Executive Summary: Children's Health and Air Pollution in Lumbini

Research Conducted By:

LEADERS Nepal

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This report presents key findings from a comprehensive study conducted by LEADERS Nepal on the impact of air pollution on children's health in Lumbini, Nepal. While the full study methodology and detailed results are available in the main body of the report, this executive summary highlights the most significant findings, implications, and some recommendations.

1. Summary of findings

1.1 Background

The Lumbini Development Zone (LDZ) has been a UNESCO World Heritage Site since 1997. Given its cultural, ecological, and religious significance, Lumbini attracts tourists from around the world year-round. In 2018, approximately 1.17 million people visited Lumbini, a threefold increase from 2011. Many visitors come to meditate or pray in their preferred indoor (monastery) or outdoor locations. From March 30 to April 5, 2024, 5,000 people participated in a weeklong meditation program called "Birat Chakra Bigyan" in Lumbini.

1.1.1 Industrial boom: Cultural and environmental concerns

Recently, there has been significant industrial growth around the LDZ, particularly along the 24 km Bhairahawa-Lumbini corridor ((NEFEJ) 2019). The cement industry is one of the fastest-growing industries near LDZ. In addition to cement, there are brick kilns, steel factories, paper processing factories, a couple of thread mills, a noodle industry, and flour mills (Annex 1 has the list of industries near LDZ). The expansion of industries near LDZ has raised concerns about their impact on the environment, biodiversity, residents' health, and archaeological properties due to emissions and other activities.

1.1.2 Air quality crisis in Lumbini: Sacred Buddhist site grapples with pollution

Archeologists have documented evidence of accumulation of fine powder of gypsum, calcite, dolomite, and magnesite on the surface of one of the famous pillars (Ashok pillars established in 249 BC by Emperor Ashoka) in Lumbini (IUCN and UNESCO 2012). These compounds are released during the cement manufacturing process.

1.1.3 Alarming air pollution level

A few ambient air pollution measurements conducted in Lumbini have revealed concerning levels of particulate matter, particularly PM 2.5 (particulate matter with a diameter of 2.5 micrometers or less). PM2.5 can penetrate deep into the lungs if inhaled over an extended period, potentially increasing the risk of various respiratory and other diseases in both children and adults.

An air pollution measurement conducted at the Lumbini International Research Institute (LIRI), a Buddhist library in Lumbini, during the pre-monsoon season of 2013 has documented concentrations of PM2.5 and PM10 at approximately 53 ± 35 $\mu g/m^3$ (range: 6-272 $\mu g/m^3$) and 129 ± 92 $\mu g/m^3$ (range: 11-604 $\mu g/m^3$), respectively (Rupakheti et al. 2016). These values are

1.3 and 1.1 times higher than the 24-hour National Ambient Air Quality Standard (NAAQS) of 40 $\mu g/m^3$ for Nepal.

During the 2012 monsoon season, the PM2.5 value was measured at 19 $\mu g/m^3$(± 12 $\mu g/m^3$) (Ali et al. 2019). The short-term (48-hour) measurements of PM2.5 and PM10 by the Ministry of Science, Technology, and Environment (Government of Nepal) in January and March of 2015 found 153 $\mu g/m^3$ and 41.5 $\mu g/m^3$, and 264.5 $\mu g/m^3$ and 178 $\mu g/m^3$, respectively (लुम्बिनी संरक्षित क्षेत्र आसपासमा रहेका उद्योगहरुको संचालनको अवस्था र स्थिति क स्थलगत अ ध्यन प्रतिबेदन, २०७७). Some of these values are very high when compared with NAAQS.

1.1.3.1 The air quality in Lumbini and the surrounding Rupandehi district is becoming more concerning

According to recent data, the Air Quality Index (AQI) in Lumbini-Rupendehi is classified as "Unhealthy for sensitive groups" with a US AQI of 130 [1],[2]. The poor air quality in Lumbini poses significant risks to public health and quality of life in the region [3], [4], [5], [6]. However, there is a critical lack of long-term data on PM2.5 levels during the pre-monsoon and post-monsoon seasons in Lumbini, as well as limited information on their associated health impacts.

1.1.4 Polycyclic aromatic hydrocarbons (PAHs) level

The concentrations of a known carcinogen, polycyclic aromatic hydrocarbons (PAHs) in atmospheric aerosols in Lumbini have shown higher levels (94.8 ± 54.6 ng/m³) compared to three other measured locations in Nepal (Chen et al. 2017). The PAH levels in Lumbini are comparable to those found in coal-based industrial cities in China (Wu et al. 2014; Zhang et al. 2016). Carcinogenic risk assessments based on the benzo(a)pyrene equivalent (BaPeq) of PAHs (~18.6 ng/m3) have shown a potential high cancer risk for residents of the Lumbini area (Neupane et al. 2018).

1.1.5 Monks and residents' concerns over deteriorating air quality

Lumbini which is situated in the Rupandehi district has a large population of 1,118,975[7]. Residents of the Lumbini area have complained about air quality problems for years. Tourists, pilgrims, and monks who come to Lumbini to seek inner peace often complain about uneasiness while breathing the air inside the Lumbini Development Zone (LDZ). Even monks have complained about the problem of poor air quality and have often been seen meditating while wearing masks (BBC 2017).

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[1] Lumbini - Rupendehi Air Quality Index (AQI) and Nautanwa Air Pollution | IQAir
[2] Rupandehi Real-time Air Quality Index (AQI) & Pollution Report - Air Matters (air-quality.com)
[3] Buddha's birthplace faces serious air pollution threat - BBC News
[4] Lumbini – The birthplace of Buddha in Nepal faces serious threat from pollution | Environment News | Zee News (india.com)
[5] Lumbini area affected by the pollutants and chemicals emitted by large-scale industries operated on the other side of the border (kathmandupost.com)
[6] Air pollution at Buddha's birthplace is 10 times the safe level - BBC News
[7] https://localelection2079.ekantipur.com/pradesh-5?lng=eng

1.1.6 Urgent need for comprehensive air quality data and impact assessment in Lumbini

Unfortunately, there is limited data available on the public health burden (morbidity and mortality) caused by air pollution in LDZ. Additionally, there is a lack of detailed data on air pollution levels, particularly PM2.5.

1.2 Aim and objectives of the present study

This study aimed to:

1. Examine the levels and long-term trends of ambient air pollution (PM2.5) in the LDZ.

2. Examine the meteorological conditions (including temperature, wind speed, and wind direction) in the LDZ.

3. Assess the impact of nearby industrial activities and associated air pollution on the respiratory health of school-aged children living at varying distances from industries located in close proximity to the Lumbini Development Zone (LDZ).

1.2.1 Specific objectives:

The specific objectives of the present study are:

1. To monitor and document real-time air pollution levels over a one-year period, with a particular focus on PM2.5 concentrations in the Lumbini area.

2. To investigate the prevalence of respiratory illnesses, including acute respiratory illness (ARI) and asthma, among schoolchildren aged 6 to 14 years and adults.

3. To compare the Peak Expiratory Flow Rate (PEFR) values of children studying in various schools and residing in the exposed and control (unexposed) areas in Lumbini, and to compare their PEFR values with those of healthy schoolchildren in the United States.

   Peak expiratory flow rate (PEFR) measures how well air moves out of the lungs. It is an indicator of lung function and airway obstruction

1.3 Materials and Methods

1.3.1 Air pollution (PM2.5) and meteorological data

This cross-sectional study collected PM2.5, temperature, wind speed, and wind direction data at 15-minute intervals over the course of one year to investigate the levels and trends of air pollution and some meteorological parameters in the LDZ. These data were collected using the US-EPA approved method and factory calibrated air pollution monitor-- E-sampler. The air pollution monitor was located within 1500 meters of the LDZ and between 8222 and 10124 meters from 18 industrial clusters. The daily mean mass concentrations of PM2.5 were compared with the daily Nepal's National Ambient Air Quality Standards (NAAQS) of 40 $\mu g/m^3$ for PM2.5.

1.3.2 Respiratory illness data: Survey

This study documented the impact of industrial clusters and their emissions on the respiratory health of school-aged children living and studying near these industrial clusters in the LDZ (exposed area), compared to children residing approximately 14-17 kilometers away from the industrial cluster (control area). Three sets of questions were used to assess the prevalence of respiratory illnesses and symptoms in children living in both the exposed and control areas. These questions focused on asthma, rhinitis, and eczema. The mothers of the study participants (i.e., the children) were asked whether their child currently has or has previously had these conditions.

1.3.3 Peak Expiratory Flow Rate (PEFR) data

The respiratory capacity of school-aged children was assessed using peak flow meters to measure their PEFR. The PEFR values of students living in the exposed and control areas were compared both to each other and to the standard average peak flow rates for healthy children and teenagers in the United States[8].

Lower PEFR values suggest narrowed airways, which can signify respiratory conditions like asthma, COPD, or other lung diseases. PEFR is crucial in asthma management, as regular monitoring helps detect early signs of airway narrowing or impending asthma attacks, prompting timely treatment adjustments. Additionally, PEFR measurements assess the severity of respiratory illnesses, with lower values indicating more severe airway obstruction and respiratory impairment.

The PEFR was measured using a Rossmax Therapy (Swiss GMBH, Widnauerstrasse 1, CH-9435, Heerbrugg, Switzerland) Peak Flow meter. To measure peak flow, each child took a deep breath and forcefully exhaled into the peak flow meter as quickly as possible. After each measurement, the marker was reset to zero. A total of three measurements were taken, and the average value was recorded. During the measurement, the mouthpiece and the child's lips were sealed tightly. After removing the mouthpiece from each subject, it was cleaned and sterilized for the next use.

The age of all study participants was obtained by asking their mothers and confirming it with their date of birth. Weight (in kg) was measured on a standard calibrated bathroom scale with participants standing without shoes. Height (in cm) was measured using a standard (Kobo) portable stadiometer.

1.3.4 Geospatial data collection

Geographic Positioning System (GPS) data were collected for various locations relevant to the study, including study participants' homes, industrial locations, educational institutions, air pollution (E-sampler) monitoring stations.

1.3.5 Exposed and control area

The present study defined the exposed area as the region within a 10 km radius of the group of 18 industries near the LDZ (represented by the Khadwa Bangai to Motipur area of Mayadevi Rural Municipality). Conversely, areas located approximately 14-17 km away from the LDZ and its

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[8] Ref: Peak flow meter (childrensmn.org)

industrial clusters were categorized as unexposed or control area (represented by Shuddhodhan Rural Municipality of Kapilvastu district within the Lumbini province).

1.3.6 Study time period

The data were collected between April 2023 to March 2024. This timeframe was chosen to provide a snapshot of the current situation regarding air pollution and its impact on respiratory symptoms in school-aged children residing near industries.

1.3.7 Statistical analysis

To determine if there is a significant relationship between two categorical variables, a chi-square test was used. Similarly, to determine the relationship between two continuous variables, or between a continuous and a categorical variable, regression analysis was conducted. A p-value < 0.05 from statistical analyses was considered statistically significant. All statistical analyses, including the creation of geospatial maps, were performed using the open-source software R (R Core Team 2024).

1.4 Research hypotheses

4. Children residing far away (>15 km) from the 18 industrial clusters (control/unexposed area) have a lower prevalence of respiratory symptoms compared to those living near the heavy industrial presence (exposed area) in the Lumbini Development Zone (LDZ).

5. Children residing far away (> 15 km) from the 18 industrial clusters (control/unexposed area) have higher Peak Expiratory Flow Rate (PEFR) values compared to those living near the heavy industrial presence (exposed area) in the LDZ.

1.5 Ethical approval

The study received ethical approval from the Nepal Health Research Council (NHRC) and permission from local municipalities: Mayadevi Rural Municipality in Rupandehi district (exposed area) and Shuddhodhan Rural Municipality in Kapilvastu district (control area). Data collection was conducted with (parental) informed consent from all study participants.

2. Results

2.1 Eighteen high polluting industries are operating near Lumbini Development Zone (LDZ)

Eighteen industries currently operate near the Lumbini Development Zone (LDZ). The closest industry is located approximately 7.5 km from the LDZ, followed by a cement industry at a distance of 9.5 km.

To safeguard the Lumbini World Heritage Site and its surrounding areas of cultural significance related to the life of Buddha, the Government of Nepal has implemented regulations prohibiting the establishment of new polluting industrial activities within a 15-kilometer radius from the Lumbini boundaries. However, non-polluting industries are exempt from this restriction.

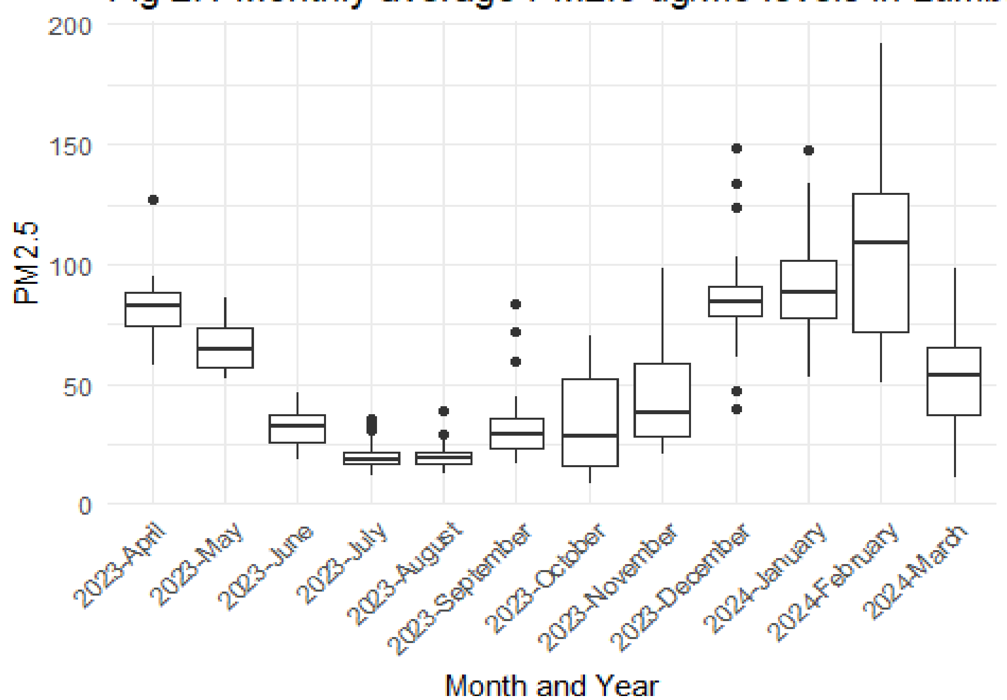
2.2 The air pollution (PM2.5) levels near the LDZ are alarmingly high

The air pollution data collected between April 2023 and March 2024 for this study indicates very poor air quality near the LDZ. The average PM2.5 level during the 291 days of air quality measurements was 58 $\mu g/m^3$ (microgram per cubic meter), ranging from a minimum of 4 $\mu g/m^3$ to a maximum of 500 $\mu g/m^3$ (microgram per cubic meter). The observed annual average PM2.5 level exceeded Nepal's 24-hour Ambient Air Quality Standard of 40 $\mu g/m^3$, highlighting the severity of the air pollution problem in the region.

During the 291-day measurement period, PM2.5 levels exceeded Nepal's National Ambient Air Quality Standards for 162 days, which accounts for 56% of the time. The winter months exhibited more severe air pollution, with December 2023 recording PM2.5 levels above the national standard for 24 out of 31 days (77% of time). Alarmingly, in January 2024, the daily average PM2.5 concentration surpassed the 24-hour national ambient air quality standard of 40 $\mu g/m^3$ for the entire month, representing a 100% exceedance rate, posing significant health risks to residents and visitors. Figure 2.1 shows the monthly average PM2.5 $\mu g/m^3$ in Lumbini.

The regression analysis suggested for every 1°C increase in temperature, the PM2.5 concentration decreases by 2.67 $\mu g/m^3$.

Fig 2.1 Monthly average PM2.5 ug/m3 levels in Lumbi



2.3 The wind speeds in the LDZ are inadequate for effective dispersion of Particulate Matter (PM2.5)

Wind speed plays an important role in reducing PM2.5 levels. In the Lumbini area, during the study period, the average wind speed was 0.64 m/sec, with the lowest and highest values recorded at 0.30 m/sec and 3.5 m/sec, respectively. Unfortunately, wind speeds greater than 2 m/sec, which are considered more effective in dispersing particulate matter, were observed for only 146 out of 17,540 15-minute measurements (0.83% of time) during the 291-day period, highlighting the prevalence of stagnant air conditions that can exacerbate air pollution levels.

The linear regression analysis between wind speed and PM2.5 concentrations revealed a negative correlation, indicating that for every 1 m/s increase in wind speed, the PM2.5 level decreased by 1.97 $\mu g/m^3$ ($p = 0.06$).

2.4 Southeast followed by Northeast wind direction influence the PM2.5 concentrations in Lumbini

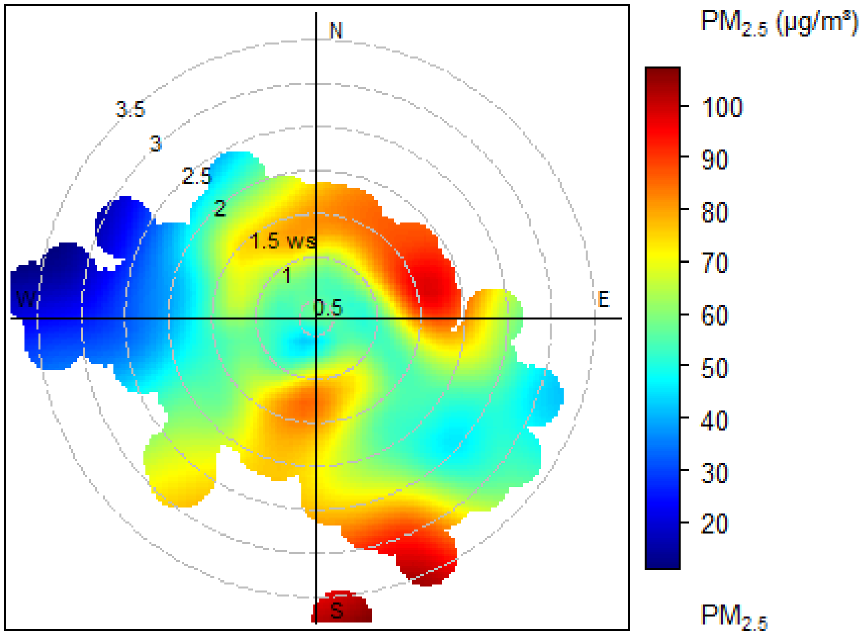
Throughout the study period, the predominant wind inflow was from the southeast (SE) direction, except for October and November when the wind mainly originated from the northwest (NW). Higher concentrations of PM2.5 were observed when the wind was predominantly from the SE followed by northeast (NE) wind dominance.

The southeast direction from Lumbini Development Zone (LDZ) includes bordering towns in India, while the northeast (NE) direction encompasses the Lumbini-Bhairahawa corridor, where several industries including eighteen industries are located.

The bivariate polar plot (Figure 6.2), illustrating the relationship between PM2.5 concentrations, wind speed, and wind direction, further confirmed that higher PM2.5 concentrations occurred at low wind speeds (1-1.5 m/s). Notably, elevated PM2.5 concentrations were also observed when winds originated from the southeast (SE), even at higher wind speeds (3-3.5 m/s).

The higher concentration of PM2.5 at low wind speeds around the monitoring station could be attributed to the accumulation of PM2.5 from local sources such as vehicular emissions, local industries, and household biomass burning. The high concentrations of PM2.5 observed in the SE direction, in association with higher wind speeds, suggest that transboundary sources and tall industrial stacks may be responsible for the release and transport of PM2.5 to the Lumbini Development Zone (LDZ).

Figure 6.2. Bivariate Polar Plot of $PM_{2.5}$ Concentration

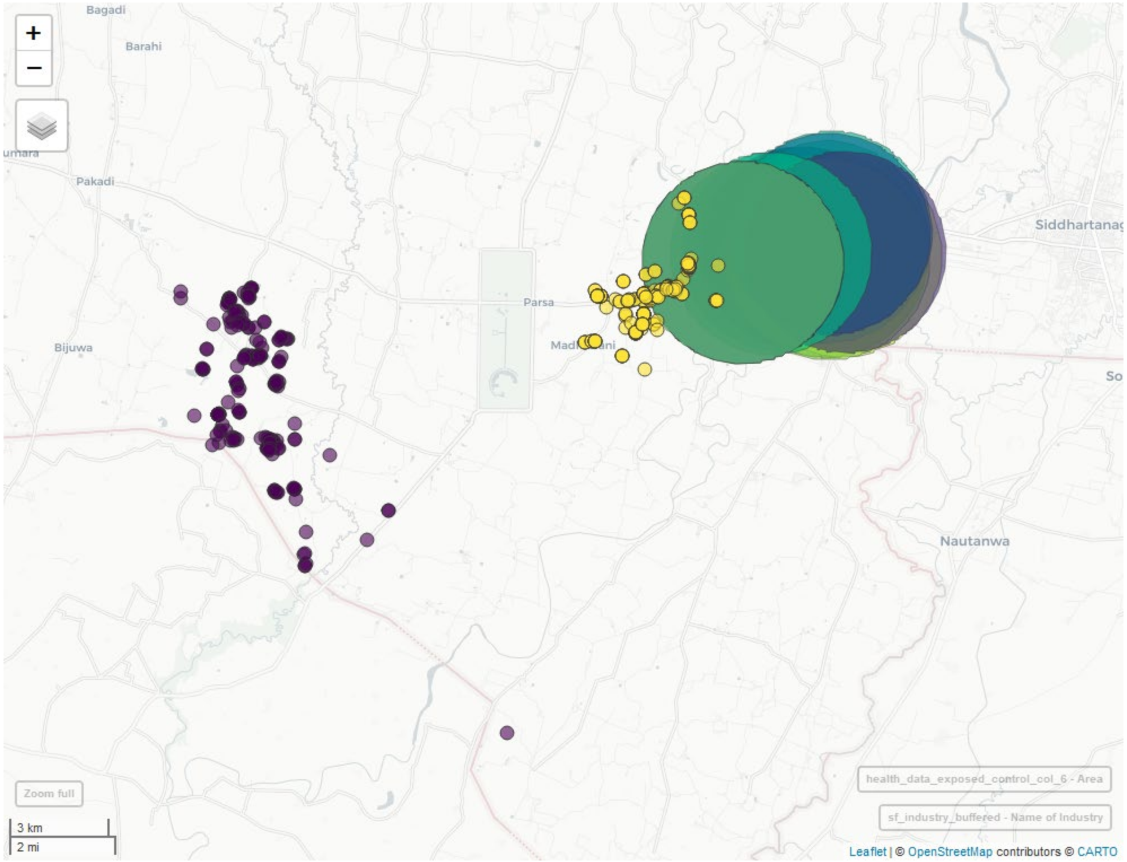


2.5 Children who live and attend schools near the industrial cluster close to the LDZ are exposed to high levels of air pollution

There are multiple schools located near the industrial cluster close to LDZ. A significant number of children involved in the current study live within a 3 km radius around some of the industrial clusters. Within a 3.1 km radius of these eighteen industrial clusters, there are two schools where students spend at least 6-7 hours per day on weekdays.

The map below shows the locations of the study participants' homes in both the exposed and control areas. The light blue dots indicate the locations of homes of study participants from the exposed area, while the yellow and dark purple dots on the left side of the map represent the homes of study participants from the control area. The circle indicates the 3 km buffer zone around the industries. The faint rectangle in the middle of the map (closer to the exposed area) is the LDZ.

The distance between the industries and the homes in the control area is approximately 14000 meters.



2.6 In Lumbini, children living near industrial clusters are more prone to respiratory illnesses

The analysis of health data suggests that the prevalence of major respiratory illnesses and symptoms among study participants (school-aged children) is higher in those living in the exposed area near the eighteen industrial clusters compared to those in the control area, which is located 15-17 km away from the industrial clusters near the LDZ. Specifically, children in the exposed area exhibited a higher prevalence of wheezing, asthma, and nighttime coughing unrelated to colds or chest infections. Furthermore, these children demonstrated more frequent asthma-related symptoms compared to their counterparts in the control area.

When the mothers were asked if their children had ever had asthma, 20 of them replied "Yes," and all of these children (100%) were from the exposed area. Similarly, when these same mothers were asked if their children had ever experienced wheezing or whistling in their chest, 32 of them answered "Yes". Of these 32 children, 97% were from the exposed area, while only 3% of children from the control area reported such symptoms. Furthermore, more children from the exposed area reported wheezing or whistling in the chest in the past 12 months, more attacks of wheezing in the past 12 months, and more sleepless nights due to wheezing.

In cases of symptoms related to rhinitis, such as sneezing, coughing, and a runny or blocked nose, both children from the control and exposed areas experienced these symptoms. Similar observations were made for eczema. However, when mothers were asked about how often they administered antibiotics to their children for any infection, more mothers from the exposed area reported giving their children antibiotics at least once a year for an infection.

Tables 1-3 in Annex 2 present the responses to health-related questions categorized by area of residence (i.e., exposed and control areas). The core questions from the questionnaires used in the study are also provided in these tables.

2.7 Peak Expiratory Flow Rates of children living in the exposed area are substantially lower than those in the control area

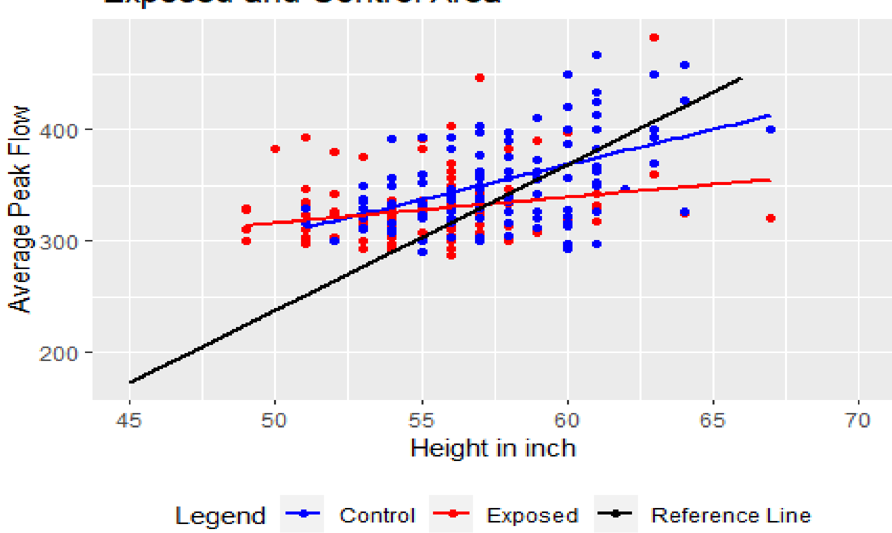
The average peak flow rate among students residing in the control area was higher than those in the exposed area (Chi-square test: Welch Two Sample t-test: $t = 6.15$, $df = 273.08$, p-value = 0.00).

2.7.1 Standard vs. Peak flow rate of students in exposed and control area

Figure 8 compares the average peak flow rates of children in the exposed and control areas to the expected standard rates for healthy children (black straight line), plotted against height (in inches). The graph reveals that:

1. Children from both the exposed and control areas have lower peak flow rates than the standard for healthy US children.
2. Children in the exposed area have substantially lower peak flow rates compared to both the control area and the healthy standard.

Figure 8. Average Peak Flow Value by Height (in) Amc
Exposed and Control Area



2.7.2 Regression Analysis: Peak Flow Rates and Anthropometric Factors

The regression analysis (Table 1) showed that the peak flow rates of children living in the exposed area were substantially lower than those in the control area and the standard peak flow rates for healthy children. Even after accounting for height and weight, children in the exposed area tended to have lower peak flow rates compared to those in the control area. On average, the peak flow rate was 15.75 units lower among children living in the exposed area compared to the control area, holding height and weight constant ($p < 0.001$). This extremely low p-value indicates that the difference is statistically significant.

Table 1. Regression coefficients for average peak flow

Variable	Estimate	Std. Error	t value	P value (>|t|)
Intercept	179.47	44.35	4.05	0.000
Height	2.15	0.99	2.16	0.031
Weight	1.38	0.51	2.73	0.006
Area: Exposed	-15.75	3.90	-4.04	0.000

3. Recommendation

Based on the main findings of the study. We recommend the followings:

1 Establish a Comprehensive Air Quality Monitoring Network in Lumbini and Surrounding Areas

1.1 Install permanent air quality monitoring stations:

- Set up a network of fixed air quality monitoring stations throughout Lumbini and nearby regions.

- Ensure continuous, year-round data collection on key pollutants, with a focus on PM2.5.

- Include measurements of other relevant pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), PM10, and PAHs.

1.2 Integrate meteorological monitoring:

- Equip each station with meteorological instruments to measure parameters that influence air pollution levels.

- Collect continuous data on temperature, humidity, wind speed, wind direction, precipitation, and solar radiation (solar radiation plays a significant role in the formation of secondary pollutants).

1.3 Implement real-time data reporting:

- Develop a system for real-time air quality data transmission and public reporting.

- Make air quality information easily accessible to residents and visitors through online platforms and mobile applications.

1.4 Ensure data quality and consistency:

- Regularly calibrate and maintain monitoring equipment to ensure accurate measurements.

- Implement quality control procedures for data collection and analysis.

1.5 Expand monitoring coverage:

- Strategically place monitoring stations to capture pollution variations across urban and rural municipalities, industrial areas, and LDZ.

- Consider the use of mobile monitoring units to supplement fixed stations and identify pollution hotspots.

1.6 Source apportionment studies:

- Conduct source apportionment studies to identify and quantify the contributions of various pollution sources, including industrial emissions, agricultural burning, forest fires, and transboundary pollution.

2. Conduct Health Impact Assessment and Mitigation

2.1 Long-term health studies:

- Conduct comprehensive, multi-year (longitudinal) studies on the health impacts of air pollution in Lumbini and surrounding areas.

- Focus on respiratory diseases, cardiovascular issues, and other health problems including IQ of children linked to air pollution exposure.

- Include diverse population groups in the study, with particular attention to vulnerable populations such as children, elderly, pregnant and postpartum women, outdoor workers and those in high-exposure occupations, people with pre-existing health conditions (e.g., respiratory or cardiovascular diseases), immunocompromised individuals, low-income communities, racial and ethnic minorities, individuals with disabilities.

- Collaborate with local healthcare providers and research institutions to ensure robust data collection and analysis.

2.2 Air Quality Improvement in Schools:

- Install high-efficiency air filtration systems in all classrooms within a 10 km radius of industrial clusters near the Lumbini Development Zone (LDZ).

- Regularly maintain and replace filters to ensure optimal performance.

- Monitor indoor air quality in schools to assess the effectiveness of filtration systems.

- Educate school staff, students, and parents about the importance of air quality and proper use of filtration systems.

2.3 Community Health Interventions:

- Establish mobile health clinics to provide regular check-ups and treatment for air pollution-related health issues.

- Implement a public awareness campaign on the health risks of air pollution and preventive measures.

- Distribute personal protective equipment, such as N95 face masks, to vulnerable populations during high pollution episodes. The N95 masks are highly effective at filtering out airborne particles, including those smaller than 0.3 micrometers. They can filter out at least 95% of airborne particulates, making them more effective than surgical or cloth masks. However, N95 masks are not effective against gases, vapors, or smells.

2.4 Health Impact Monitoring System:

- Develop a real-time health impact monitoring system that correlates air quality data with hospital admissions and health clinic visits (time series analysis).

- Use this data to issue timely health advisories and to inform policy decisions.

3 Implement a Phased Relocation Plan for Polluting Industries Near Lumbini

3.1 Industry assessment and categorization:

- Conduct a comprehensive survey of all industries within a 30 km radius of Lumbini.

- Categorize industries based on their pollution levels and environmental impact.

3.2 Develop a relocation strategy:

- Prioritize the relocation of high-polluting industries, such as cement factories and brick kilns, far away from human settlements.

- Establish a timeline for phased relocation, starting with the most harmful industries.

3.3 Create an eco-industrial park:

- Designate a new area for an eco-industrial park, sufficiently distant from Lumbini.

- Implement strict environmental standards and pollution control measures in the new location.

3.4 Provide incentives for relocation:

- Offer tax breaks and subsidies to industries that voluntarily relocate within the specified timeframe.

- Assist with land acquisition and infrastructure development in the new industrial area.

3.5 Enforce regulations:

- Implement stricter emission standards for industries that cannot be immediately relocated.

- Increase monitoring and penalties for non-compliance with environmental regulations.

3.6 Support affected workers:

- Develop job training and placement programs for workers affected by the relocation.

- Encourage relocated industries to prioritize hiring from the local workforce.

3.7 Rehabilitate vacated areas:

- Implement environmental restoration projects in areas formerly occupied by polluting industries.

- Create green spaces and promote sustainable land use in the buffer zone around Lumbini.

4 Agricultural Impact Studies: Assessing Air Pollution Effects on Lumbini's Farming Sector

4.1 Crop yield analysis:

- Conduct long-term studies comparing crop yields in areas with varying levels of air pollution exposure.

- Focus on major local crops, including rice, wheat, and vegetables.

- Analyze the effects of specific pollutants (e.g., PM2.5, ozone, nitrogen dioxide) on different crop types and growth stages.

4.2 Soil quality assessment:

- Perform regular soil testing to measure pollutant accumulation, particularly heavy metals and acidifying compounds.

- Evaluate changes in soil pH, nutrient content, and microbial activity in relation to air pollution levels.

- Assess the long-term impacts of pollutant deposition on soil fertility and structure.

4.3 Foliar damage studies:

- Examine leaf surfaces for visible damage caused by air pollutants, such as necrosis or chlorosis.

- Use microscopic analysis to detect subtle changes in leaf structure and stomatal function.

4. 4. Crop nutritional content:

- Analyze the nutritional composition of harvested crops to determine if air pollution affects their nutritional value.

- Compare results with historical data or crops from less polluted areas.

4.5. Pollinator impact assessment:

- Study the effects of air pollution on local pollinator populations, including bees and other insects.

- Evaluate any changes in pollination rates and their subsequent impact on crop yields.

4.6 Economic impact analysis:

- Quantify the economic losses to farmers due to reduced crop yields and quality.

- Assess the potential long-term economic consequences for the agricultural sector in the Lumbini region.

4.7 Mitigation strategies:

- Explore agricultural practices that can minimize the impact of air pollution on crops and soil.

4.8 Air quality monitoring in agricultural areas:

- Establish air quality monitoring stations specifically in agricultural zones around Lumbini.

- Correlate air quality data with agricultural productivity metrics.

5 Livelihood Assessment: Analyze Air Pollution's Impact on Economic Activities in the Lumbini Development Zone (LDZ)

5.1 Tourism industry analysis:

- Examine visitor/tourists statistics and trends, correlating them with air quality data.

- Survey tourists about their experiences and perceptions of air quality in Lumbini.

- Assess the economic impact of potential reductions in tourism due to air pollution.

- Evaluate the effects on hotels, restaurants, and other tourism-related businesses.

5.2 Cultural heritage preservation:

- Analyze the impact of air pollution and acid rain on Lumbini's World Heritage sites and monuments.

- Assess the costs associated with increased maintenance and restoration due to pollution damage
- Evaluate potential long-term risks to Lumbini's status as a UNESCO World Heritage site.

5.3 Local business impact study:

- Conduct surveys and interviews with local business owners to understand how air pollution affects their operations.

- Analyze sick leave patterns and productivity in various sectors.

- Assess the economic burden of health issues related to air pollution on local businesses.

5.4 Agricultural sector assessment:

- Evaluate crop yields and quality in relation to air pollution levels.

- Analyze the economic impact on farmers and agribusinesses in the region.

5. Healthcare sector analysis:

- Examine the increased burden on local healthcare facilities due to pollution-related illnesses.

- Assess the economic impact of additional healthcare costs on families and the community.

- Evaluate the potential for growth in the healthcare sector as a response to air quality issues.

6. Real estate market evaluation:

- Analyze property values and real estate trends in relation to air quality.

- Assess the impact on residential and commercial development in the LDZ.

7. Industrial sector impact:

- Evaluate the costs of compliance with environmental regulations for local industries.

- Analyze the economic impact of potential industrial relocation or closure due to air quality concerns.

8. Cost-Benefit analysis of air quality improvement:

- Conduct a comprehensive cost-benefit analysis of potential air quality improvement measures.

- Consider both the short-term costs and long-term economic benefits of pollution reduction strategies.

4. Acknowledgement

LEADERS Nepal would like to thank Friends Foundation, Berkeley for providing funding support to conduct this study.

Annex-1: Industries and their locations near the LDZ, as well as the locations of schools and the air pollution monitoring station.

S.N	Name of Industry	Industry type	Latitude	Longitude
1	Jagadamba Thread Industires	Thread	27.50553	83.36021
2	Jagadamba Jute Industries	Jute	27.50638	83.36554
3	Brize Cement	Cement	27.50628	83.36650
4	Jagadamba Cement	Cement	27.50608	83.36742
5	Tej Oil mill	Oil	27.50449	83.37268
6	Ambe Steel	Steel	27.50405	83.37328
7	Jayashee Flour Inustries	Flour	27.50418	83.37356
8	Siddartha Cement	Cement	27.50406	83.37351
9	Suprime Cement	Cement	27.50414	83.37812
10	Pathak Cement	Cement	27.50793	83.37372
11	Shyam Play Industries	Ply	27.50329	83.37420
12	Nepal Ambbuja Cement	Cement	27.51053	83.37490
13	Hira Briks Industries	Brick	27.50997	83.37441
14	Ganesh Briks Industries	Brick	27.50518	83.37929
15	P.L.C Braeaks	Brick	27.50480	83.35672
16	Goyenka Steel	Steel	27.50238	83.34805
17	Goyenka Cement	Cement	27.50238	83.34806
18	Rilayance Paper	Paper	27.50236	83.34797
19	Lumbini	Lumbini Temple	27.48139	83.27583
20	Sundi Ma Bi	School	27.49286	83.31849
21	Nilh Son Bording School	School	27.49228	83.31095
22	Nepal Rastriya Namuna Ma. Bi	School	27.46159	83.18861
23	Sibajeet Boarding School	School	27.46149	83.18859
24	E-sampler	Air pollution monitoring station	27.46714	83.27474

Annex 2

Table 1. Respiratory illnesses among children living in the exposed and control areas in LDZ.

Variable	Control Area (%)	Exposed Area (%)	Chi-square value	P value
Gender				
Female	96 (50.8)	93 (49.2)	0.23	0.63
Male	103 (47.9)	112 (52.1)		
Ever Wheeze/Whistling in the chest?				
Yes	1 (3.1)	31 (96.9)	27.62	0.00
No	198 (53.2)	174 (46.8)		
Ever Wheeze/Whistling in the chest in the past 12 months?				
Yes	0 (0.0)	27 (100.0)	0.93	0.34
No	1 (20.0)	4 (80.0)		
NA	198 (53.2)	174 (46.8)		
How many attacks of wheezing have you had in the past 12 months?	1 (100.0)	0 (0.0)	30.0	0.00
None	0 (0.0)	12 (100.0)		
1-3 times	0 (0.0)	3 (100.0)		
4-12 times	0 (0.0)	14 (100.0)		
>12 times	198 (52.9)	176 (47.1)		
NA				
In the past 12 months, how often, on average, has your child’s sleep been disturbed due to wheezing?	0 (0.0)	0 (0.0)	NA	NA
Never woken with wheezing	0 (0.0)	31.0 (0.0)		
Less than one night per week	0 (0.0)	0 (0.0)		
One of more nights per week	199 (53.4)	174 (46.6)		
NA				

Table 1 contd. Respiratory illnesses among children living in the exposed and control areas in LDZ.

Variable	Control Area (%)	Exposed Area (%)	Chi-square value	P value
In the past 12 months, has wheezing ever been severe enough to limit your child's speech to only one or two words at a time between breaths? Yes No	0 (0.0) 199 (51.2)	15 (100.0) 190 (48.8)	13.15	0.00
Have you ever had asthma? Yes No	0 (0.0) 199 (51.8)	20 (100.0) 185 (48.2)	18.41	0.00
In the past 12 months, has your child's chest sounded wheezy during or after exercise? Yes No	28 (15.8) 171 (75.3)	149 (84.2) 56 (24.7)	138.55	0.00

Table 2. Rhinitis among children living in the exposed and control areas in LDZ.

Variable	Control Area (%)	Exposed Area (%)	Chi-square value	P value
Have your child ever had a problem with sneezing? Or a runny or blocked nose when he/she did not have a cold or the flu?				
Yes	168 (92.3)	14 (7.7)	242.46	0.00
No	31 (14.0)	191 (86.0)		
In the past 12 months, have your child had a problem with sneezing or a runny or blocked nose when he/she did not have a cold or the flu?				
Yes	131 (87.9)	18 (12.1)	138.73	0.00
No	68 (26.7)	187 (73.3)		
In the past 12 months has his or her nose problem been accompanied by itchy-watery eyes?			8.11	0.00
Yes	30 (75.0)	10 (25.0)		
No	101 (93.5)	7 (6.5)		
NA	68 (26.6)	188 (73.4)		
In the past 12 months, how much did this nose problem interfere with your child's daily activities?				
Not at all	19 (100.0)	0 (0.0)	NA	NA
A little	8 (66.7)	4 (33.3)		
A moderate amount	3 (100.0)	0 (0.0)		
A lot	0 (0.0)	0 (0.0)		
NA	169 (45.7)	201 (54.3)		
Have your child ever had hay fever?				
Yes	16 (39.0)	25 (61.0)	1.48	0.22
No	183 (50.4)	180 (49.6)		

Table 3. Eczema among children living in the exposed and control areas in LDZ.

Variable	Control Area (%)	Exposed Area (%)	Chi-square value	P value
Have your child ever had a problem of itchy rash which was coming and going for at least six months? Yes No	197 (83.5) 2 (1.2) 0 (0.0)	39 (16.5) 163 (98.0) 3 (100.00)	259.59	0.00
Has this rash cleared completely at any time during the past 12 months? Yes No NA	166 (98.2) 31 (50.0) 2 (1.2)	3 (1.8) 31 (50.0) 171 (98.8)	80.24	0.00
In the past 12 months, how often, on average, has your child been kept awake at night by this itchy pain? Never in the past 12 months A little Less than one night per week One or more nights per week	187 (99.5) 12 (5.9) 0 (0.0) 0 (0.0)	1 (0.5) 193 (94.1) 11 (100.0) 0 (0.0)	NA	NA
Has your child ever had eczema? Yes No	5 (19.2) 194 (51.3)	21 (80.8) 184 (48.7)	8.78	0.00
In the past 12 months, how often, on average, have you given your child an antibiotics for any infection? Never At least once a year	1 (100.0) 124 (37.7)	0 (0.0) 205 (62.3)	94.87	0.00

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