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LETTER

Air pollution exposure and its impacts on everyday life and livelihoods of vulnerable urban populations in South Asia

Amina Maharjan[1,*], **Sagar Adhikari**[1], **Rida Ahmad**[2], **Usman Ahmad**[3], **Zulfiqar Ali**[4], **Sugat Bajracharya**[1], **Jeevan Baniya**[5], **Sadikshya Bhattarai**[5], **Amit Gautam**[5], **Elisabeth Gilmore**[6], **Hein Min Ko**[7], **Nilar Myat**[7], **Theingi Myint**[7], **Parth Sarathi Mahapatra**[1], **Arabinda Mishra**[1] and **Chandni Singh**[8]

[1] International Centre for Integrated Mountain Development (ICIMOD), Nepal
[2] Lahore College Women University, Pakistan
[3] College of Earth and Environmental Sciences, University of the Punjab, Pakistan
[4] Environmental Health and Wildlife, Institute of Zoology, University of the Punjab, Pakistan
[5] Social Science Baha, Nepal
[6] Department of Civil and Environmental Engineering, Carleton University, Canada
[7] Yezin Agricultural University, Myanmar
[8] Indian Institute for Human Settlements, India
[*] Author to whom any correspondence should be addressed.

E-mail: amina.maharjan@icimod.org

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Abstract

Urban populations in South Asia are regularly exposed to poor air quality, especially elevated concentrations of fine particulate matter ($PM_{2.5}$). However, the potential differential burden for the urban poor has received little attention. Here, we evaluate the links between occupation, patterns of exposure to $PM_{2.5}$, and the impacts at an individual and household level for vulnerable populations in Lahore (Pakistan), Kathmandu (Nepal), and Mandalay (Myanmar). We conduct personal exposure measurements and detailed interviews, identifying a wide range of impacts at individual and household levels. Low-income populations are concentrated in occupations that expose them to higher concentrations. Individuals report a range of adverse health impacts and limited capacities to reduce exposure. The lost income, compounded with the costs of managing these health impacts and limited opportunities for alternative employment, can deepen the socioeconomic vulnerability for the household. Reducing these risks requires targeted interventions such as improved social safety nets.

1. Introduction

In South Asia, rapid economic growth, industrialization, and unplanned urbanization has led to deteriorating air quality [1]. According to the Global Disease Burden Study 2017, mean annual exposure to ambient PM2.5 concentration in the South Asian region was 84 μg m^{-3}, as compared to the global average of 46 μg m^{-3}. Many big cities in this region regularly exceed ambient air quality standards for fine particulate matter ($PM_{2.5}$) set by their respective countries and the World Health Organization (WHO) [2]. Within these cities, however, it is expected that the most disadvantaged populations will experience both higher exposure and more severe impacts [3–6]. However, by comparison to the Global North, the level of exposure and the impacts on socioeconomic vulnerable populations in the Global South have not been as widely studied [4].

To address this gap, this paper evaluates exposure and impacts of air pollution on marginalized urban dwellers in three cities in South Asia: Lahore (Pakistan), Kathmandu (Nepal), and Mandalay (Myanmar), who are often rural to urban migrants (Maharjan *et al* [7]). These poor urban dwellers may face greater risks from higher exposure than the general population due to limited occupational choice as well as increased vulnerability due to income constraints and lower access to health and social services. For example, the urban poor are more

likely to be employed in traffic-related occupations [8–10]. The impacts on the urban poor may also be poorly captured in mortality and morbidity measures of air pollution burdens, which tend to be applied at the population-level. Newer studies that focus on the effects of air pollution on lives and livelihoods, such as subjective well-being and quality of life [11], highlight the range of and the need to consider socioeconomic conditions when evaluating impacts. Other outcomes of air pollution exposure may have differential effects on already marginalized populations, such as lower labour productivity [12–14]; higher school absenteeism ([15–17]; and adverse educational outcomes [18, 19].

Migration, behavioural, and health scholars have established the importance of looking at the household as the decision-making unit, whereby households optimize their combined resources in making livelihood choices (e.g. [20–22]). Thus, the risks experienced by the urban poor from air pollution and the strategies they employ to avert or adapt to this risk may also be understood as a series of household-level decisions about occupational choices and the willingness to undertake risks from air pollution exposure. Additionally, the direct and indirect outcomes of air pollution such as illness may also be more comprehensively captured at the household level, especially as it tends to influence future exposure.

This work focuses on four main research questions:

1. How does air pollution exposure vary by occupations that are predominantly occupied by the urban poor?
2. How does individual occupational choice, socio-economic situations and risk perception affect exposure?
3. What are the impacts of this exposure as subjectively experienced by the individuals and their households?
4. What averting behaviours or measures are available and adopted by individuals and households to reduce exposure and/or moderate the impacts?

Focusing on five occupations that are held predominantly by the urban poor, we investigate exposure to ambient air pollution through personal measurements and patterns related to occupational activities. Second, we evaluate the effects of this exposure through semi-structured, life history interviews for individuals and their households, recording their perceptions of risk, immediate and long-term impacts on livelihoods, and access to and limitations of averting behaviours and measures. This mixed methods approach provides direct evidence of unequal exposure, the constraints of occupational choice and socioeconomic status that underpin this exposure, and the feedback of this exposure into increased vulnerability for the household. These dynamics then reveal multiple entry points for policy beyond air pollution mitigation strategies, including increased social safety provisions, which may moderate the effects of air pollution on the urban poor. To our knowledge, we are the first group to take a household perspective on the impacts of ambient air pollution, whereby we expand the effect of the adverse health impacts and loss of income from the individual to the household level.

2. Methods and data

To gain insight into exposure, impacts and response related to ambient air pollution we conducted semi-structured life history interviews, performed personal measurements of exposure to ambient air pollution, and ambient $PM_{2.5}$ diurnal pollution measurements in the three study sites. The study sites—Kathmandu/Nepal, Lahore/Pakistan, and Mandalay/Myanmar—were selected as they all suffer from air pollution issues. This set of cities was also selected to provide air pollution information for South Asia beyond those that are concentrated in Indian cities [23].

The original study was designed to record personal exposure measurements to ambient air pollution and conduct life histories for 30 households in each of the three cities. A total of six households were selected for personal exposure measurement and interviews across five occupations − 2-wheel taxi drivers, 4-wheel taxi drivers, street vendors, construction workers, and traffic police. We identified a set of criteria by which to select households for interview: individual working a minimum of 3 hours per day with a minimum of 3 years of experience in the current occupation, a minimum household size of two, and a minimum of 3 years in the urban centre. Then a convenience sampling approach was applied to select households. For recruitment of interview participants, local research assistants visited downtown areas, major traffic junctions, and market places and selected individuals who consented to give time and information necessary. Additionally, we aimed to balance male and female respondents in these occupations.

This study was unexpectedly interrupted by the first months of the covid-19 pandemic in early 2020 which required modifications to the original design. Personal exposure was limited to 30 respondents in Lahore, Pakistan as this was completed in January—February 2020. Diurnal patterns in ambient air quality measurements were used in their place to evaluate exposure patterns in Kathmandu. Unfortunately, for Mandalay, no ambient $PM_{2.5}$ measurements were available to compare with experienced exposure and impacts.

However, we opt to pool the life histories as part of understanding the impacts due to richness of the information even though we cannot link the air pollution exposure. The emergence of the Covid-19 pandemic before data collection also required some modifications to the life history data collection. It meant that only three occupations were interviewed as motorbike taxi and traffic police were difficult to find. We maintained the original sample size of 30 by selecting 10 households from the remaining three occupations. In Mandalay, Myanmar, only 4 traffic officers were interviewed, reflecting general challenges with interviewing traffic police officers.

2.1. Measurements of ambient PM2.5 and personal exposure

To capture exposure patterns by occupation, personal exposure measurements to ambient air pollution were conducted in the urban centre of Lahore in January—February 2020 for 30 individuals. During the measurement, individuals wore a light jacket with the battery-operated samplers at the back. Adjustable tubes were connected to both the samplers and placed near to the breathing zone of the individual. This approach is frequently employed to understand occupational exposure of air pollutants [24, 25]. A total of 8 hours of exposure measurement representing the active working period was collected. Measurements started between 8:00 AM to 10:00 AM and concluded between 4:00 PM to 6:00 PM. We used the Aerocet-831 (Met One Instrument, Inc.) for PM exposure and the microAeth, AE51 (AethLabs, CA) to measure black carbon (BC) [26, 27]. More details of these instruments and measurements can be found in (28).

In Kathmandu and Lahore, open access ambient $PM_{2.5}$ data were obtained from the US Embassy sites, available at an hourly resolution. These ambient concentrations were mapped to occupational patterns that were identified in the life history interviews. As noted above, no $PM_{2.5}$ information was available for Mandalay.

2.2. Assessments of impacts and behaviour using life history interviews

To capture perceptions and lived experiences of air pollution exposure, impacts, and averting behaviours we used a qualitative research method. We conducted life history interviews to capture a comprehensive understanding of the awareness about air pollution issues, the drivers of differential exposure, and its impacts on life and livelihoods of specific occupational groups. Life histories are particularly useful to provide a contextual understanding of how and why certain decisions are made by individual and to explore factors that have shaped decision processes [29, 30].

A total of 120 interviews were conducted during January—June 2020 in the three study cities. The interviews were conducted between February—March 2020 in Lahore, between January - February 2020 in Mandalay, and between March—June 2020 in Kathmandu. In each city, 30 households were selected for interview and in each household, the main interviewee was the person working in the chosen occupation. The secondary interviewee was his/her spouse or another adult member of the household, in order to capture both male and female views. Interviews were generally conducted in person, although some of the interviews, especially those in Nepal, were conducted in part or completely over telephone due to the pandemic lockdowns (see Supplemental Information SI 1 (available online at stacks.iop.org/ERC/4/071002/mmedia)). An initial set of questions were developed covering general household characteristics, occupational history, migration history, exposure to and impact of air pollution, coping mechanisms to reduce exposure and negative impacts. This questionnaire was tested at each site to review the approach of interview, questions, type of data being collected before finalizing the interview protocol (see Supplementary Information SI 2). At each site, two researchers conducted the interview with male and female members. Wherever possible, in keeping with local social norms, female researchers spoke with female research participants and male with male research participants. In most cases, the interviewer teams conducted the interviews over 2–3 visits, with repeat visits ensuring rapport building and completeness of data. The interview data were transcribed and coded based on themes relevant to the research questions. The coded data were then examined and grouped to highlight similarities and differences within the dataset as well as make associations between reported exposure and impacts.

3. Results and discussion

Here, we present the results and discuss how exposure and vulnerability affect the lives and livelihoods of the urban poor in South Asia. First, we present exposure as the intersection of ambient concentrations and patterns related to occupation, socioeconomic vulnerability that determine occupation and the economic constraints of the urban poor, and the perceptions of the risks from exposure. Second, we evaluate the impacts of these high levels of exposure on individuals and households. Specifically, we show how initial adverse health effects can compound and aggregate over time at the household level.

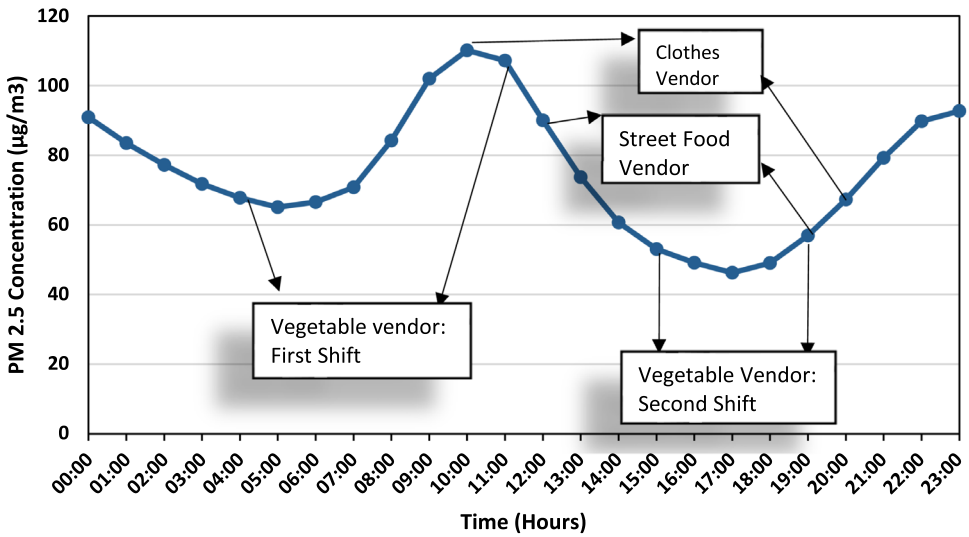

Figure 1. Variation in the working period of different street vendors in Kathmandu.

Table 1. Personal exposure to $PM_{2.5}$ (in $\mu g\,m^{-3}$) measured in Lahore by occupation.

Occupation	Average	Standard Deviation
Construction Labourer	46.3	32.4
Rickshaw Driver	68.0	27.9
Street Vendor	66.6	33.9
Taxi Driver	51.9	26.0
Traffic Warden	62.3	45.3

Note: For each occupation, the sample size is n = 6. Exposure was averaged over 8 hour with sampling from mid-January to mid-March 2020.

3.1. Exposure to ambient air pollution by occupation

Average personal exposure measurements by occupation in Lahore are presented in table 1. Exposure levels for all occupations exceeded WHO's 24 h air quality standards for $PM_{2.5}$ (15 $\mu g\,m^{-3}$) and Pakistan Ambient Air Quality Standard (35 $\mu g\,m^{-3}$). Similar to other studies (e.g. [24, 26, 31–33]), we found that exposure levels varied among the selected occupations and even within occupation depending on nature, time, duration and location of work. Average $PM_{2.5}$ exposure was relatively higher in rickshaw drivers and street vendors with average eight hours of exposure value of 68 $\pm$ 27.9 $\mu g\,m^{-3}$ and 66.6 $\pm$ 33.9 $\mu g\,m^{-3}$ respectively. Exposure was relatively lower for construction labourers and taxi drivers (46.3 $\pm$ 32.4 $\mu g\,m^{-3}$ and 51.6 $\pm$ 26.0 $\mu g\,m^{-3}$ respectively). This was because traffic wardens either stay put in high-density vehicle locations or travel from one traffic point to another, exposing them to high vehicular pollution.

In figure 1, we also show an example of exposure differences that can be observed within the occupation by time of day by matching up the ambient $PM_{2.5}$ measurements in Kathmandu with working patterns reported by each occupational group. For example, cloth vendor worked during the most polluted hours of the mid-morning to afternoon when demand is higher. Similarly, vegetable vendors worked during high pollution period of the early morning and low pollution period in late afternoon. By contrast, street food vendors worked primarily in the relatively less polluted hours from mid-day to late afternoon. These decisions related to timing of activities, and hence exposure, are largely determined by consumer demand and socio-cultural patterns.

Note: The figure depicts diurnal average $PM_{2.5}$ concentrations during the study period (January—April 2020).

3.2. Socioeconomic sources of exposure and vulnerability

While demand drives much of the exposure patterns, other reported sources, related to socioeconomic vulnerability, largely explain why an individual is employed in these occupations and how long they remain exposed to outdoor air pollution. Understanding these reported sources is a critical first step to developing risk

reduction policies. In this section, we report findings of key socioeconomic sources that explain air pollution exposure and impacts with illustrative quotes from the interviews that underpin our findings.

3.2.1. Occupational choice is driven by limited marketable skills, low levels of educational attainment, and social norms

Most individuals are exposed to high $PM_{2.5}$ concentrations because of their occupation. We did not observe any evidence that the individuals consider the risks from this elevated exposure when selecting their occupations. Rather their socioeconomic conditions underpin and restrict their occupational options. Our research participants were either illiterate (18 in Lahore, 8 in Kathmandu and 1 in Mandalay out of 30) or had less than 6 years of schooling (7 in Lahore, 6 in Kathmandu and 22 in Mandalay out of 30), and traffic police had more than 10 years of schooling (1 with 10 years of school, 6 with Bachelor's and 3 with Master's degree) . Of the occupations surveyed, only taxi drivers require having a formal driving license; other occupations did not require any formal skill certification, making it easy to enter the occupation.

Pre-existing vulnerabilities such as low education, limited marketable skills and constrained resources have been previously identified as major drivers for workers to engage in informal low wage employment ([34, 35]). Additionally, informal employment generally lacks basic social or legal protections or employment benefits [36] and hence, typically represent a survival strategy for workers and their families [37]. For migrant workers, consisting of 8 of research participants in Lahore, 19 in Myanmar and 27 in Kathmandu, poor earning opportunities in their villages interacted with low education and skills to compound vulnerability and constrain occupational choices in cities. Taxi driving, however, was also occupied by individuals with some secondary and tertiary education, particularly in Mandalay city, as the earning is relatively high and other jobs are scarce. For educated, younger (less than 40 years old) interviewees in Kathmandu and Lahore, however, the present occupation is a 'transit occupation' due to unfavourable socio-economic situation. This is expressed by a rickshaw driver in Lahore—'My father died suddenly leaving behind my mother and myself. So, in order to meet our basic requirements, I have started to work as rickshaw driver. I am looking for ways to continue my studies so that I can find better paying job in future. This is only a temporary work'

3.2.2. Economic constraints determine daily exposure

Total daily exposure for the urban poor can be largely explained by the need to earn sufficient funds to cover basic household needs. This constraint restricts the discretion of these individuals to undertake averting behaviour that may either shift or restrict their work patterns. For example, individuals with daughters of marriageable age in Pakistan showed high disregard for their own welfare, choosing to earn money to meet substantial expenses involved in a wedding.

The informal nature of these jobs can also exacerbate air pollution exposure. Labourers, for example, report that they are influenced by having no guarantee of finding work every day. Since each day's wages may be critical for an urban poor household, individuals need to work each day and may not adjust these hours for any reason as it results in wage loss. Similarly, taxi drivers and vegetable vendors from Nepal report that they must wait in areas that entail higher exposure to air pollution and vehicular emissions, such as main roads, bus stands, temple, and other locations. These areas have higher flows of people with better chances of selling products and services.

3.2.3. Perceptions of air pollution impacts influence exposure

Perceptions and understanding of air pollution determine the degree to which individuals may try to reduce exposure. These perceptions were captured through i) perceptions of air pollution occurrence, and ii) perceptions of the adverse impacts of air pollution (e.g., on health or income). Perceptions of air pollution varied across the three cities. In Lahore and Kathmandu, respondents were highly aware of the occurrence as well as the impact of air pollution and discussed the impacts of air pollution in detail whereas respondents from Mandalay did not perceive it to have significant adverse impacts.

Air pollution perceptions also differed by age, gender, and education levels, confirming previous studies ([38–41]). Younger respondents (< 40 years old) were more knowledgeable about air pollution. However, older individuals had experienced more adverse health impacts and focused on compounding risk factors rather than single risk factor. Women were in general more concerned with the adverse health impact than men, however, they were less able to attribute it to air pollution, as expressed by wife of a labourer - 'I do not know about it [air pollution]. I do not go out often and I do not know where my husband works either. But my husband often suffers from cough and cold due to his work'. However, when women were educated, their level of knowledge about air pollution and its adverse impacts were higher and they exhibited a high degree of risk averse decisions. This is well articulated by wife of a taxi driver in Lahore, 'I am well aware about the problem of air pollution in Lahore and its adverse health impacts. Therefore, when air pollution becomes excessive in the city, I ask my husband to work late and end early. During extremely smoggy days in winter. I ask him to not work at all.'

3.2.4. Gendered social norms result in disproportionate occupational and total exposure for women

Gender norms also determined exposure. While all female research participants highlighted economic compulsions in joining labour force, social norms also drive their occupational choices, particularly for women where patriarchal social norms are stronger (e.g. Kathmandu and Lahore). Thus, social capital and social acceptance were as important as earning potential and thus, women were in occupations with higher exposure and lower earnings. This is expressed by a street vendor in Lahore in her interview, 'I was forced to work as a street vendor as my husband is old, ill and cannot work. My son should have worked and supported family, but he is a drug addict. So, in order to support my family I started to work. But I am illiterate and have no marketable skills. In my social circle, people have experience working as street vendor. This is also an occupation where women are socially accepted and can earn sufficient to support my family's basic needs. Thus, I have decided to work selling fruits and vegetables in a hand-pulled cart in Lahore.'

As per the prevailing gender norm, all working women research participants mentioned that after completing outside jobs, they are still expected to do household works such as cooking, cleaning. In all the three sites fuel stacking was reported, with biomass fuel as a primary source of energy for cooking, which is known to cause indoor air pollution [42]. This dual responsibility (at home and work) of working women, therefore, can result in a 'double exposure' to elevated levels of ambient and indoor air pollution.

3.3. Impacts of air pollution: from individual health to family wellbeing

3.3.1. Health impacts for the individual

When asked about perceptions of adverse impacts of air pollution on their life and livelihoods, research participants elucidated adverse impacts on personal health. Everyday difficulties reported include illnesses and symptoms such as cold, cough, sore throat, headache, irritation/itching and on extremely polluted days, breathing difficulties and fatigue. When these ailments persist for a longer duration than respiratory disease (persistent cough, asthma, bronchitis), hypertension, and high blood pressure were reported. These reported types of adverse health effects are consistent with exposure to poor air quality.

Also, as our research efforts overlapped with the first part of the pandemic for some of our sites, individuals also experienced a sharp break in pollution levels. Due to reduced economic activities in the first months of the pandemic, the air quality improved [43, 44]. Thus, pandemic-related lockdowns provided a unique natural experiment for the research participants. Many participants noted an improvement in their health and attributed some impacts to air pollution by observing changes in their health condition before and during lockdown period.

3.3.2. Cascading risks on individuals and households

Mental health impacts of exposure to air pollution are well established [45] and are of particular concern as they can lead to increased aggression within households, impacting quality of life for entire family. Exposure to poor air quality can contribute to compound risks from high temperatures and humidity, extended exposure to noise, and aggressive behaviour at work to cause substantial mental stress. The adverse impact of mental stress then cascades to affect overall family well-being and quality of life. For example, a spouse of a labourer shared how her husband's work-related mental stress affects their household. She shared that when her husband is home, she asks her children not to make noise and tries her best to keep peace at home and not trigger her husband's aggression.

3.3.3. Income effects of ill-health compound vulnerability at the household level

Ill-health through lost income and medical bills can push households into a vicious cycle of exposure and vulnerability and ultimately into a poverty trap. We illustrate these dynamics in figure 2. When the primary or only income earning household member falls ill, the economic precarity of the household can increase quickly. The effect of these lost wages is often compounded by medical bills, for example:

'The household medical expenditure amounts to NPR 10,000–30,000 (USD 86–258) per annum. Considering average earning ranging between NPR 10,000–30,000 per month, the medical expenses were equivalent to almost a month's earning annually.' (Taxi driver in Kathmandu)

It is commonly reported that households take out loans to cover both the loss of income and increased medical expenditures, as they generally have little savings. As loans run out, the disease burden affects the affordability of children's education and food and nutrition security of the entire household. This pushes the earning household member to return to work as soon as possible and to working even longer hours to recover the income losses. Paradoxically, this entails increased exposure to air pollution and over time, more acute and chronic health effects that would further reduce income and increase the costs of treatment, thus entrenching poverty and vulnerability.

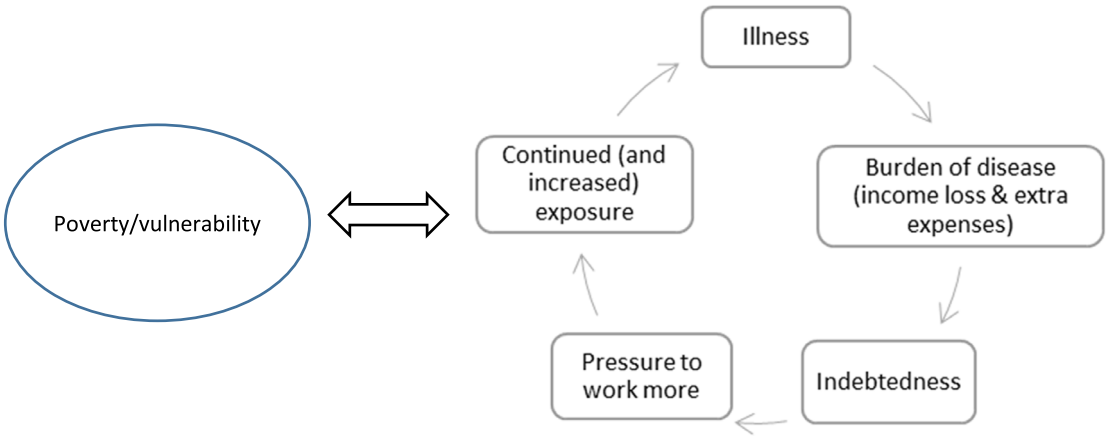

Figure 2. Cycle of increasing exposure and vulnerability for the urban poor.

3.4. Explaining the limited averting behaviours and responses

The urban poor face multiple risks—economic, physical, social and environmental—at home and at work. Air pollution was only one of the risks. Thus, despite acknowledging the existence of air pollution issue and awareness about their adverse impacts, it was not considered a 'priority' risk and low overall responses were observed. Poverty, struggle to provide basic needs (such as food, shelter, education, health), and informal nature of work are more pressing [46], while air pollution is perceived as '*part of their job*' and something to '*live with*'. The fatalism and helplessness of vulnerable population towards addressing the risks presented by exposure to air pollution may also reflect the lack of agency that is often associated with lower socio-economic status and restricted occupational choice [47–50]. Further, they largely reported that only way to reduce exposure is to change jobs, which they do not perceive as a real option given their limited levels of education and skill. This feeling of having no alternatives may also further reduce their willingness to perceive the risks of air pollution and take averting action [28]. Further, there was no mention of receiving any support from local authorities or non-government stakeholders in dealing with air pollution exposure.

4. Conclusion

All three cities in this study experience elevated levels of ambient air pollution, specifically $PM_{2.5}$, and the urban poor are often exposed to higher than the average levels that are determined by occupational patterns. The urban poor perceive air pollution as a risk factor affecting their health and livelihoods and articulate a wide range of direct and compounding consequences for themselves and their households. Precarious livelihoods with low and often irregular incomes, as well as inadequate awareness about possible risk reduction responses, means that the urban poor are unable to reduce their overall exposure and risk to air pollution. We also find that the secondary impacts of air pollution to the household may trap the individual and the household in a cycle of continued exposure and vulnerability.

This points to a clear gap in the management of air pollution, which has generally focused on reducing overall population-level exposure. While there is no questioning the need for general air pollution mitigation, the evidence of differential burdens of air pollution and the links to pre-existing vulnerabilities also shows that mitigation policies by themselves cannot address the needs of the urban poor. Risk reduction approaches that provide broad social and income support (e.g., access to paid medical leave) would increase the agency of these workers to take averting actions, such as reducing hours on high pollution days or purchasing a high-quality protective mask. Additionally, direct support to households that are managing the burdens of illness could ensure that the effects are not transmitted through increased economic precarity, reduced capacity to pay for school fees, and food insecurity. In this way, achieving air pollution goals becomes part of a comprehensive strategy to reduce poverty and vulnerability, recognizing the importance of environment, social and gender considerations.

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The views and interpretations in this publication are those of the authors and are not necessarily attributable to ICIMOD.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Ethics declarations

All clearances for this study were completed and adhered to. Participants' consent was taken before the interviews in all the study sites. The bioethical clearance for the personal exposure measurements in Lahore was taken from the University of Punjab, Lahore to conduct the experiment and verbal consent was also taken from each of the respondents before the start of the sampling.

Declaration of conflict of interest

Competing interests: The authors declare no competing interests.

Author Contributions

A.M., A.Mi., P.S.M. developed the study concept; A.M., P.S.M., S.A., C.S., Z.A., T.M, J.B. contributed to study design; R.A, U.A., S.B., A.G., H.M.K, N.M, helped in data collection, transcribing and analysis under the direction of C.S., A.M., P.S.M., S.A., S.B, Z.A., T.M., J.B; A.M., S.B, C.S, E.G. drafted the manuscript; A.Mi., C.S., E.G. helped in final version of the paper

ORCID iDs

Amina Maharjan https://orcid.org/0000-0003-4002-3242
Elisabeth Gilmore https://orcid.org/0000-0002-9037-6751
Parth Sarathi Mahapatra https://orcid.org/0000-0001-6019-1644
Chandni Singh https://orcid.org/0000-0001-6842-6735

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