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Exposure of Ambient $PM_{2.5}$ and Acute Upper-and Lower Respiratory Infection in Children Under the Age of Five in South and Southeast Asia

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Abstract: Studies on ambient $PM_{2.5}$ exposure and AURI and ALRI in regions such as South and South-East Asia, where levels of $PM_{2.5}$ are among the highest, are limited. We assessed the associations between ambient $PM_{2.5}$ exposure and AURI and ALRI in children under the age of 5 years from South and Southeast Asia. We identified subjects from the demographic health survey (DHS). We retrieved $PM_{2.5}$ information from the Atmospheric Compositional Analysis Group. Annual mean levels of $PM_{2.5}$ ranged from 21.3 to 73.2 μg/m^3. We performed the meta-analytical approach to obtain the pooled results. Our initial results show an association between ambient $PM_{2.5}$ exposure and AURI (OR 1.06, 95% CI: 1.01-1.11) but not ALRI (OR 1.03, 95% CI: 0.98-1.09). However, after controlling for indoor SHS, effect estimates became stronger for AURI and ALRI (OR 1.27, 95% CI: 1.04-1.54 and OR 1.20, 95% CI: 1.00-1.44) compared to the uncontrolled group. Our study shows an association between ambient $PM_{2.5}$ exposure and the prevalence of AURI and ALRI in children under the age of 5 years from South and Southeast Asia. Promoting awareness of air pollution in line with the implementation and monitoring of relevant policies is crucial in establishing clean air and health.

Key words: Respiratory infection, particulate matter ($PM_{2.5}$), children, second-hand smoke, pooled-analysis.

Introduction

Ambient $PM_{2.5}$ is becoming an important environmental risk because of its increasing role from occupying the fifth and has now become the main contributor to the global burden of disease (Cohen et al., 2017; Murray et al., 2020). Due to its size, $PM_{2.5}$ can reach deep into the lungs causing oxidative stress and inflammation (Anderson et al., 2012; D'Amato et al., 2010). Vohra et al. (2016) utilised the GEOS-Chem model to estimate global mortality from ambient $PM_{2.5}$, there was a double-fold in premature deaths that reached 10.2

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million compared to what is previously known (~4.2 million premature deaths) (Cohen et al., 2017; Vohra et al., 2021).

Young children are susceptible to the effects of air pollution due to their immature defense systems (Goldizen et al., 2016). This condition affects the balance of multicellular immune response, which could manifest in a disease (Glencross et al., 2020). Indeed, children exposed to long-term ambient $PM_{2.5}$ have been reported to show reduced lung function (Guo et al., 2019). Furthermore, studies suggest that exposure to ambient $PM_{2.5}$ is associated with AURI and ALRI in children under the age of five (Abudureyimu et al., 2022; Darrow et al., 2014; Kim et al., 2020; Sherris et al., 2021). However, there is a lack of evidence showing ambient $PM_{2.5}$ exposure and its effects on AURI and ALRI in regions such as South and South-East Asia, where levels of $PM_{2.5}$ are among the highest globally (IQAir, 2021; World Population Review, 2022). Thus, in this study, we assessed the associations between ambient $PM_{2.5}$ exposure and AURI and ALRI in children under the age of 5 years from South and South-East Asia.

Methods

Source of Data

We used secondary data available from the Demographic Health Survey (DHS). We focussed on the birth records dataset in the regions of South and Southeast Asia (Table 1) with the most recent GPS information. Subjects in this study included children under the age of 5 years.

Exposure

We obtained information on particulate matter ($PM_{2.5}$) from the Atmospheric Compositional Analysis Group using satellite observations, chemical transport modeling, and ground-based monitoring to produce annual mean geophysical $PM_{2.5}$ estimates at 0.01° × 0.01° (approximately 1 km × 1 km) (Hammer et al., 2020). After obtaining levels of $PM_{2.5}$ in each country, accordingly, with the years of study with the following details: 1) Bangladesh in 2017-2018; 2) India in 2015 to 2016; 3) Indonesia from 2002 to 2003; 04) Myanmar in 2015 to 2016; 5) Nepal in 2016, and 6) Pakistan in 2017 to 2018, we used QGIS 3.16.8 to calculate annual levels of $PM_{2.5}$ for every subject using the location of the DHS sampling cluster (ICF, 2002-2018b). When the survey spanned two years, we used mean levels of $PM_{2.5}$. Information of $PM_{2.5}$ represented clusters of surveyed households with the following numbers for each country: 1) 672 clusters in Bangladesh; 2) 28,526 clusters in India; 3) 1392 in Indonesia; 4) 441 clusters in Myanmar; 5) 383 clusters in Nepal; and 6) 561 clusters in Pakistan. We excluded 605 clusters from the following countries (Bangladesh: 12 clusters, India: 419 clusters, Indonesia: 161 clusters, Myanmar: 11 clusters, and Pakistan: 2 clusters) due to missing levels of $PM_{2.5}$ in the modeled dataset and left a total of 31,370 clusters for the analysis. One limitation of using the DHS GPS information to establish respondents' confidentiality is their random displacement, located up to 10 kilometers. In line with the study by Grace et al. (2015) that assessed the association between low birth weight and climate change using DHS datasets from 19 countries in Africa, we included this random displacement meaning that clusters can be displaced up to 10 kilometers of their recorded latitude and longitude (Grace et al., 2015).

Table 1: Characteristics of subjects included in the study

Characteristics	*Total*
Child:	
Age, years, mean ± SD	2.1 ± 1.4
Sex, n (%)	
Male	20120.3 (51.4)
Female	18851.0 (48.7)
Mother:	
Education, n (%)	
Higher	3623.0 (11.2)
Secondary	16958.8 (35.7)
Primary	6479.0 (27.8)
No education	11910.5 (25.2)
Residency:	
Type of residence, n (%)	
Urban	10088.3 (36.7)
Rural	28883.0 (63.3)
Solid fuel use, n (%)	
Solid fuel	26776.3 (69.2)
Non solid-fuel	12173.0 (30.8)
Population density, people per square kilometer, mean ± SD	12496.0 ± 24332.0
Levels of $PM_{2.5}$, μg/m^3, mean ± SD	
3 years prior to the study	50.0 ± 16.9
During the study	51.3 ± 16.5

SD: standard deviation, $PM_{2.5}$: fine particulate matter

Outcomes

We focused on two outcomes: acute upper respiratory infection (AURI) and acute lower respiratory tract infection (ALRI). AURI and ALRI were identified from the DHS questionnaires, "Whether the child had suffered from a cough over the past two weeks?" for AURI and "Whether the child had suffered from rapid breathing when he/she had the cough?" for ALRI (ICF, 2002-2018a). We categorised AURI and ALRI dichotomously (yes and no) in the analysis. The DHS birth dataset included subjects born five years before the study. Information on AURI and ALRI was available up to 2 weeks before the survey. Furthermore, the definition of AURI and ALRI has been used in previous studies (Hollm-Delgado et al., 2014; Mosites et al., 2014; Suryadhi et al., 2019).

Statistical Analysis

First, we assessed the effects of ambient $PM_{2.5}$ on AURI and ALRI in each country using the generalised estimating equation (GEE) analysis. The GEE analysis was used to account for correlations among mothers. Here, we adjusted the child's age (continuous: years), child's sex (dichotomous), mother's education (categorical: no education, primary, secondary, and higher), residential area (dichotomous: rural and urban), solid-fuel use (non-solid fuel and solid-fuel), and population density (continuous). We adjusted for solid-fuel use because of high solid-fuel use (more than 50%) in several countries (i.e., Bangladesh, Myanmar, and Nepal). Second, we performed a meta-analysis to obtain the pooled results by generating forest plots with information on the odds ratios, 95% confidence intervals, and the weight of each country. We used a random-effects meta-analysis that accommodates the analysis of multiple populations, generalizes to a similar population, and assess heterogeneity across studies or countries (Borenstein et al., 2010). The random effects followed the DerSimonian and Laird method (DerSimonian and Laird, 1986). Third, we further adjusted for second-hand smoke (SHS). Because some countries had no information on indoor SHS, we performed a subgroup analysis controlling for indoor SHS. Based on the DHS, we used the question "How often does anyone smoke inside your house? Would you say daily, weekly, monthly, less than monthly, or never?" to identify information on indoor SHS. Then we categorized it into high exposure (smoking frequency: daily) and low exposure to SHS (smoking frequency: less than daily).

Finally, we performed the following sensitivity analyses restricting the analysis on countries with information on indoor SHS. First, we evaluated annual levels of ambient $PM_{2.5}$ ($\mu g/m^3$) 3 years prior to the study conducted in each country using the mean as the exposure level. Second, we adjusted for the wealth index (categorical: poorest, poorer, middle, richer, richest), replacing the mother's education as an indicator of socioeconomic status in each country. For the results, we presented the estimates as odds ratios with 95% confidence intervals (CI) for every 10 $\mu g/m^3$ increase in $PM_{2.5}$. We used Stata version 15.0 for the analyses (StataCorp, College Station, TX, USA).

Results

We assessed children under the age of 5 years from 6 demographic health surveys in South and Southeast Asia, which included 268,394 subjects for AURI and 268,235 for ALRI analysis. Table 1 shows the characteristics of the subjects. Although almost equally distributed in the urban and rural, rural subjects mainly originated from Bangladesh, India, and Myanmar. Mean annual ambient $PM_{2.5}$ spanned from 21.3 to 73.2 $\mu g/m^3$.

The pooled analysis showed an association between ambient $PM_{2.5}$ and AURI (OR 1.06, 95% CI: 1.01-1.11), but not ALRI (OR 1.03, 95% CI: 0.98-1.09) (Figures 1 and 2). However, after controlling for indoor SHS, effect estimates became stronger for AURI (OR 1.27, 95% CI: 1.04-1.54) and ALRI (OR 1.20, 95% CI: 1.00-1.44) compared to the uncontrolled group (OR 1.01, 95% CI: 0.98-1.04 and OR 1.01, 95% CI: 0.95-1.07, for AURI and ALRI) (Figures 3 and 4).

In the sensitivity analyses, after using mean levels of $PM_{2.5}$ 3 years prior to the study as the main exposure and further adjusting for wealth index instead of the mother's education level, we found no substantial findings for AURI and ALRI (Figures 5 to 8).

Discussion

In this study, we assessed the effects of exposure to ambient $PM_{2.5}$ on AURI and ALRI in children under the age of 5 years. Annual mean levels of ambient $PM_{2.5}$ were higher than the WHO annual mean standard for $PM_{2.5}$ (World Health Organization, 2021) in the countries included in our study. Our initial findings suggested that $PM_{2.5}$ exposure correlated with the prevalence of AURI but not ALRI. However, after controlling for indoor SHS, ambient $PM_{2.5}$ exposure

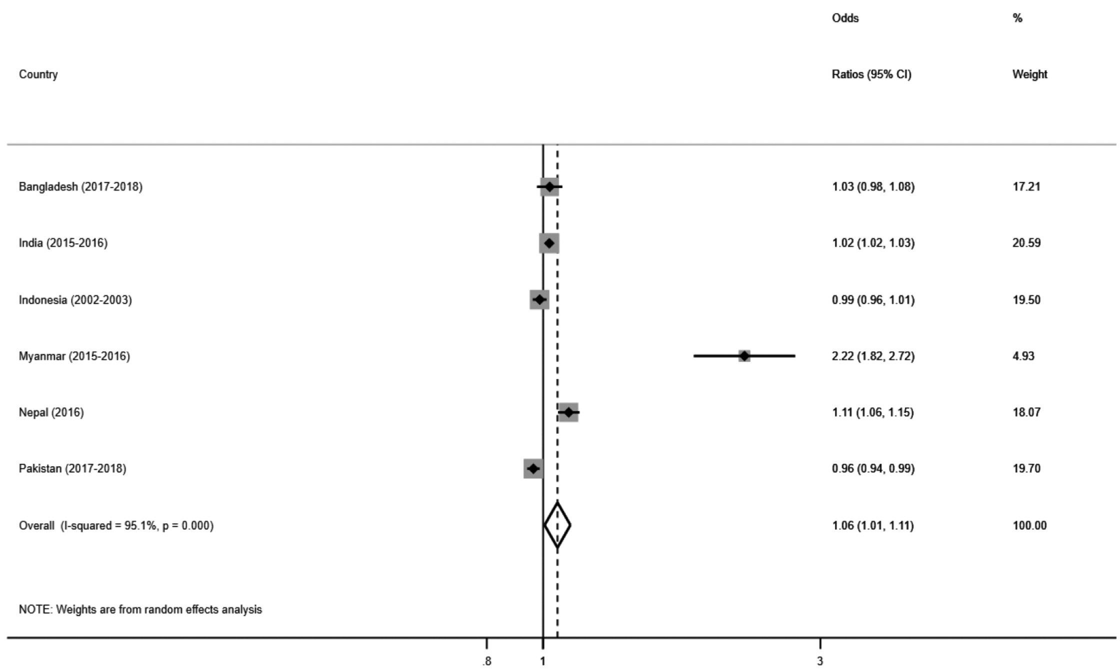

Figure 1: The association between exposure to $PM_{2.5}$ and acute upper respiratory infection: country-specific and pooled analysis.

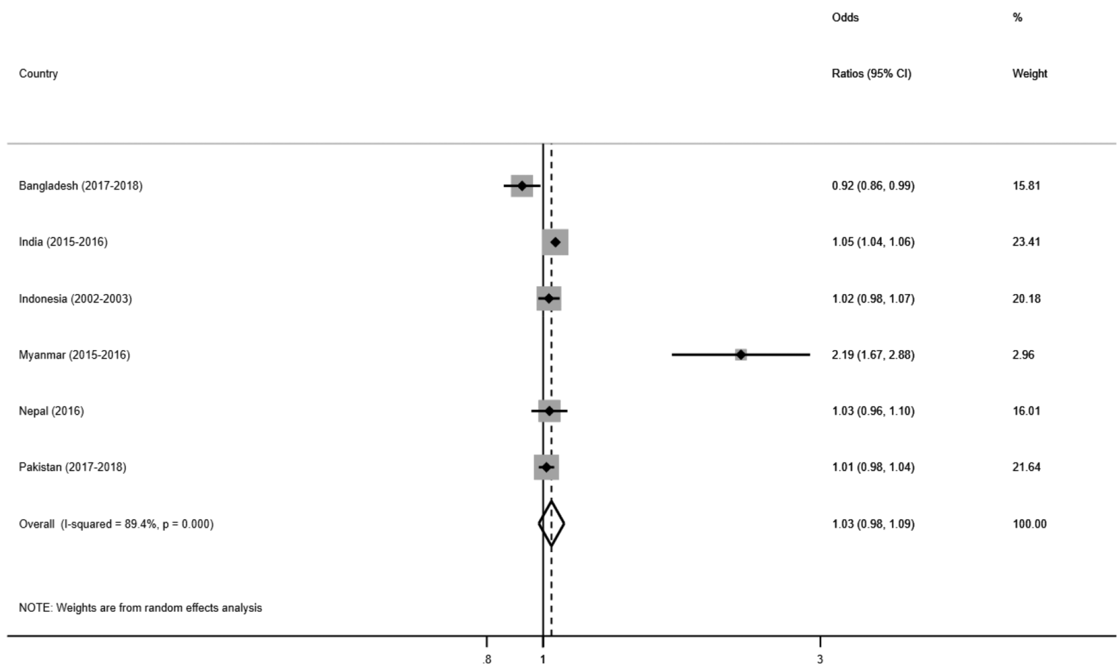

Figure 2: The association between exposure to $PM_{2.5}$ and acute lower respiratory infection: country-specific and pooled analysis.

was associated with the prevalence of AURI and ALRI in children under the age of 5 years from South and Southeast Asia.

Our findings align with previous studies suggesting that exposure to ambient $PM_{2.5}$ correlated with AURI in children (Darrow et al., 2014; Kim et al., 2020; Zheng et al., 2017). A recently published study by Kim et al. (2020) showed that although findings on the association between exposure to $PM_{2.5}$ are still limited and presented inconsistent findings, they found an association between

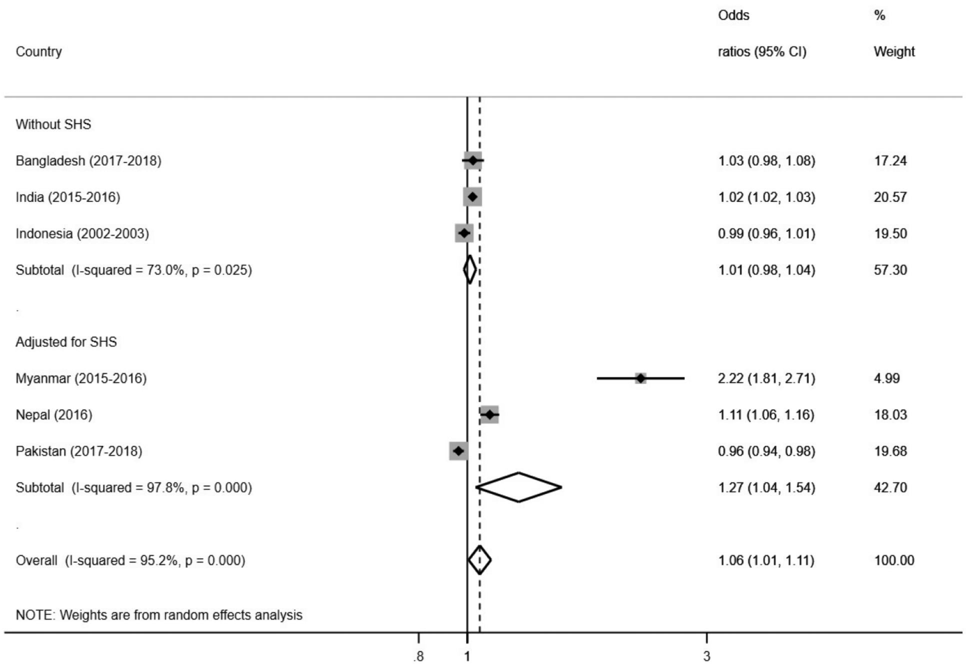

Figure 3: The association between exposure to $PM_{2.5}$ and acute upper respiratory infection: country-specific and pooled analysis by second-handsmoke.

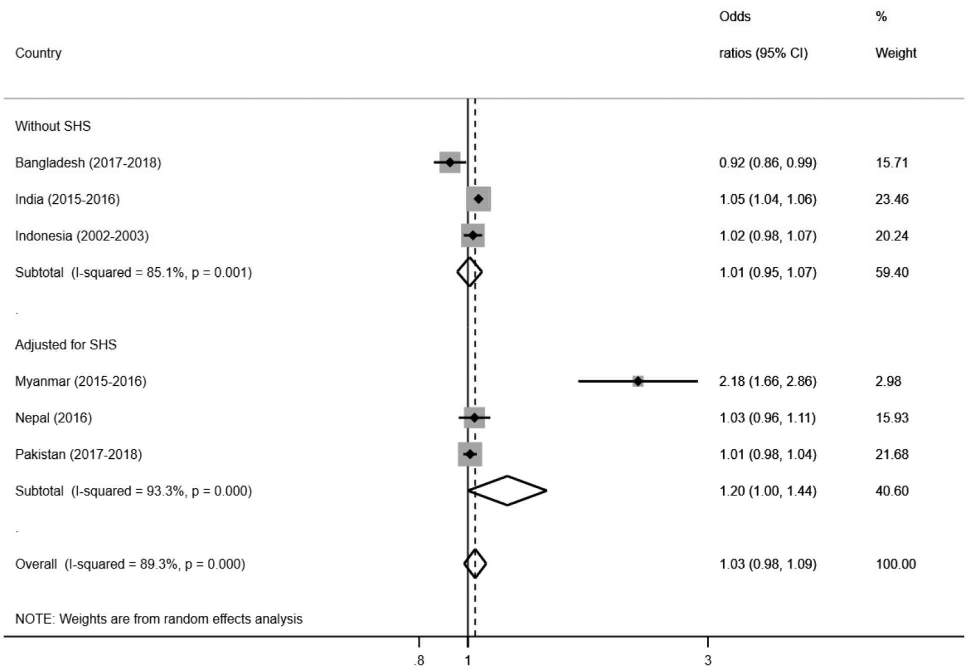

Figure 4: The association between exposure to $PM_{2.5}$ and acute lower respiratory infection: country-specific and pooled analysis by second-handsmoke.

AURI and bronchitis or bronchiolitis from short-term exposure to $PM_{2.5}$ in children aged 0-4 years (Kim et al., 2020). Bronchitis is a known form of lower respiratory tract infection (NHS, 2021). Although our findings for ALRI showed insignificant correlations with exposure to $PM_{2.5}$, this became significant when we controlled for indoor SHS. Wang et al. (2021) performed a study based on hospital visit rates in Taiwan has also reported that after adjusting for smoking rates, estimates for the effects of $PM_{2.5}$ on respiratory illnesses became significant.

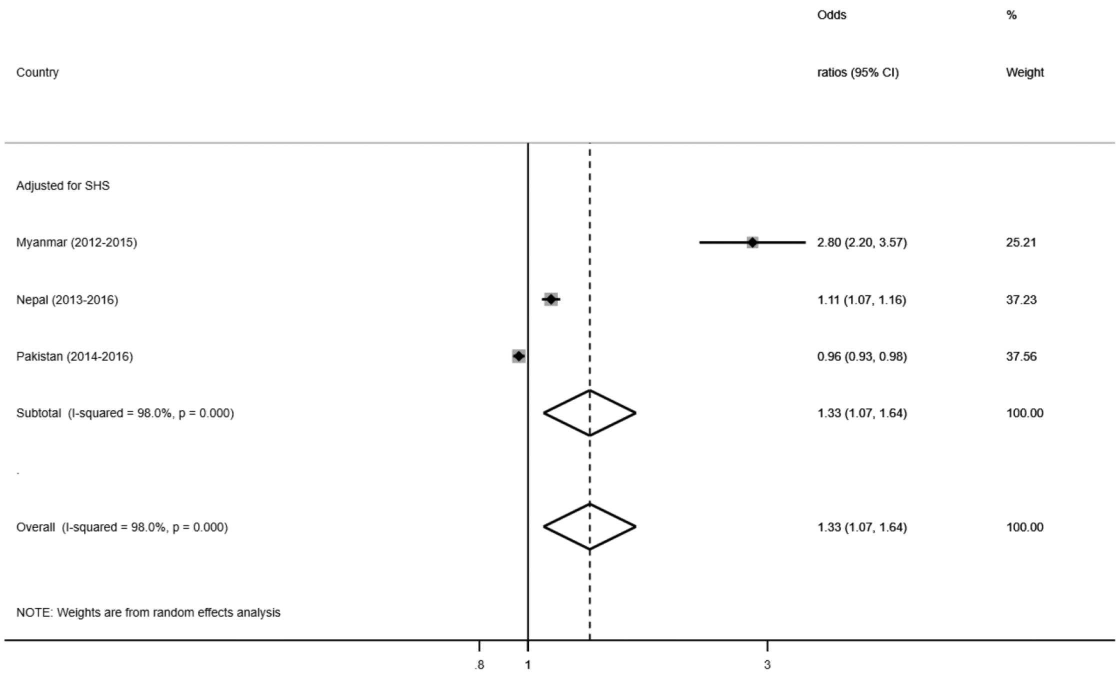

Figure 5: The association between exposure to $PM_{2.5}$ and acute upper respiratory infection: country-specific and pooled analysis using $PM_{2.5}$ levels 3 years prior to the study.

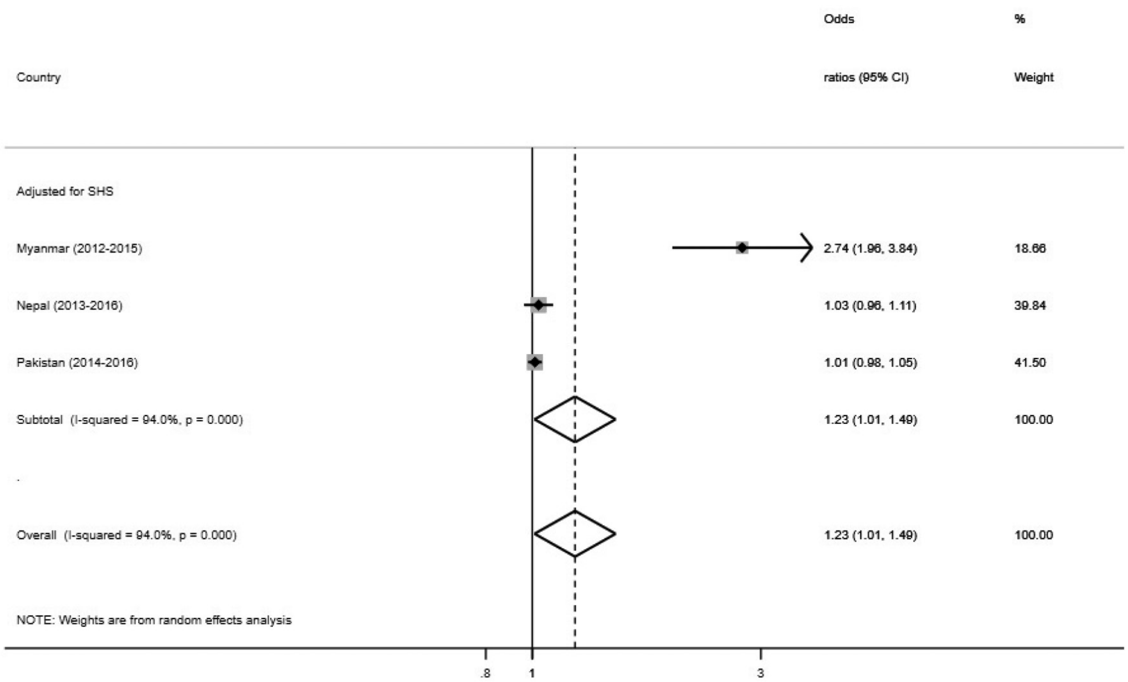

Figure 6: The association between exposure to $PM_{2.5}$ and acute lower respiratory infection: Country-specific and pooled analysis using $PM_{2.5}$ levels 3 years prior to the study.

According to the current WHO guidelines, the annual ambient mean level of $PM_{2.5}$ should not exceed 5 μg/m^3 (World Health Organization, 2021). However, in South and Southeast Asia countries included in this study, we observed higher annual mean $PM_{2.5}$, around 4.3 to 14.6 times higher than the current WHO guidelines. Similarly, IQ Air has shown in their world air quality report that one of the regions with the highest ambient $PM_{2.5}$ was South and Southeast Asia, with Bangladesh as the most polluted country in 2021 (IQ Air, 2021).

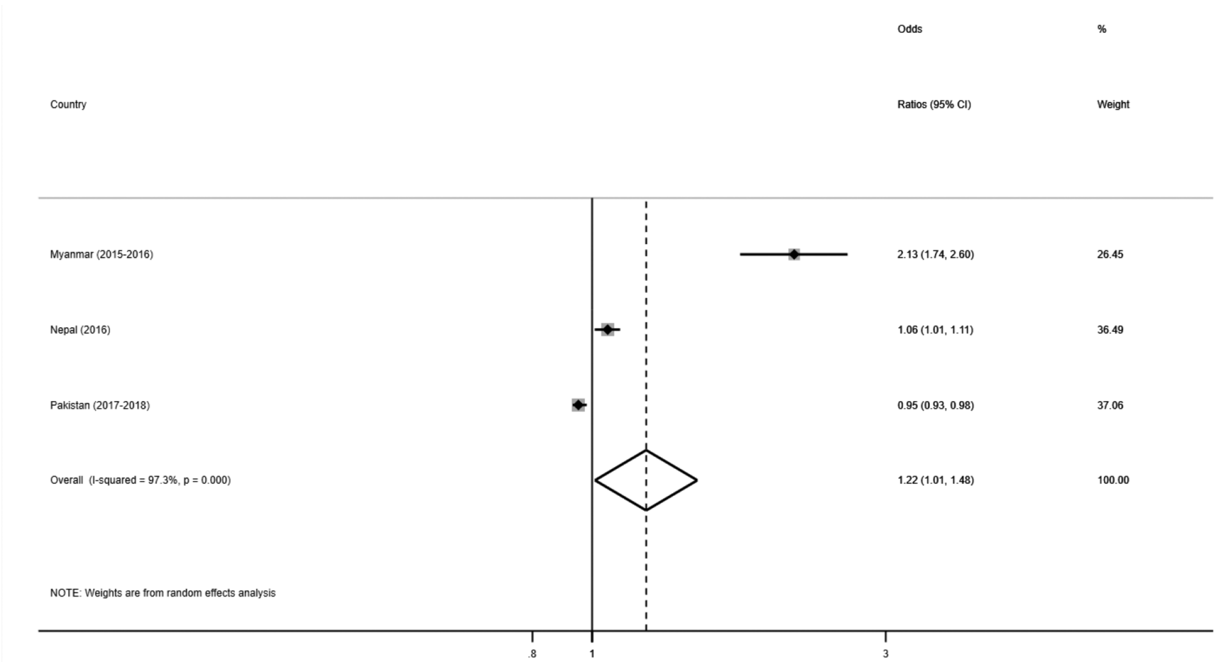

Figure 7: The association between exposure to $PM_{2.5}$ and acute upper respiratory infection: country-specific and pooled analysis adjusting for wealth index instead of mother's education.

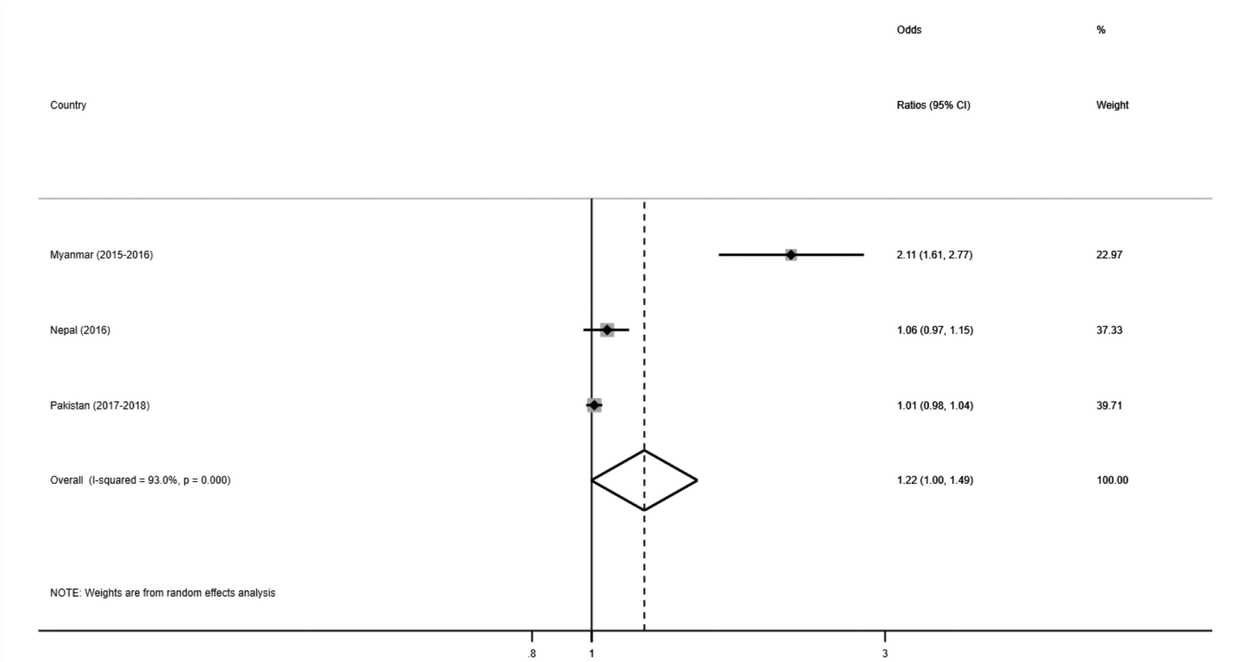

Figure 8: The association between exposure to $PM_{2.5}$ and acute lower respiratory infection: country-specific and pooled analysis adjusting for wealth index instead of mother's education.

Furthermore, countries in this study have not adopted the current WHO guidelines for ambient $PM_{2.5}$. The high level of $PM_{2.5}$ found in South and Southeast Asia could be influenced by rapid population growth, urbanisation, industrialisation, and economic capacity and focus. This could influence the level of $PM_{2.5}$ across South and Southeast Asia, which in our study varied. Exposure to high levels of ambient $PM_{2.5}$ brings alarming short- and long-term health consequences for children. The smaller the size of the particle, the more likely it could end up in the blood circulation resulting in detrimental effects on health or even death (Leiva et al., 2013; Yorifuji et al., 2015). Although there is a need for studies to examine the unclear biological mechanism in which air pollution affects the respiratory tract, the size, number, surface, and elemental composition of the particle could be responsible for causing oxidative stress and inflammation of the respiratory tract (Ghio et al., 2000; Hatzis et al., 2006; Neuberger et al., 2004).

Finally, our study has several limitations and strengths. The limitations include: First, the outcome variable in our study is based on self-reported responses, which can lead to a misclassification of the outcome status. However, this misclassification tends to be nondifferential, moving the effect estimates towards the null (Rothman, 2012). Second, this study assessed secondary data from a cross-sectional survey. Therefore, we could not assess the causal relationship between $PM_{2.5}$ exposure and AURI and ALRI which will be possible in other study designs such as cohort and case-control studies. Third, we included rural areas in our analysis. The subject's random displacement of up to 10 kilometers may result in the Berkson error in exposure which can introduce bias in the estimates. However, this bias tends to be small (Girguis et al., 2020). Fourth, there may be residual confounding from heredity factors due to the absence of a parent's disease history. However, after adjusting for the wealth index replacing the mother's education in each country, we found no substantial changes to the pooled estimates. The strengths of our study include: First, we used a nationally representative dataset from countries in South and Southeast Asia, assessing large numbers of children under the age of 5 years. Second, we presented the results from each country in a pooled analysis.

Conclusion

Our study showed an association between ambient $PM_{2.5}$ exposure and the prevalence of AURI and ALRI in children under the age of five in South and Southeast Asia. There is a need to improve awareness of air pollution and its adverse effects on child health, especially in areas where air pollution is an issue that continues to grow. Thus, strengthening, implementing, and monitoring relevant policies are crucial to establishing clean air and health.

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Contents