)	842	211.965	220.114
H. Additional household property characteristics			
1 if household used gas & electricity as main fuel type	842	0.688	0.464
1 if household floor has terrazzo/tiles/granite	842	0.323	0.468

1 if household roof has tiles	842	0.185	0.389
1 if household wall has bricks	842	0.401	0.490
1 if household has a radio	842	0.700	0.459
1 if household has a television	842	0.926	0.261
1 if household has a land telephone	842	0.397	0.489
1 if household has a refrigerator	842	0.784	0.412
1 if household has a computer	842	0.379	0.485
1 if household has a washing machine	842	0.477	0.500
1 if household has a rice cooker	842	0.773	0.419
1 if household has a bicycle	842	0.234	0.424
1 if household has a motor bike	842	0.403	0.491
1 if household has a trishaw	842	0.219	0.413
1 if household has motor car	842	0.248	0.432
1 if household owned an agriculture land	842	0.145	0.352
1 if household uses tap water for cooking	842	0.752	0.432
1 if household uses tap water for drinking	842	0.751	0.433
1 if household used flushed to piped sewer system	842	0.145	0.352
1 if house is owned by a household member	842	0.739	0.440

Appendix Table A2. 2: SO_2 pollution effects on cough for 5km sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	**cough**	**cough below 20%**	**cough below 40%**	**cough below 60%**	**cough below 80%**	**cough below 20&40**	**cough below 20 40&60**	**cough below 20, 40,60&80**
Panel A								
D_SO2	-0.015	-0.070	-0.074	-0.006	-0.015	-0.074	-0.010	-0.024
	(0.053)	(0.058)	(0.065)	(0.077)	(0.129)	(0.065)	(0.076)	(0.129)
below20%		-0.040				-0.038	-0.046	-0.036
		(0.0625)				(0.064)	(0.071)	(0.077)
below20% * D_SO2		0.243***				0.231**	0.226**	0.226**
		(0.085)				(0.110)	(0.109)	(0.109)
below40%			-0.026			-0.006	-0.028	-0.020
			(0.057)			(0.059)	(0.062)	(0.068)
below40% * D_SO2			0.139*			0.017	0.134	0.134
			(0.075)			(0.097)	(0.108)	(0.108)
below60%				-0.018			0.011	0.017
				(0.060)			(0.067)	(0.070)
below60%*D_SO2				-0.014			-0.176*	-0.182*
				(0.077)			(0.091)	(0.094)
below80%					0.010			0.016
					(0.057)			(0.0692)
below80%*D_SO2					0.0005			0.021
					(0.125)			(0.147)
Constant	0.085	0.099	0.101	0.104	0.081	0.103	0.152	0.131
	(0.330)	(0.329)	(0.331)	(0.324)	(0.330)	(0.331)	(0.327)	(0.336)
Observations	841	841	841	841	841	841	841	841
R-squared	0.267	0.273	0.270	0.267	0.267	0.273	0.276	0.276
Panel B								
Co-efficient for bottom 20 %		0.173**				0.173	0.174	0.174
		(0.085)				[0.044]	[0.043]	[0.045]
Co-efficient for bottom 40 %			0.064					
			(0.065)					
Co-efficient for bottom 60 %				-0.020				
				(0.057)				
Co-efficient for bottom 80 %					-0.0149			
					(0.0541)			
Co-efficient between 20-40%						-0.058	0.124	0.110
						[0.519]	[0.340]	[0.530]

Co-efficient between 40-60%	-0.186	-0.207
	[0.022]	[0.198]
Co-efficient between 60-80%		-0.004
		[0.966]

Notes: This table is based on the author's calculation. Standard errors are shown in parenthesis and clustered at the GN level, and P-Values are shown in brackets. We used several fixed effects; district fixed effect and survey year fixed effect. Control variables include child-specific controls, mother-specific controls, household-specific controls, and weather controls. ***Significant at 1 percent, **significant at 5 percent, * significant at 10 percent.

Figures

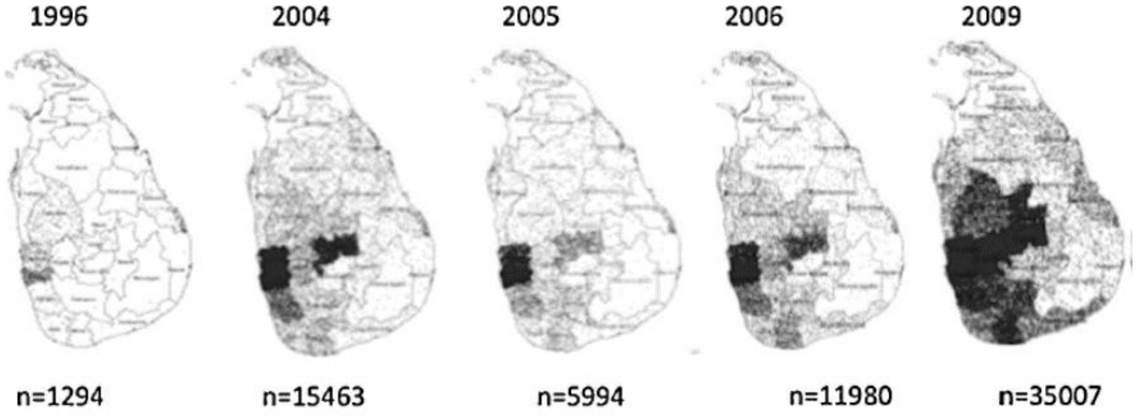


Figure 2. 1: Dengue affected areas in Sri Lanka from 1996 to 2009

(Source: Sirisena & Noordeen, 2014)

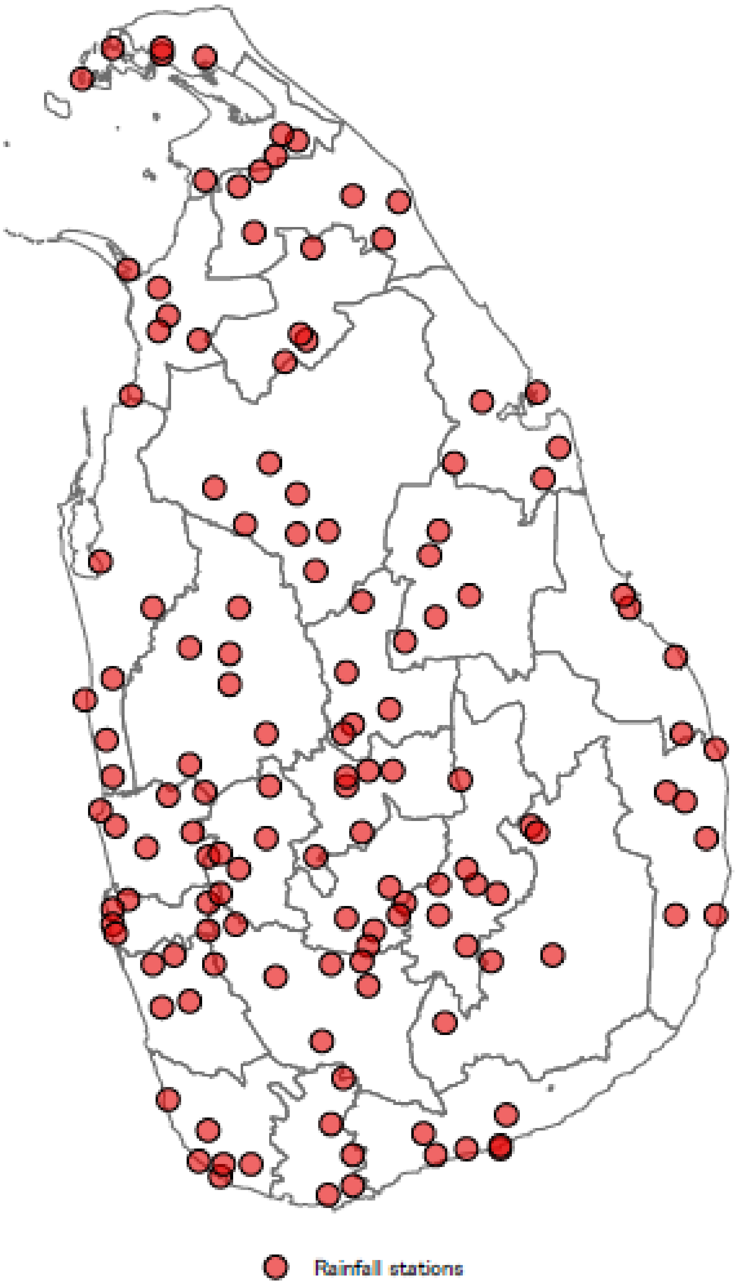


Figure 2. 2: Rainfall stations

(Source: Author's elaboration)

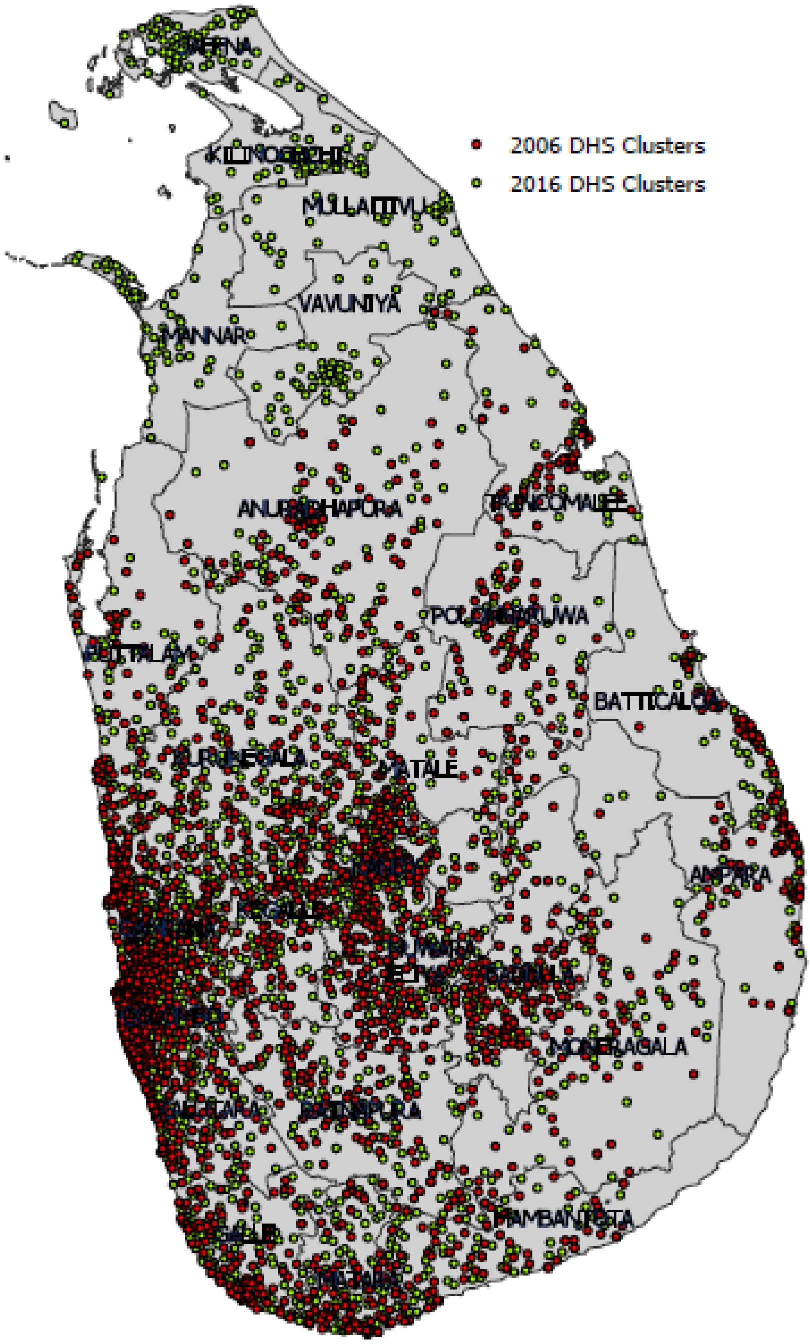


Figure 2. 3: DHS clusters

(Source: Author's elaboration)

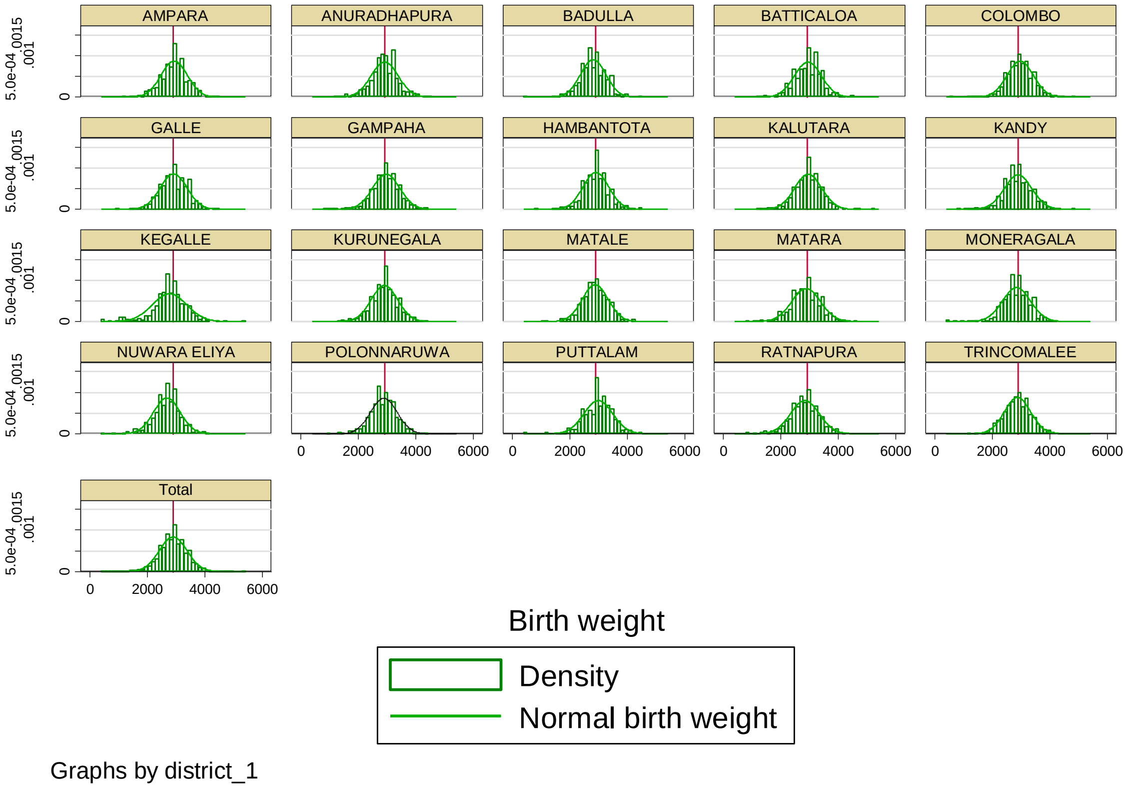


Figure 2. 4: Birth weight by districts

(Source: Author's elaboration)

Note: In this study, the average birth weight of the total sample is 2,897 grams, and it is shown in the red vertical lines for each district. However, the average birth weight in Badulla, Kegalle, Matale, Matara, Anuradhapura, Moneragala, Nuwara Eliya, Polonnaruwa, Rathnapura, and Trincomalee districts is below the average.

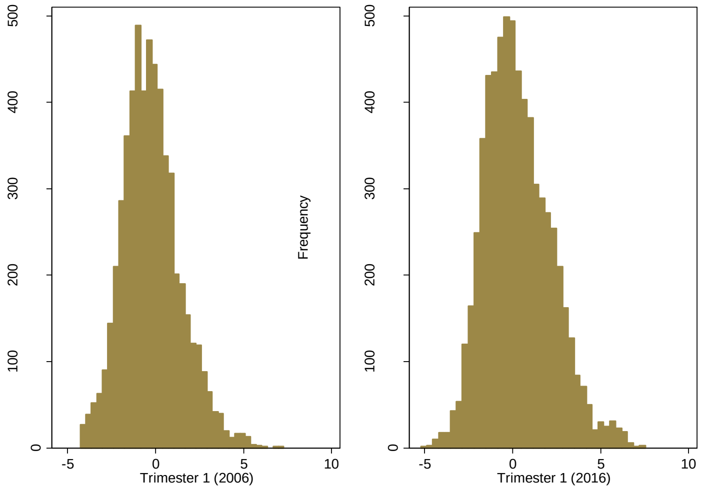


Figure 2. 5: Rainfall shock in trimester 1 in 2006 and 2016

(Source: Author's elaboration)

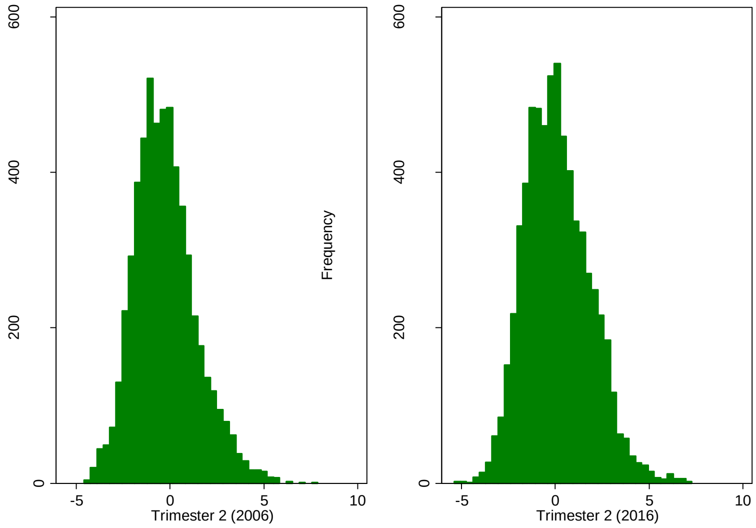


Figure 2. 6: Rainfall shock in trimester 2 in 2006 and 2016

(Source: Author's elaboration)

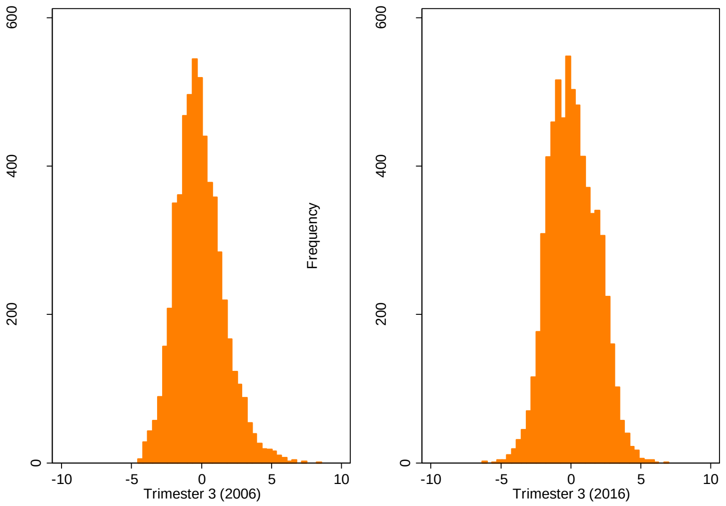


Figure 2. 7: Rainfall shock in trimester 3 in 2006 and 2016

(Source: Author's elaboration)

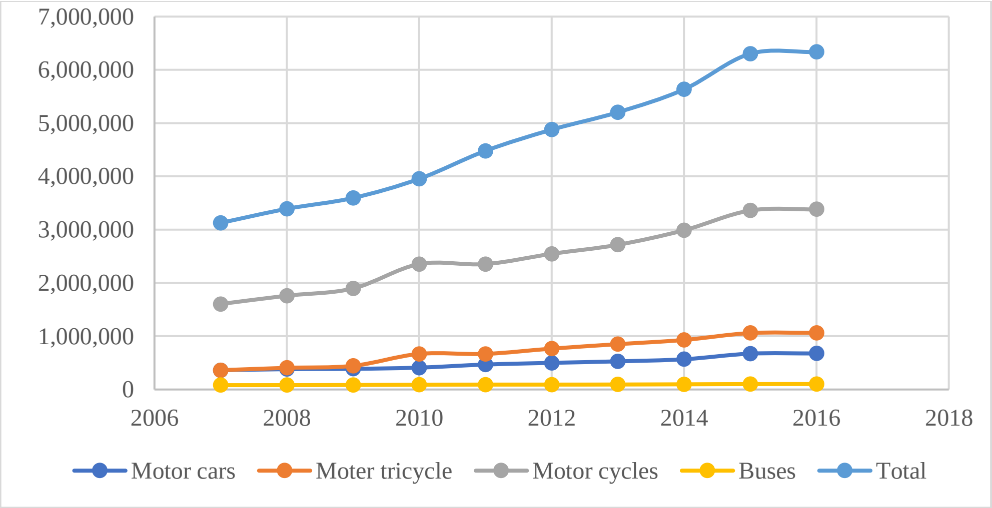


Figure 3. 1: Vehicle population for 2007-2017 in Sri Lanka

(Source: DMTSL, 2015; DMTSL, 2016)

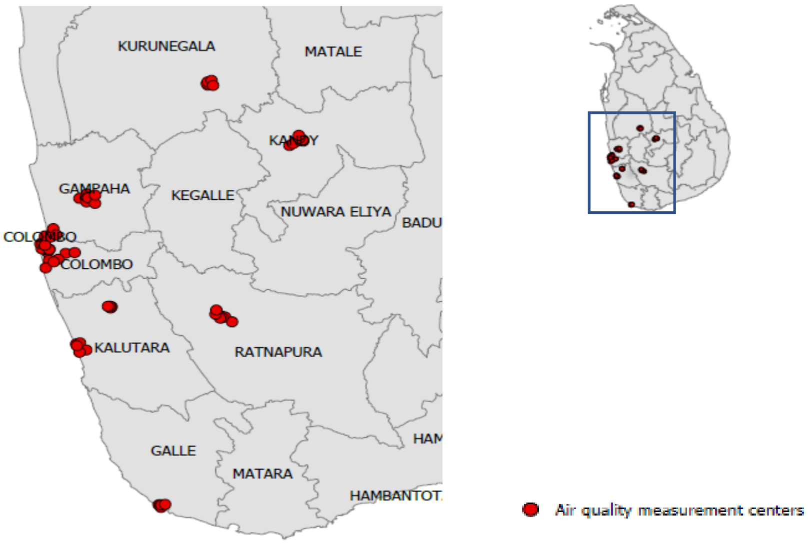


Figure 3. 2: Air quality measurement centers

(Source: Author's elaboration)

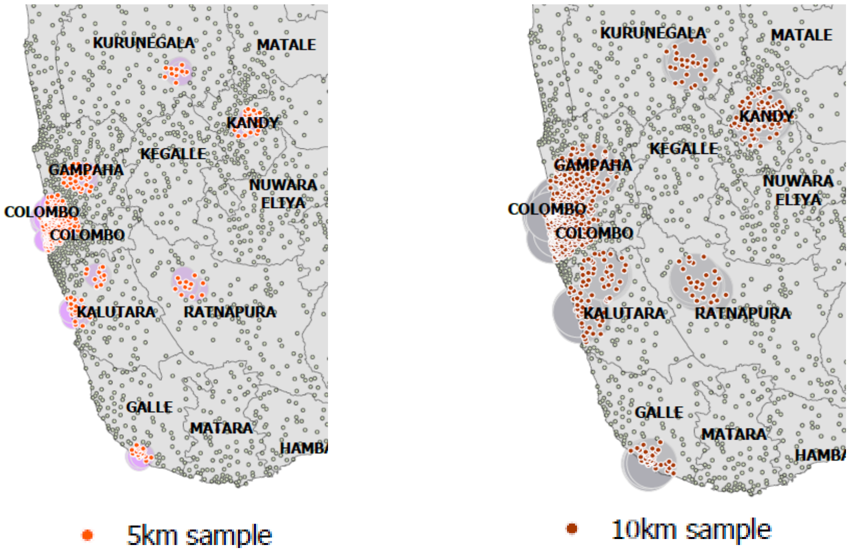
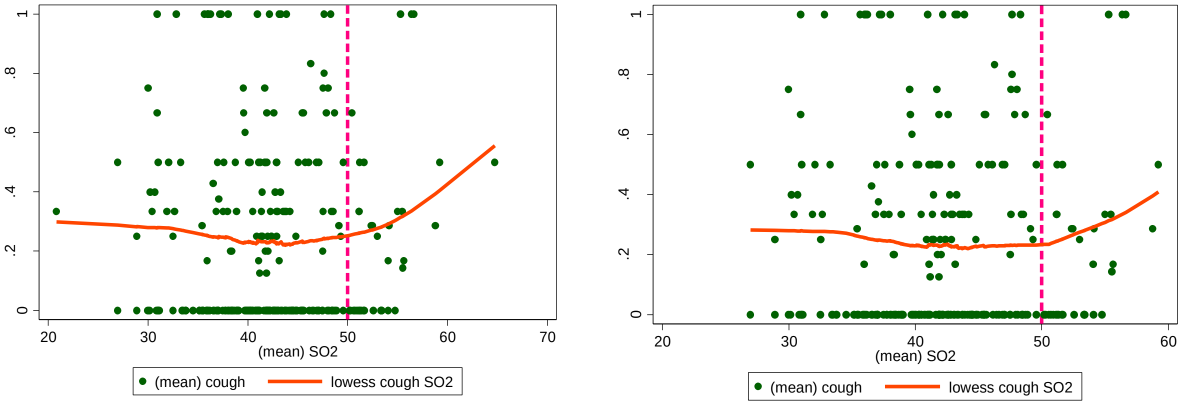


Figure 3. 3: Selected DHS clusters from both 5km and 10km samples

(Source: Author's elaboration)

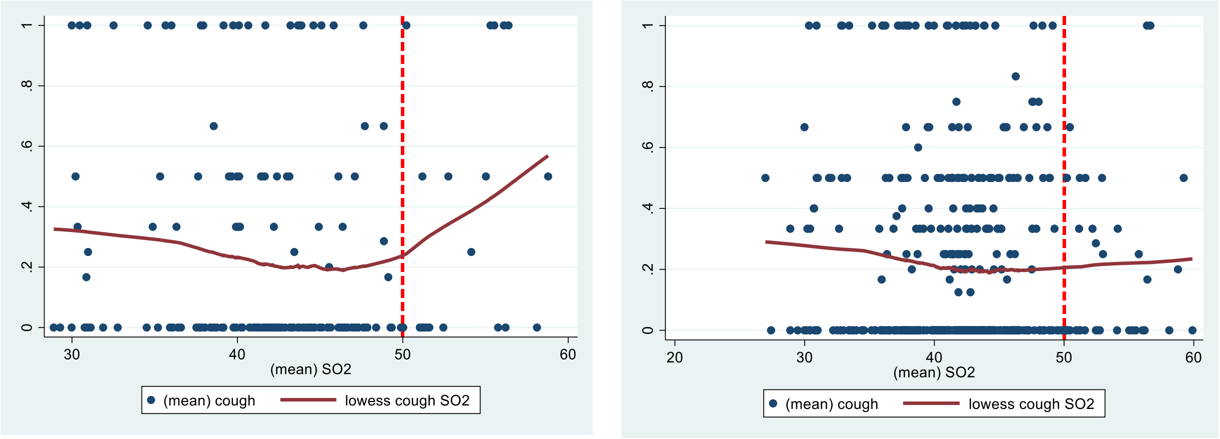


Panel A

Panel B

Figure 3. 4: The association between SO₂ pollution and the share of coughing incidences

(Source: Author's elaboration)



Panel A

Panel B

Figure 3. 5: The association between SO₂ pollution and the share of coughing incidences by wealthy groups

(Source: Author's elaboration)