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Air pollution walk as an impact education tool for air quality sensitization: a pilot from an Indian megacity

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Abstract. Air pollution has become a serious matter of concern in the global south, and a significant amount of funding has been used to create awareness of air pollution. The conventional method of sensitization relies on workshops where slide-based presentations, images, plots and graphs are shown to participants. However, sensitization about air quality using such an audio-visual format might not be sufficient to create adequate impact. Here, in this study, we propose a new sensitization technique, the pollution walk, where participants and a subject matter expert will walk through different urban micro-environments with a live air quality monitor. A pilot involving three such pollution walks with 24 participants was conducted in a South Asian megacity, and pre- and post-walk surveys were conducted. The results indicate a greater sense of understanding among the participants, and the multi-disciplinary nature of the air pollution problem has been communicated well. To understand the long-term impact, a survey after 1 year was conducted which clearly indicates high levels of awareness and behavioural changes among the participants.

1 Introduction

The IQAIR Report (2020) showed that 37 of the 40 most polluted cities on the globe are from South Asia, and the national ranking shows that India (Rank 5) is leading in terms of poor air quality; 33 % of global deaths due to air pollution occur in South Asian countries, and air pollution contributes to approximately 11 % of all these deaths. The global burden of disease study shows that 1.24 million deaths in India were attributed to air pollution in 2017, and both indoor (0.48 million deaths) and outdoor (0.68 million deaths) sources contributed significantly (Balakrishnan et al., 2019). Overall, the air quality over Indian cities has a significant health impact on citizens (Guttikunda and Goel, 2013; Gargava and Rajagopalan, 2015). Among air pollutants, $PM_{2.5}$, or particulate matter with a diameter of less than 2.5 µm, is considered the dominating air pollutant due to its immense health impact (Balakrishnan et al., 2019). Generated via a combustion process, these tiny particles can enter into human lungs and increase the risk of lung cancer, chronic obstructive pulmonary disease and asthma (Apte et al., 2018: Bu et al., 2021). $PM_{2.5}$ exposure is decreasing global life expectancy by 1 year, and for polluted regions over Asia, it can decrease life expectancy by up to 1.9 years (Apte et al., 2018).

Awareness of air pollution could play a vital role in reducing air pollution (Selden and Song, 1994; Liao et al., 2015; Veloz et al., 2020). A lack of awareness among air-pollution-vulnerable groups was reported in previous studies conducted in the global south (Guttikunda et al., 2014; Mor et al., 2022). The scope of air pollution in educational curricula is limited and confined to indoor syllabus-oriented modules, whereas there are scopes to improve awareness beyond a syllabus-oriented approach (Huo et al., 2020). Community-based outdoor education approaches have been proven to improve the understanding of participants irrespective of their age groups (Commodore et al., 2017; Szczytko et al., 2020; Garip et al., 2021). Fieldwork, community learning and outdoor engagement could help in developing better environmental literacy and could inspire people to shift towards more sustainable consumption and environmentally friendly practices (Christie and Waller, 2019; Persson et al., 2022). Previous studies have shown that citizen participation programmes or "citizen-science"-driven air quality monitoring have been able to create active engagement and result in larger social objectives in cities in the global north (Nali and Lorenzini, 2007; Gabrys et al., 2016; Commodore et al., 2017; Varaden et al., 2018). However, such studies in the polluted global south are not available where impact sensitization has been created through a citizen science programme on air quality measurement.

Kolkata is one of the megacities in the eastern part of India, with 14.1 million people (census data taken from https://bengallocal.in/districts/kolkata/, last access: 22 June 2023). Previous studies have reported poor air quality and associated respiratory illness in the city (Ghose et al., 2005; Haque and Singh, 2017; Dutta and Pal, 2023). Industry, transport and biomass burning are known to be major sources of air pollution in Kolkata, and approximately 10 200 people die because of air pollution per year (Lelieveld et al., 2015; Gurjar et al., 2016). The deterioration of air quality is coupled with a lack of air quality information, public display and awareness among citizens. The present study intends to introduce a new awareness-building tool to improve understanding of air pollution among citizens. A walk across different parts of the city with air quality monitors and live data displays (in brief, a "pollution walk") was conducted with diverse groups of citizens, and several complex air-quality-related topics were introduced. To the best of our knowledge, such innovative tools have not been introduced in India before and globally: we have only found a single approach in London (Gabrys, 2017). In the global north megacities, where air pollution has become a primary reason for premature mortality, no such innovative sensitization techniques have been used to the best of our knowledge.

2 Methodology

The air pollution walk began with a short pre-walk discussion, and then the participants were asked to follow a specific path comprised of roads, food stalls, traffic intersections, etc., with a handheld $PM_{2.5}$ monitor (see the Supplement). The $PM_{2.5}$ monitoring procedure is discussed in detail in Sect. 2.3. Short training was given to all the participants regarding the operation process of the $PM_{2.5}$ monitor and data collection procedure. On the path, the participants were sensitized about the relevant sources by showing them the live $PM_{2.5}$ data, and detailed explanations were provided. Post-walk, a focus group discussion was organized with the participants from the walk to discuss the results. Three such air pollution walks were organized during the month of July 2022 with 24 participants altogether. Pre- and post-walk surveys were done with the participants. A follow-up open-ended survey was done after 1 year (July 2023) with the participants. The walk works as a citizen science programme where scientists designed the programme and walk with the participants, who act as contributors to the project (Wildschut, 2017).

2.1 Route for demonstration

Several aspects need to be taken care of before finalizing a route for demonstrating air quality. The route that has been selected for the study was comprised of indoor housing, followed by a kitchen, minor roads with residential houses and commercial outlets, a major road, a busy traffic intersection, roadside food stalls, and an industrial unit. Each of the micro-environments has different sources of air pollutants. The major roads have a stretch of 400 m, and this includes a busy cross section with 1 min of signal time. On average, approximately 10 000 cars pass during office hours on the major road. The minor roads ($\sim$ 600 m long) have one-tenth of the traffic as compared to the major road. Multiple roadside restaurants using biomass as cooking fuel were observed during the trial. The industrial unit uses smelters and is located on the main road. The entire trail map is represented in Fig. 1. The walk took place during busy hours while most of the city's people were returning home from the office (18:00 GMT+5:30) and took nearly 2 h to finish.

2.2 Targeted air pollutant characteristic

Traditionally, air quality has been measured using a fixed monitoring station installed at traffic sites or background sites to understand the compliance and trend of air quality (Varaden et al., 2021). Such stations are limited in terms of data availability and accessibility to citizens and also do not represent individual pollutant exposure (Snyder et al., 2013; Steinle et al., 2013). The recent advancement of low-cost mobile air quality sensors provides a unique opportunity to improve spatial monitoring extents as well as the perception of air quality among citizens (Nieuwenhuijsen et al., 2015). Live data also provide an interesting scope to explain several air quality-related topics which generally remain untouched during a conventional workshop. Here, the participants were able to visualize (a) how ventilation improves indoor air quality, (b) differential emission from different sources, (c) improvement of air quality away from the sources, (d) the impact of meteorology on air quality and (e) the spatial distribution of air pollutants. The pre-walk briefing was conducted in a room where the entire procedure was described to the participants, and we also measured the ambient $PM_{2.5}$ concentration in the room. Then the participants were asked to visit the adjacent kitchen to monitor the indoor pollution contribution from cooking. Then the participants moved outside, and it was explained to them how ventilation helps to dilute air pollutants. Further, the participants walked through major and minor roads and measured air pollutants in different settings. The participants walked through

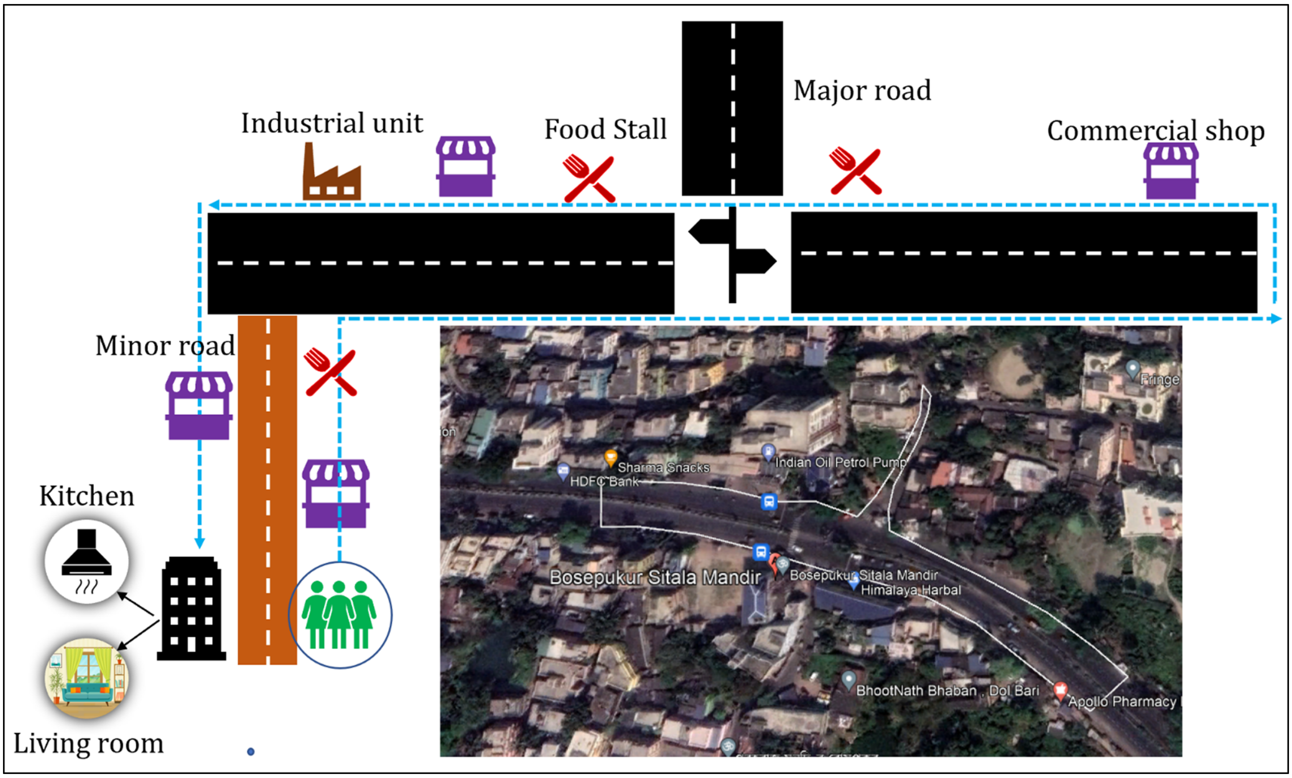

Figure 1. Schematic and satellite image of the pollution walk path for the study. The blue dashed line indicates the walking trail (© Google Earth).

the same route to the room, and a semi-structured interview was conducted.

2.3 Measurement of the air pollutant

$PM_{2.5}$ has been considered this study's target pollutant since it is indisputably the most harmful air pollutant in India (Balakrishnan et al., 2019). A high-precision digital $PM_{2.5}$ concentration sensor, Plantower PMS5003, has been used to measure the mass and amount of suspended particulate matter ($PM_{2.5}$) in the air. This PMS5003 sensor has been integrated with an Arduino Mega 2560 micro-controller. A temperature and relative humidity sensor, DHT22, has also been attached to the micro-controller. A DS3231 real-time clock (RTC) module has been integrated with the system to provide a precise time and date to the $PM_{2.5}$ data. A NEO-6M GPS module has been connected to the system to receive georeferenced $PM_{2.5}$ pollution data at any location. An LCD has been interfaced with the system to display the $PM_{2.5}$ data. For real-time data capture, a micro SD card has been connected to the system using a micro SD card module. A 18650 lithium battery shield has been used to supply the required power to operate this system. The code has been written and uploaded to the Arduino Mega 2560 micro-controller board using the Arduino IDE 1.8.19 software. The $PM_{2.5}$ monitor has been calibrated against a reference monitor, and relative humidity corrections have been made following the previous literature (Badura et al., 2018; Feenstra et al., 2019; Jha et al., 2021).

2.4 Participants and interviews

Three air pollution walks were conducted thrice, with a total of 24 participants altogether. The participants came from different socio-economic and educational backgrounds summarized in Table 1. The age range of the participants was from 18 to 68 (all the participants were adults, and minors were accompanied by their parents). Among the participants, there were students, government and private employees, homemakers, and retired professionals. Pre- and post-walk surveys were conducted among the participants. The immediate post-walk interview was conducted to understand whether this improved their understanding of air pollution and whether they preferred this format (pollution walk) over audio-visual presentation-based sensitization. Follow-up interviews were conducted 1 year after the walk to understand how the learning impacted their understanding of air pollution and whether the takeaway messages were integrated into their lifestyle or not.

The entire questionnaire from the interviews is presented in Fig. 3.

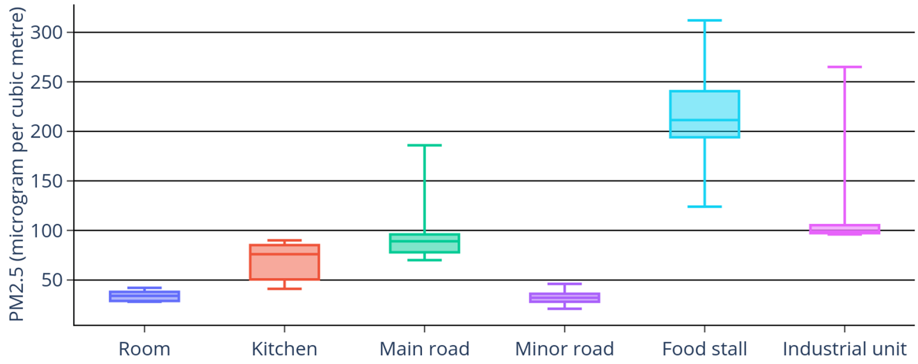

Figure 2. Box plot depicting the $PM_{2.5}$ concentration profile in different micro-environments during the pollution walk.

Table 1. Description of the backgrounds of the participants.

Variables	Category	Percentage ($n = 24$)
Gender	Male	46 % ($n = 11$)
	Female	54 % ($n = 13$)
	Unknown	0 % ($n = 0$)
Age	< 25	25 % ($n = 6$)
	25–60	54 % ($n = 13$)
	> 60	21 % ($n = 5$)
Education	Undergraduate	29 % ($n = 7$)
	Postgraduate	71 % ($n = 17$)
Occupation	Student	25 % ($n = 6$)
	Employed	38 % ($n = 9$)
	Unemployed	17 % ($n = 4$)
	Retired	20 % ($n = 5$)

3 Results

3.1 Distribution of $PM_{2.5}$

Participants measured $PM_{2.5}$ concentrations in different micro-environments during the pollution walk (Fig. 2). The average $PM_{2.5}$ concentration was found to be $85 \pm 66\,\mu g\,m^{-3}$, which is approximately 17 times higher as compared to World Health Organization (WHO) standards (https://www.who.int/tools/air-quality-standards, last access: 22 June 2023). Higher $PM_{2.5}$ concentrations were observed in the kitchen ($70 \pm 19\,\mu g\,m^{-3}$) as compared to the room ($34 \pm 5\,\mu g\,m^{-3}$). The pollution level dropped after the participants began the outdoor walk, due to the increased ventilation. As the participants started walking toward the main road, gradual increases in the pollutant concentration were observed. The highest outdoor concentration was observed when the participants stopped at a busy traffic intersection. As the signal turned green, vehicles started their engines and the participants measured the $PM_{2.5}$ concentration ($186\,\mu g\,m^{-3}$). The average concentration of $PM_{2.5}$ on the main road was found to be $98 \pm 31\,\mu g\,m^{-3}$. An exponential fall in the $PM_{2.5}$ concentration was observed when the participants entered the minor roads with lower traffic density. The participants also measured the pollutant concentration near the roadside food stalls, where biomass was used as a fuel source. The smoke from the food stall was clearly visible, and the participants measured $214 \pm 51\,\mu g\,m^{-3}$ 1 m from the oven. Concentrations near a small workshop near the streets that uses a smelter were found to be $121 \pm 53\,\mu g\,m^{-3}$. When coming back, the participants also measured these points to re-check the concentration, and it was found to be comparable. During the walk, pollutants were monitored during windy periods where substantial reductions in concentration were observed.

3.2 Participant perception of air quality from the pre-walk and post-walk times

The pre-walk and post-walk surveys were conducted to understand the improvement of a participant's knowledge of air pollution, sources and impacts (Fig. 3). Some questions are very basic and should be answerable by people who regularly read news reports on air pollution. Other questions are more advanced and require more in-depth understanding to answer. Not all participants know about the deteriorating air quality over Kolkata or that smaller-sized particles are more harmful as compared to larger-sized particles. Half of the participants still considered gaseous pollutants to be the major air pollutants in the atmosphere. It was also found that participants have a basic knowledge of indoor pollution, and a significant proportion identified incense sticks as harmful air pollutant sources and also supported the statement that indoor pollution is a significant source of particulate matter pollution. It was evident that most of the participants did not have a specific idea regarding air pollution sources or monitoring overall.

The post-walk survey was conducted just after the walk and before the discussion. A significant improvement in air quality knowledge can be observed (Fig. 3). Specifically, answers to the specific questions on how the smaller-sized particulate matter has an impact on health and sources have im-

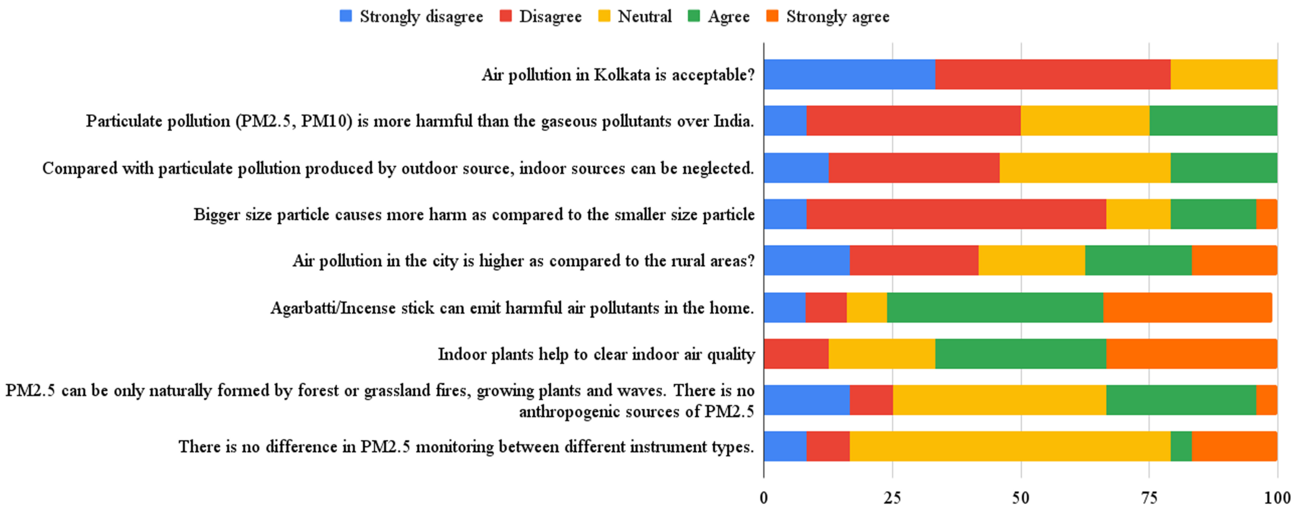

Figure 3. Interview questions and answers during the pre-walk and post-walk times.

proved. Participant knowledge on indoor air pollution has also marginally increased. Overall knowledge on air pollution has improved, and the answers to the questions post-walk have shifted more towards the extreme (strongly agree and strongly disagree), which indicates that the participants are now confident regarding their understanding of air pollution as well. We raised the question during the post-walk meeting about their preference regarding the mode of the learning exercise. The participants clearly mentioned that the pollution walk is definitely better as compared to conventional PowerPoint presentations.

3.3 Long-term participant sensitization and behavioural change

At each point of the walk, the participants measured the $PM_{2.5}$ concentration and, after that, they were briefed on the possible reason for such an observation. The native language, Bengali, was used as the communication medium. The observation, related concept introduction and adaptation procedures are summarized in Table 2.

The walk began in a room where participants measured the concentration in the living room and in the kitchen. The higher concentration in the kitchen was explained by the emission of air pollutants during the different cooking procedures like frying or toasting. The impact of ventilation was also shown through measurement of $PM_{2.5}$ while opening and closing the window. This was surprising to the participants, as even after using clean cooking fuel (liquefied petroleum gas – LPG) the concentration of $PM_{2.5}$ was found to be twice as high compared to the room. Here we elaborated on the emission of $PM_{2.5}$ in the different cooking procedures (Chafe et al., 2014; Shupler et al., 2018), and the participants were advised to use an induction cooking top or LPG if possible, install a kitchen chimney, and keep the doors and window of the kitchen open during the cooking procedure.

During our survey carried out 1 year after the experience, we realized that 83 % of the participants had remembered to keep windows open while cooking; 17 % of the participants had made their cooking procedure electrical. Moreover, 4 % of them had even installed a kitchen chimney. These changes in behaviour indicate that these participants were aware of the harmful effects of indoor air pollution due to cooking as a result of the previous event and had tried to modify their lifestyles accordingly. During the discussion, the participants mentioned that they were intrigued by how ventilation can reduce the pollution in a room, and they had remembered this during the cooking procedure. They also mentioned passing the information on to several near and dear ones and asking them to do the same.

The participants moved out of the building and found that the concentration of $PM_{2.5}$ went down significantly. Here, the participants explained how ventilation improved the air quality (Becker et al., 2007; Vassella et al., 2021). We introduced the concept of the boundary layer at this point to the participants. The accumulation of pollutants inside a room with a certain height and, on the outside, the concentration, is low due to the larger mixing place. “Winter high and summer low” for the pollutants and the role of the atmospheric boundary layer were explained to the participants. This example was quickly grasped by the participants, and they instantly related this to high pollutant concentrations and haze during winter.

The participants further went on to measure the concentrations on the minor and major roads. The concentration difference between the two road types was explained by the number of vehicles and the types of vehicles. The vehicle fleet on the major roads comprises cars, bikes, autos and buses, whereas only motorbikes and very few cars were observed on

Table 2. Different concept introductions to air pollution during the pollution walk.

Phenomenon	Observation	Concept introduction	Adaptation statement
Higher pollution emissions during cooking	Elevated concentration in the kitchen as compared to the living room	Indoor sources and accumulation of air pollutants	Ventilation during cooking is necessary.
Ventilation improves air quality.	Decreased $PM_{2.5}$ concentration when moving from inside to outside	Boundary layer, temporal variation of $PM_{2.5}$	Wintertime is more dangerous compared to summer.
Vehicles as a source of $PM_{2.5}$	Concentration difference of $PM_{2.5}$ on major and minor roads	$PM_{2.5}$ source and pedestrian exposure	Behavioural change helps to avoid major sources.
Traffic junctions as pollution hotspots	High $PM_{2.5}$ at the traffic junction as compared to the other parts	Spatial variation of the $PM_{2.5}$ concentration	Pedestrian exposure can be very high at traffic junctions.
Biomass burning as a $PM_{2.5}$ source	High $PM_{2.5}$ in the roadside food stall with coal fuel	Biomass burning, stubble burning, exposure inequity	Cook using clean fuel or use a well-ventilated kitchen area.
$PM_{2.5}$ and meteorology	Decreasing $PM_{2.5}$ during windy periods	Firework episode and $PM_{2.5}$	Dispersion of $PM_{2.5}$ is important.
Industry as a $PM_{2.5}$ source	Increasing $PM_{2.5}$ near the smelter	Industrial emission, control	People living near industries are vulnerable.
Highest PM near the source	Very high PM concentration near the tailpipe of a vehicle	Daily exposure and health burden	Sitting in a low-height vehicle can expose one to extra $PM_{2.5}$.

the minor roads. Exponential decay in the pollutant concentration was observed when the participants moved away from the main road. This helped the participants to understand the impact of $PM_{2.5}$ on the houses located on the main street. The participants were sensitized to the extent of pedestrian exposure on the main road. The participants were also advised to keep this in mind when getting a new home. In addition, the participants were advised to use masks while travelling in low-height vehicles such as autos due to the proximity of the tailpipe to other vehicles.

Participants were introduced to the concept of biomass burning and its role in pollutant accumulation while measuring air quality near the food stall (Milà et al., 2018; Xu et al., 2020). A very high concentration was observed as the smoke was coming from the cooking and burning of wood fuel. Here, we briefly introduced the participants to stubble burning and its role in the formation of haze in rural parts of India. Concepts related to industrial emission were introduced near the smelter. The participants were also sensitized to the inequity of air pollution exposure during the measurement near the smelter and the food stall. How poor people are more vulnerable to air pollution was introduced. During the walk, windy periods coincided with decreasing $PM_{2.5}$ concentrations. Here the role of wind and overall ventilation in the reduction of $PM_{2.5}$ concentrations was clarified again to the participants. The role of low wind speed during wintertime and how air pollutants accumulate during the Diwali festival were explained to the participants. Adaptation statements included how to improve cross-circulation and ventilation at home. After the walk, the participants were taken to the starting point, where a focus group discussion was conducted to evaluate their perceptions.

During the 1 year after the pollution-walk discussion, the participants reported taking extra precautions during travel in autos or low-height vehicles: 33 % of the participants reported shifting their walk time from winter mornings, and 21 % of the participants mentioned that they had changed their habit of igniting candlesticks inside closed rooms. All the participants mentioned that they had discussed air pollution issues in the last year with multiple people and kept track of air quality regularly through apps.

4 Discussion and implication

Different approaches were taken to improve sensitization to air pollution. In this study, we took a very different approach where a walk is organized with a group of citizens with live air quality monitors and where several complex concepts of air quality are explained to them. The live data help participants to grasp complex problems easily. One participant was quoted during the post-walk group discussion:

> I did not understand the complex nature of air pollution and its control strategy before the walk.

Table 3. Quotations from the interviews of the participants.

Quote ID	Topic	Quotes
PW1_4	The workshop	I wish more of the people joined. I want to attend more such workshops. I prefer the "NO POWERPOINT" approach.
PW2_5		I knew about the fact that $PM_{2.5}$ comes out from cooking but did not have the idea of this amount. The walk and associate discussion help a lot.
PW3_1		I am a retired government employee and have been to such workshops hundreds of times. However, the walking and visualizing data was an eye-opener.
PW2_2	Air pollution source	We prefer living on the main road due to logistical facilities, but even 50 m away from the main road could really reduce the health impact.
PW3_2		I thought stopping stubble burning as one step solution for combatting air pollution in Delhi. I did not know, that the issue is so complex and interlinked with socio-economy.
PW1_8		Living in a very clean residential area for whole days, but 15 min in traffic signal could put all harmful pollutants in our body.
PW2_7	Inequity	Why does the food seller or the person working in the workshop are inhaling high $PM_{2.5}$ all the time? What would be the solution for them?
PW3_5		My mom cooks for us everyday and she is risking her life due to bad air quality during cooking.
PW3_4		Those who can't afford LPG gas for cooking, or those who work outdoor or the traffic policies who are exposed to pollutants every day – what about them? How we will help them?
PW1_2	Solution statements	The problem related to air pollution has multiple layers and does not have any easy or over-simplified solution.
PW1_7		From public transport to controlling industries, we have to go a long path to fight air pollution. We need to go for data-driven advocacy.
PW2_6		The combination of an expert who is doing research work on air pollution and initiative of the community, especially social activities can promote a pro-air environment, and fix and resolve the issues related to air pollution.
PW1_1		We must start to create groups of volunteers in our areas. We need to identify the hotspots and vulnerable communities first.

> Also, the walk shows me how different people are exposed to the air pollution level differently.

The perception of the participants after the pollution walk changed from an over-simplified solution of "planting trees" before the walk to "data-driven advocacy" after the walk (Table 3). The participants raised questions about inequities in pollution exposure as economically deprived communities unable to use clean cooking fuel are exposed to massive amounts of air pollutants. "Those who can't afford LPG or air purifiers, how they will survive this massive air pollution?" asked one participant. The differential impact of socio-economic status and air quality exposure was identified by the participants, and this can be considered one of the major impacts of the pollution walk. Here the participants could visualize the enormous amounts of pollutants inhaled by outdoor workers, food vendors or factory workers who are compelled to work with such high air pollution levels. This changes their perception, which becomes more analytical and helps them understand the complex nature of the problem. They clearly identified the changes in their opinion as they spoke during the post-walk interview, where they mentioned "community initiative", "data-driven advocacy" and "social activity" as solution statements (Table 3).

All the participants named the pollution walk as a better way of understanding air pollution as compared to an audio-visual presentation. We asked the participants to rate how the walk with the sensor helped with their overall understanding of air pollution levels: 96 % of the participants replied that the process was highly innovative and helped them to understand the complex nature of the air pollution problem in a much better way. Impact sensitization has always been an open problem in the fields of the environment and sustainability (Okaka, 2010; Syaharuddin et al., 2020). The pollution walk could be a better alternative compared to organizing a seminar or a workshop on educating citizens about air quality. Our survey 1 year after the pollution walk among the participants clearly indicates that the pollution walk is associated with long-term learning and behavioural changes among the participants. It takes a lot less time and far fewer logistics and engages citizens in a much better way. The pollution walk is an ideal teaching method for small groups (8–10 participants) of individuals with diverse backgrounds. As air quality has been getting worse, such a technique could prove very useful and robust in the resource-limited global south.

Data availability. Data generated during the study are presented in the paper. Raw data are available on request to the corresponding author.

Supplement. The supplement related to this article is available online at: https://doi.org/10.5194/gc-7-151-2024-supplement.

Author contributions. DB alone designed and calibrated the low-cost sensors used in the pollution walk. SSG helped with implementing the walking programme and provided all the logistical support. All four authors helped with analysing the data. AR conceived the idea and designed the implementation plans, conducted the interviews, and wrote the first draft of the manuscript. DB and SH helped with the manuscript writing, corrections and editing.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Ethical statement. For the pollution walk event, we collected signed consent forms from each participant regarding their willing participation. The survey and group discussion were conducted following the ethical guidelines of the associated non-profit organization (The Climate Thinker).

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