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

Debabrata Bej[1], Sandip Sankar Ghosh[2] , Srijan Haldar[3] and Arindam Roy*[2]

[1]Department of Electronics and Communication Engineering, National Institute of Technology (NIT) Durgapur, Durgapur, West Bengal, India

[2]The Climate Thinker, Kolkata, West Bengal, India

[3]Swami Vivekananda University, Barrackpur, West Bengal, India

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 live air quality monitor. A pilot involving three such pollution walks with 24 participants were conducted in a south Asian megacity and pre and post-walk survey were conducted. The results indicate a greater sense of understanding among participants and multidisciplinary nature of the air pollution problem has been well communicated. To understand the long-term impact, a survey after one year has been done which clearly indicates high levels of awareness and behavioural changes among participants.

Keywords

Air quality; Sensitization; Outdoor education; Risk communication

***Corresponding author**

arindam.roy@epfl.ch

1.0 Introduction

World Air Quality Report (2020) has listed 37 of 40 most polluted cities in the globe are from South Asia and the national ranking shows India (Rank 5) is leading in terms of poor air quality. 33% of the global death due to air pollution occurs in South Asian countries and air pollution contributes to approximately 11 percent of all deaths (Bart and Mattos, 2018). The global burden of disease study shows that 1.24 million death in India was attributed to air pollution in 2017 and both indoor (0.48 million death) and outdoor (0.68 million death) sources contributed significantly (Balakrishnan et al., 2019). Overall, the air quality over Indian cities has significant health impact on the citizens (Guttikunda & Goel 2013; Gargava & Rajagopalan, 2015). Among the air pollutants, PM2.5, or Particulate Matter with less than 2.5µm diameter is considered as the dominating air pollutants due to its immense health impact (Balakrishnan et al., 2019). Generated via 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). PM2.5 exposure is decreasing global life expectancy by 1 year and for polluted regions over Asia, it can decrease life expectancy 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). Lack of awareness among the 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 through the educational curriculum is limited and confined to the indoor syllabus-oriented modules, whereas there are scopes to improve awareness beyond the syllabus-oriented approach (Huo et al., 2020). Community-based outdoor education approaches have been proven to improve the understanding of participants irrespective of the 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 inspire people to shift towards more sustainable consumption and environmental-friendly practice (Christie and Waller; 2019; Persson et al., 2022). Previous studies have shown that citizen participation program or “Citizen Science” driven air quality monitoring has been able to create active engagement and results in achieving larger social objectives in cities over global north (Nali & 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 program in 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/). 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 one of major sources of air pollution in Kolkata and an 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 the citizens. The present study intends to introduce a new awareness-building tool for improving the understanding of air pollution among the citizens. A walk across different parts of the city with air quality monitors and live data display (in brief, “pollution walk”) has been conducted with diverse groups of citizens and several complex air quality-related topics have been introduced. To the best of our knowledge, such innovative tools have not been introduced in India before and globally, only we have 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.

2.0 Methodology

The air pollution walk began with a short pre-walk discussion and then participants were asked to follow a specific path comprising of roads, food stalls, traffic intersections etc. with a handheld PM2.5 monitor (See Supplementary information). The PM2.5 monitoring procedure has been discussed in detailed at Section 2.3. A short training was given to all participants regarding operation process of PM2.5 monitor and data collection procedure. During the path, participants were sensitized about the relevant sources by showing them the live PM2.5 data and detailed explanations were provided. Post-walk, a focus group discussion was organized with participants from the walk to discuss the results. Three such air pollution walks have been organized during the month of July 2022 with 24 participants together. Pre and post-walk survey were done with participants. A follow-up open-ended survey was done after one year (July 2023) with participants. The walk works as a citizen science program where scientists designed the program and walk with participants who act as a contributor 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 meters and it includes a busy cross-section with one minute of signal time. On average, approximately 10,000 cars pass during office hours on the major road. The minor roads (~600m 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 people are returning home from office (6:00pm) and took nearly two hours to finish.

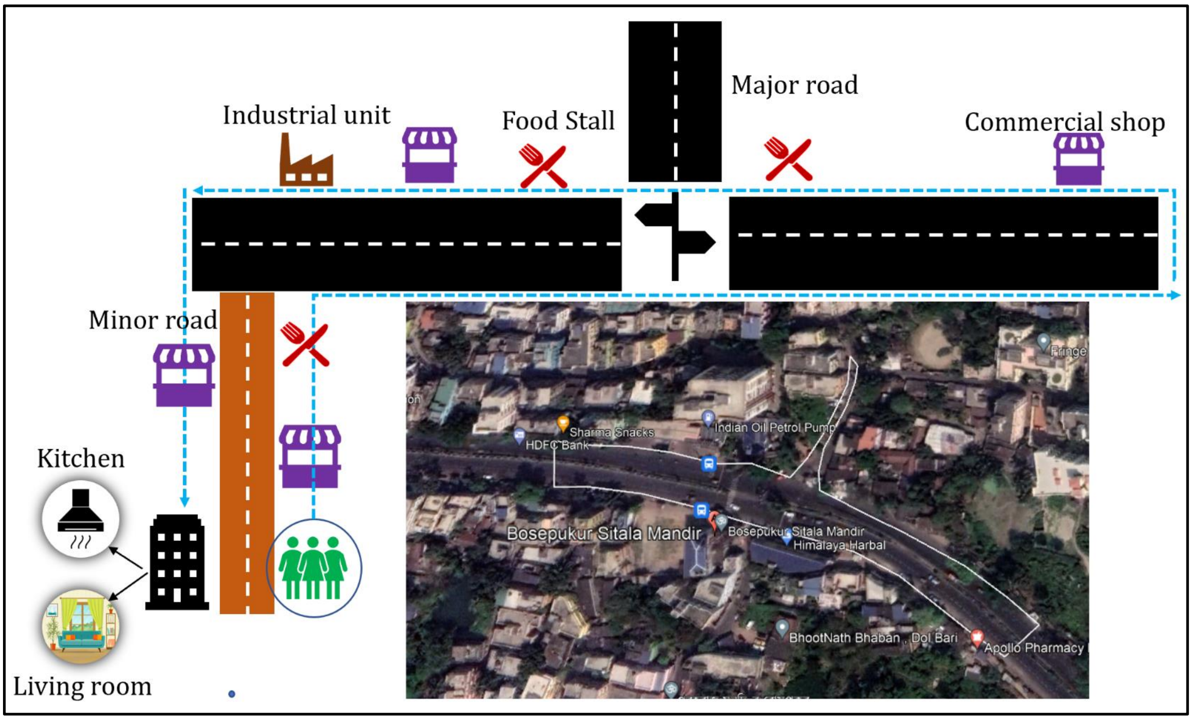

Fig 1: Schematic and satellite image of the pollution walk path for the study. The blue dash line indicates walking trail (© Google Earth).

2.2 Targeted air pollutant characteristic

Traditionally air quality has been measured using a fixed monitoring station installed in 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 the 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 the citizens (Nieuwenhuijsen et al., 2015). Live data also provide an interesting scope to explain several air quality-related topics which generally remain unturned during a conventional workshop. Here, 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) impact of meteorology on air quality; e) spatial distribution of air pollutants. The pre-walk briefing was conducted in a room where the entire procedure was described to participants, and we also measured the ambient PM2.5 concentration in the room. Then participants were asked to visit the adjacent kitchen to monitor the indoor pollution contribution by cooking. Then participants moved outside, and it was explained how ventilation helps to dilute air pollutants. Further, participants walked through major and minor roads and measure air pollutants in different settings. Participants walked through the same route to the room and a semi-structured interview was taken.

2.3 Measurement of air pollutant

PM2.5 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 particulate matter 2.5 (PM2.5) concentration sensor, Plantower PMS5003, has been used to measure the mass and amount of suspended particulate matter (PM2.5) 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. DS3231 real-time clock (RTC) module has been integrated with the system to provide precise time and date to the PM2.5 data. The NEO-6M GPS Module has been connected to the system to receive georeferenced PM2.5 pollution data at any location. An LCD has been Interfaced with the system to display the PM2.5 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 microcontroller board using the Arduino IDE 1.8.19 software. The PM2.5 monitor has been calibrated against a reference monitor, and relative humidity corrections have been made following 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. Participants come from different socio-economical and educational background which has been summarized in Table 1. The age range of participants falls from 18 to 68 (all participants are adult, minors are tagged alone with some of the parents). Among participants, there are students, government and private employees, housewives, and retired professionals. Pre and post-walk survey were conducted among participants. The immediate post-walk interview was done to understand if this improved their understanding of air pollution and if they prefer this format (pollution walk) over audio-visual presentation-based sensitization. A follow-up interviews were done a year after the walk, to understand how the learning impacted their understanding of air pollution and if the takeaway messages are integrated into their lifestyle of not.

All the questionnaire from the interviews is represented in Fig 3.

Table 1: Description about the backgrounds of 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	Under-graduate	29% (n = 7)
	Post-graduate	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 PM2.5

Participants measured PM2.5 concentration in different microenvironments during the pollution walk (Fig 2). The average PM2.5 concentration was found to be 85±66 micrograms per cubic meter which is approximately 17 times higher as compared to the WHO standards (https://www.who.int/tools/air-quality-standards). Higher PM2.5 concentrations were observed in the kitchen (70±19 µg m^{-3}) as compared to the room (34±5 µg m^{-3}). Pollution level drops after participants began the outdoor walk due to the increased ventilation. As participants started walking toward the main road, gradual increases in pollutant concentration were observed. The highest outdoor concentration was observed while participants stops at a busy traffic intersection. As the signal turned green, vehicles started their engines and participants measured PM2.5 concentration 186 µg m^{-3} concentration of PM2.5. The average concentration of PM2.5 on the main road was found to be 98±31 µg m^{-3}. An exponential fall in PM2.5 concentration was observed while participants entered the minor roads with lesser traffic density. Participants also measure pollutant concentration near roadside food stalls where biomass has been used as a fuel source. The smoke from the food stall was clearly visible and participant measured 214±51 micrograms per cubic meter at 1 meter from the oven. Concentrations near a small workshop near the streets that uses smelter were found to be 121±53 µg m^{-3}. While coming back, participants also measure these points to recheck 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.

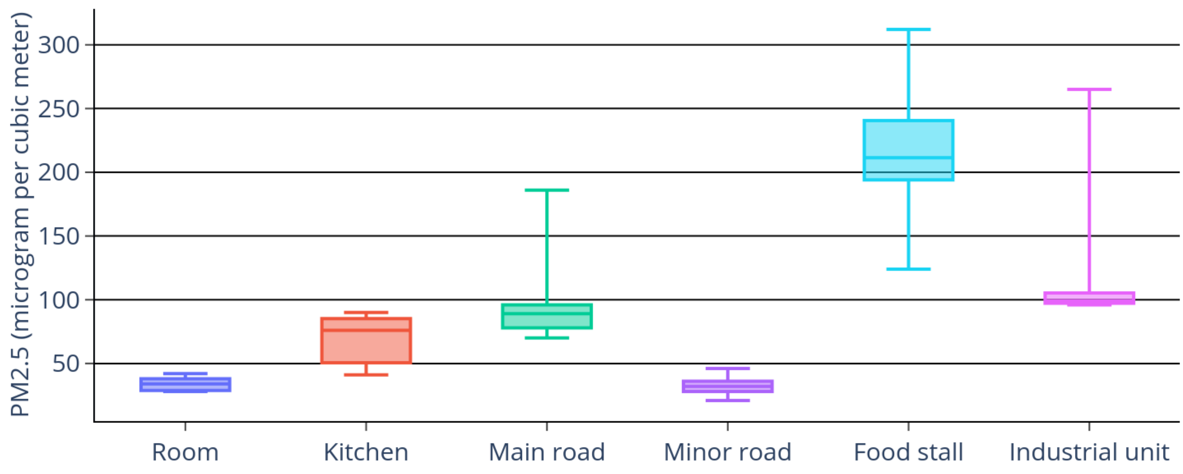

Fig 2: Box plot depicting the PM2.5 concentration profile in different micro-environments during the pollution walk

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

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

The post-walk survey was conducted just after the walk and before the discussion. Significant improvement in air quality knowledge can be observed (Fig 3). Specially, answer to the how smaller size particulate matter has impact on health and source specific questions, has been improved. Participants knowledge on indoor air pollution has been also marginally increased. Overall knowledge on air pollution has been improved and the answer of the questions during post-walk has shifted more towards the extreme (strongly agree and strongly disagree) which indicates that participants are now confident regarding their understanding on air pollution as well. We have raised the question during post-walk meeting about their preference regarding the mode of the learning exercise. Participants clearly mentioned that the pollution walk is definitely better as compared to conventional PowerPoint presentations.

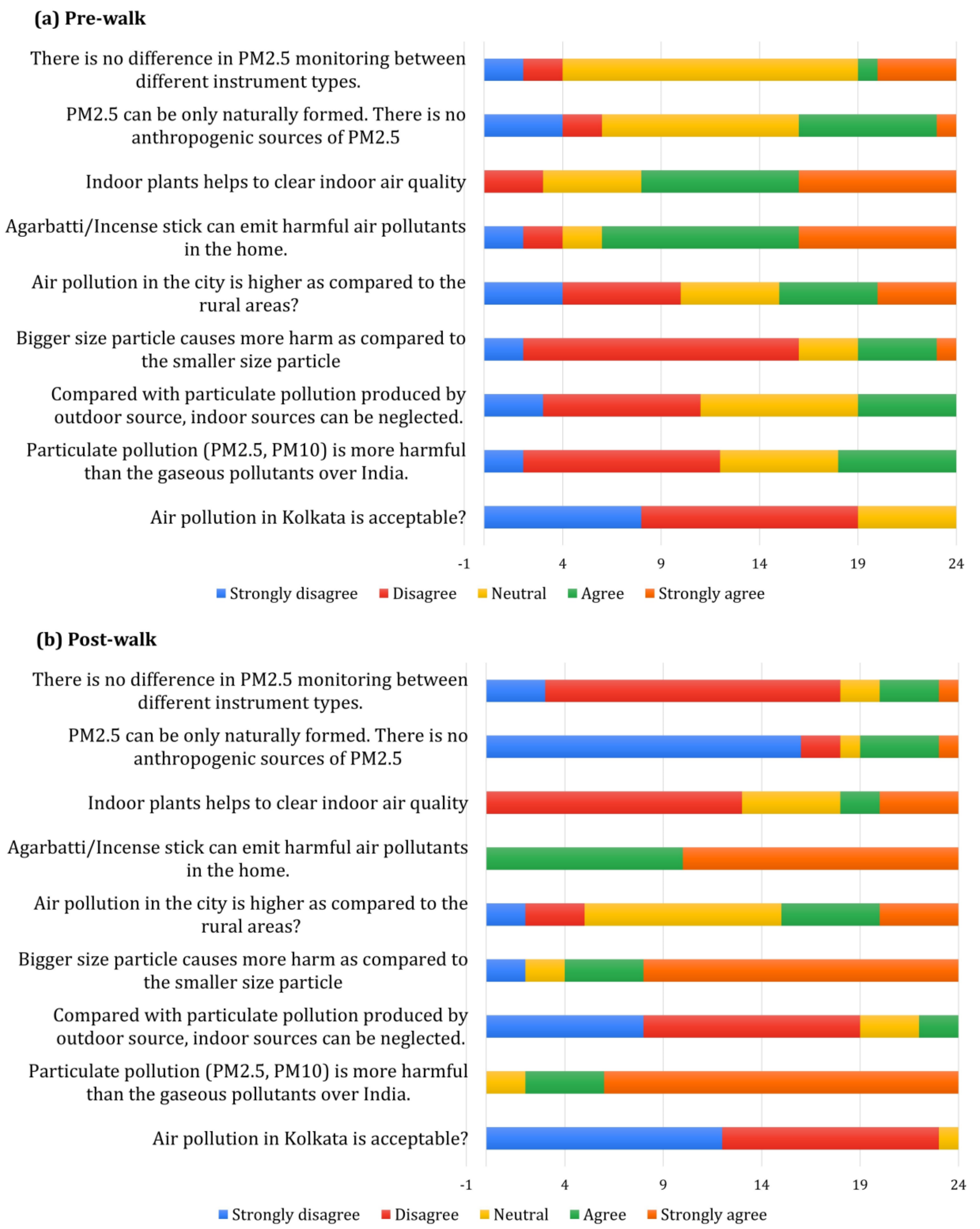

Fig 3: Interview questions and answers during pre-walk and post-walk time

3.3 Long-term participant sensitization and behavioural change

At each point of the walk, participants measured particulate matter 2.5 (PM2.5) concentration and after that, they were briefed about the possible reason behind such observation. Native language Bengali was used as communication medium. The observation, related concept introduction and adaptation procedures are summarized in Table 2.

The walk began in a room where participants measured 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 processes like frying and toasting. The impact of ventilation was also showed through measurement of PM2.5 while opening and closing of window. It was surprising for participants as even after using clean cooking fuel (LPG), the concentration of PM2.5 was found to be twice as high compared to the room. Here we elaborate on the emission of PM2.5 in the different cooking processes (Chafe et al.,2014; Shupler et al., 2018) and participants were advised to use induction cook top or LPG if possible, install a kitchen chimney, keep the doors and window of kitchen remain open during the cooking procedure.

During our survey carried out one year after the experience, we realized that 83% of the participants have remembered to keep the windows open while cooking. 17% of participants have shifted their cooking process to electrical. Moreover, 4% of them even installed a kitchen chimney. This change in behaviour indicates these participants are aware about the harmful effects of indoor air pollution due to cooking trough the previous event and tried to modify their lifestyle accordingly. During the discussion, participants has mentioned that they were intrigued by the fact how ventilation can reduce the pollution in the room, and they have remembered this during cooking process. They have also mentioned passing the information to several near and dear ones and asked them to do the same.
Participants move out of the building and found the concentration of PM2.5 goes down significantly. Here, participants explained how ventilation improves air quality (Becker et al.; 2007; Vassella et al.; 2021). We have introduced the concept of the boundary layer at this point to participants. The accumulation of pollutants inside a room with a certain height, and on the outside the concentration are low due to the greater mixing place. "Winter-high and summer-low" for the pollutants and the role of the atmospheric boundary layer were explained to participants. This example was quickly grasped by participants, and they instantly relate this to high pollutant concentration and haze during winter.

Participants further went to measure the concentration on the minor and the major roads. The concentration difference between the two road types was explained by the number of vehicles counts and types of vehicles. The vehicles fleet on major roads comprises cars, bikes, autos and buses whereas only motorbikes and very few cars were observed on minor roads. Exponential decay in pollutant concentration was observed when participants move away from the main road. This helps participants to understand the impact of PM2.5 in the houses located on the main street. Participants were sensitized about the extent of pedestrian exposure on the main road. Participants were also advised to keep this thing in mind while getting a new home. In addition, participants were advised to use masks while traveling 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 pollutants 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 participants to stubble burning and its role in the formation of haze in rural parts of India. Concepts related to industrial emission have been introduced near the smelter. 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 has been introduced. During the walk, windy periods coincided with decreasing PM2.5 concentration. Here the role of wind and overall ventilation in the reduction of PM2.5 concentration has been again clarified to participants. The role of low wind speed during wintertime and how air pollutant accumulated during the Diwali festival has been explained to participants. Adaptation statements include how to improve cross-circulation and ventilation at home. After the walk, participants were taken to the starting point where a focus group discussion was conducted to evaluate their perceptions.

Table 2: Different concept introduction about air pollution during the pollution walk

Phenomenon	Observation	Concept introduction	Adaptation statement
Higher pollution emits 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	Moving from inside to outside decreases PM2.5 concentration	Boundary layer, temporal variation of PM2.5	Winter time is more dangerous compared to summer
Vehicles as a source of PM2.5	Concentration difference of PM2.5 in major and minor roads	PM2.5 source and pedestrian exposure	Behavioural change helps to avoid major sources
Traffic junction as pollution hotspots	High PM2.5 in the traffic junction as compared to other parts	Spatial variation of PM2.5 concentration	Pedestrian exposure can be very high in traffic junctions
Biomass burning as PM2.5 source	High PM2.5 in road side food stall with coal fuel	Biomass burning, stubble burning, exposure inequity	Cooking using clean fuel or use well ventilated kitchen area
PM2.5 and meteorology	Decreasing PM2.5 during windy period	Fireworks episode and PM2.5	Dispersion of PM2.5 is important
Industry as PM2.5 source	Increasing PM2.5 near the smelter	Industrial emission, control	People living near industry are vulnerable
PM near source is the highest	PM concentration near tailpipe of vehicle is very high	Daily exposure and health burden	Sitting at low height vehicle can exposed to extra PM2.5

During the one-year after pollution-walk discussion, participants have reported about taking extra precaution during travel in auto or low-height vehicle. 33% of participant has reported shifting their walk time from winter morning. 21% of participants has mentioned that they have changed their habit of igniting candlestick inside closed room. All participants have mentioned that they have discussed air pollution issue in the last one year with multiple people and keep a track of the air quality regularly through apps.

4.0 Discussion and implication

Different approaches were taken to improve sensitization on air pollution. In this study, we took a very different approach where a walk has been organized with a group of citizens with live air quality monitors and they were explained several complex concepts about air quality. The live data helps participants to grasp complex problems easily. A participant quoted during the post-walk group discussion–-

"*I did not understand the complex nature of air pollution and its control strategy before the walk. Also, the walk shows me how different people are exposed to the air pollution level differently*."

The perception of participants after the pollution walk changes from an over-simplified solution of "planting trees" before the walk to "data-driven advocacy" after the walk (Table 3). Participants raise questions about inequities in pollution exposure as the economically deprived communities unable to use clean cooking fuel are exposed to massive air pollutants. "Those who can't afford LPG or air purifiers, how they will survive this massive air pollution" ask one participant. The differential impact of socio-economic status and air quality exposure was identified by participants, and this can be considered as one of the major impacts of the pollution walk. Here participants can visualize the enormous pollutants inhaled by the outdoor workers, food vendors or factory workers who are compelled to work under such high air pollution levels. This changes their perception and turns into more analytical which 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).

100% of participants voted the pollution walk as a better way of understanding air pollution as compared to an audio-visual presentation. We ask participants to rate how the walk with the sensor helps with their overall understanding of air pollution levels. 96% of participants replied that the process is highly innovative and helps them to understand the complex nature of the air pollution problem much better way. Impact sensitization has always been an open problem in the field of 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 one year after pollution walk survey among participants clearly indicates that the pollution walk is associated with long-term learning and behavioural changes among participants. It would take a lot lesser time, a lot fewer logistics and engage 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 the air quality has been turning worse, such a technique could be proven very useful and robust in the resource-limited global south.

Table 3: Quotation from the interview of participants

Quote ID	Topic	Quotes
PW1_4	About 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 PM2.5 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 meters 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 minutes 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 PM2.5 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 ca’'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.

Author’'s contribution

D.B. was solely to design and calibrate the low-cost sensors used in the pollution walk. S.G. helps in implementing the walking program and provides all the logistical support. All four authors help in analyzing the data. A.R conceive the idea and design the implementation plans, conducted the interviews and wrote the first draft of the manuscript. D.B and S.H. helps in manuscript writing, corrections and editing.

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Code availability

Code has not been used for this study

Ethical statement

For pollution walk event we have collected signed consent documents from each participant regarding their willingly participation. The survey and group discussion were done following the ethical guidelines of the associated non-profit organization (The Climate Thinker).

Data availability statement

Data generated during the study is represented in the paper, for raw data is available on request to the corresponding author.

Competing interest

The authors have no conflicts of interest to declare.

References

1. Apte, J. S., Brauer, M., Cohen, A. J., Ezzati, M., & Pope III, C. A. (2018). Ambient PM2. 5 reduces global and regional life expectancy. Environmental Science & Technology Letters, 5(9), 546-551.
2. Badura, M., Batog, P., Drzeniecka-Osiadacz, A., & Modzel, P. (2018). Evaluation of low-cost sensors for ambient PM2. 5 monitoring. Journal of Sensors, 2018.
3. Balakrishnan, K., Dey, S., Gupta, T., Dhaliwal, R. S., Brauer, M., Cohen, A. J., ... & Dandona, L. (2019). The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. The Lancet Planetary Health, 3(1), e26-e39.
4. Becker, R., Goldberger, I., & Paciuk, M. (2007). Improving energy performance of school buildings while ensuring indoor air quality ventilation. Building and Environment, 42(9), 3261-3276.
5. Bu, X., Xie, Z., Liu, J., Wei, L., Wang, X., Chen, M., & Ren, H. (2021). Global PM2. 5-attributable health burden from 1990 to 2017: Estimates from the Global Burden of disease study 2017. Environmental Research, 197, 111123.
6. Chafe, Z. A., Brauer, M., Klimont, Z., Van Dingenen, R., Mehta, S., Rao, S., ... & Smith, K. R. (2014). Household cooking with solid fuels contributes to ambient PM2. 5 air pollution and the burden of disease. Environmental health perspectives, 122(12), 1314-1320.
7. Christie, B., & Waller, V. (2019). Community learnings through residential composting in apartment buildings. The Journal of Environmental Education, 50(2), 97-112.
8. Commodore, A., Wilson, S., Muhammad, O., Svendsen, E., & Pearce, J. (2017). Community-based participatory research for the study of air pollution: a review of motivations, approaches, and outcomes. Environmental monitoring and assessment, 189, 1-30.
9. Dutta, D., & Pal, S. K. (2023). Prediction and assessment of the impact of COVID-19 lockdown on air quality over Kolkata: a deep transfer learning approach. Environmental Monitoring and Assessment, 195(1), 223.
10. Feenstra, B., Papapostolou, V., Hasheminassab, S., Zhang, H., Der Boghossian, B., Cocker, D., & Polidori, A. (2019). Performance evaluation of twelve low-cost PM2. 5 sensors at an ambient air monitoring site. Atmospheric Environment, 216, 116946.
11. Gabrys, J. (2017). Air walk: Monitoring pollution and experimenting with speculative forms of participation. In Walking through social research (pp. 145-161). Routledge.
12. Gabrys, J., Pritchard, H., & Barratt, B. (2016). Just good enough data: Figuring data citizenships through air pollution sensing and data stories. Big Data & Society, 3(2), 2053951716679677.
13. Gargava, P., & Rajagopalan, V. (2015). Source prioritization for urban particulate emission control in India based on an inventory of PM10 and its carbonaceous fraction in six cities. Environmental development, 16, 44-53.
14. Garip, G., Richardson, M., Tinkler, A., Glover, S., & Rees, A. (2021). Development and implementation of evaluation resources for a green outdoor educational program. The Journal of Environmental Education, 52(1), 25-39.

15. Ghose, M. K., Paul, R., & Banerjee, R. K. (2005). Assessment of the status of urban air pollution and its impact on human health in the city of Kolkata. Environmental Monitoring and Assessment, 108(1), 151-167.
16. Gurjar, B. R., Ravindra, K., & Nagpure, A. S. (2016). Air pollution trends over Indian megacities and their local-to-global implications. Atmospheric Environment, 142, 475-495.
17. Guttikunda, S. K., & Goel, R. (2013). Health impacts of particulate pollution in a megacity—Delhi, India. Environmental Development, 6, 8-20.
18. Guttikunda, S. K., Goel, R., & Pant, P. (2014). Nature of air pollution, emission sources, and management in the Indian cities. Atmospheric environment, 95, 501-510.
19. Haque, M. S., & Singh, R. B. (2017). Air pollution and human health in Kolkata, India: A case study. Climate, 5(4), 77.
20. Huo, Y. J., Shih, K. T., & Lin, C. J. (2020, November). The study on Integrating Air Pollution Environmental Education into the Teaching Personal and Social Responsibility Model in Physical Education. In IOP Conference Series: Earth and Environmental Science (Vol. 576, No. 1, p. 012006). IOP Publishing.
21. IQAIR Report. World Air Quality Report, 2020. https://www.iqair.com/world-air-quality-report
22. Jha, S. K., Kumar, M., Arora, V., Tripathi, S. N., Motghare, V. M., Shingare, A. A., ... & Kamble, S. (2021). Domain Adaptation-Based Deep Calibration of Low-Cost $PM_{2.5}$ Sensors. IEEE Sensors Journal, 21(22), 25941-25949.
23. Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. Nature, 525(7569), 367-371.
24. Liao, X., Tu, H., Maddock, J. E., Fan, S., Lan, G., Wu, Y., ... & Lu, Y. (2015). Residents' perception of air quality, pollution sources, and air pollution control in Nanchang, China. Atmospheric pollution research, 6(5), 835-841.
25. Milà, C., Salmon, M., Sanchez, M., Ambros, A., Bhogadi, S., Sreekanth, V., ... & Tonne, C. (2018). When, where, and what? Characterizing personal PM2. 5 exposure in periurban India by integrating GPS, wearable camera, and ambient and personal monitoring data. Environmental science & technology, 52(22), 13481-13490.
26. Mor, S., Parihar, P., & Ravindra, K. (2022). Community perception about air pollution, willingness to pay and awareness about health risks in Chandigarh, India. Environmental Challenges, 9, 100656.
27. Nali, C., & Lorenzini, G. (2007). Air quality survey carried out by schoolchildren: an innovative tool for urban planning. Environmental monitoring and assessment, 131, 201-210.
28. Nieuwenhuijsen, M. J., Donaire-Gonzalez, D., Rivas, I., de Castro, M., Cirach, M., Hoek, G., ... & Sunyer, J. (2015). Variability in and agreement between modeled and personal continuously measured black carbon levels using novel smartphone and sensor technologies. Environmental science & technology, 49(5), 2977-2982.
29. Okaka, W. (2010). Developing regional communications campaigns strategy for environment and natural resources management policy awareness for the East African community. Research journal of environmental and earth sciences, 2(2), 106-111.

30. Omanga, E., Ulmer, L., Berhane, Z., & Gatari, M. (2014). Industrial air pollution in rural Kenya: community awareness, risk perception and associations between risk variables. BMC public health, 14(1), 1-14.
31. Persson, K., Andrée, M., & Caiman, C. (2022). Down-to-earth ecological literacy through human and nonhuman encounters in fieldwork. The Journal of Environmental Education, 1-18.
32. Selden, T. M., & Song, D. (1994). Environmental quality and development: is there a Kuznets curve for air pollution emissions?. Journal of Environmental Economics and management, 27(2), 147-162.
33. Sharma, H. K., Dandotiya, B., & Jadon, N. (2017). Exposure of Air pollution and its health effects in traffic police persons of Gwalior City, India. Environmental Claims Journal, 29(4), 305-315.
34. Shupler, M., Godwin, W., Frostad, J., Gustafson, P., Arku, R. E., & Brauer, M. (2018). Global estimation of exposure to fine particulate matter (PM2. 5) from household air pollution. Environment international, 120, 354-363.
35. Snyder, E. G., Watkins, T. H., Solomon, P. A., Thoma, E. D., Williams, R. W., Hagler, G. S., ... & Preuss, P. W. (2013). The changing paradigm of air pollution monitoring. Environmental science & technology, 47(20), 11369-11377.
36. Steinle, S., Reis, S., & Sabel, C. E. (2013). Quantifying human exposure to air pollution—Moving from static monitoring to spatio-temporally resolved personal exposure assessment. Science of the Total Environment, 443, 184-193.
37. Syaharuddin, S., Hidayanti, H., & Mutiani, M. (2020). The Role of Waste Banks to Improve Community Environment Awareness. The Innovation of Social Studies Journal, 1(2), 129-138.
38. Szczytko, R., Stevenson, K. T., Peterson, M. N., & Bondell, H. (2020). How combinations of recreational activities predict connection to nature among youth. The Journal of Environmental Education, 51(6), 462-476.
39. Ullstein, Bart, and Helen de Mattos. "Air Pollution in Asia and the Pacific: Science-based Solutions-Summary." (2018).
40. Varaden, D., Leidland, E., Lim, S., & Barratt, B. (2021). “I am an air quality scientist”– Using citizen science to characterise school children's exposure to air pollution. Environmental Research, 201, 111536.
41. Varaden, D., McKevitt, C., & Barratt, B. (2018). Making the invisible visible: Engaging school children in monitoring air pollution in London. Research for All.
42. Vassella, C. C., Koch, J., Henzi, A., Jordan, A., Waeber, R., Iannaccone, R., & Charrière, R. (2021). From spontaneous to strategic natural window ventilation: Improving indoor air quality in Swiss schools. International Journal of Hygiene and Environmental Health, 234, 113746.
43. Veloz, D., Gonzalez, M., Brown, P., Gharibi, H., & Cisneros, R. (2020). Perceptions about air quality of individuals who work outdoors in the San Joaquin Valley, California. Atmospheric Pollution Research, 11(4), 825-830.
44. Wildschut, D. (2017). The need for citizen science in the transition to a sustainable peer-to-peer-society. Futures, 91, 46-52.

45. Xu, H., Ta, W., Yang, L., Feng, R., He, K., Shen, Z., ... & Cao, J. (2020). Characterizations of PM2. 5-bound organic compounds and associated potential cancer risks on cooking emissions from dominated types of commercial restaurants in northwestern China. Chemosphere, 261, 127758.