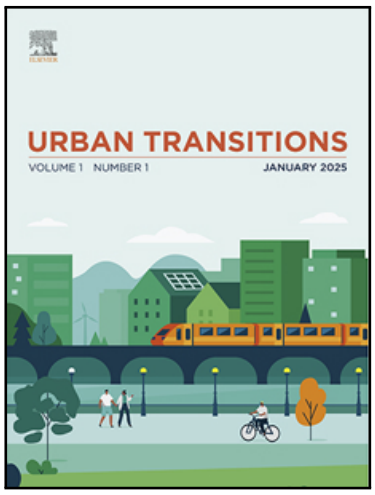

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Young people's experiences of breathing, air pollution and respiratory health in a large African city

Heather Price [a*], Fred Orina [b], Evans Amukoye [b], Cressida Bowyer [c], Darpan Das [d], Ruaraidh Dobson [e f], Graham Devereux [g], Cindy Gray [h], Maia Lesosky [i], Miranda Loh [j], Hellen Meme [b], Kevin Mortimer [k l m], Rebecca Ouma [b], Clare Pearson [n], Sean Semple [f], Marsailidh Twigg [n], Caroline Waithira [b], Melaneia Warwick [o], Michael Wilson [p], Sarah West [q]

[a] Heather Price, Biological and Environmental Sciences, University of Stirling, UK

[b] Centre for Respiratory Disease Research, Kenya Medical Research Institute, Nairobi, Kenya

[c] Revolution Plastics Institute, University of Portsmouth, UK

[d] Department of Environment and Geography, University of York, UK

[e] South London Scientific Ltd

[f] Institute for Social Marketing and Health, University of Stirling, Stirling, UK

[g] Clinical Sciences, Liverpool School of Tropical Medicine, Liverpool, UK

[h] School of Social and Political Sciences, University of Glasgow, G12 8QQ, UK

[i] National Heart and Lung Institute, Imperial College London, London UK.

[j] Institute of Occupational Medicine, Edinburgh, UK.

[k] Cambridge Africa, Department of Pathology, University of Cambridge, UK

[l] Department of Paediatrics and Child Health, School of Clinical Medicine, College of Health Sciences, University of KwaZulu Natal, Durban, South Africa

[m] Respiratory Medicine, Liverpool University Hospitals NHS Foundation Trust, Liverpool, UK

[n] UK Centre for Ecology & Hydrology, Penicuik, UK

[o] Consultant, UK and Kenya

[p] School of Design & Creative Arts, Loughborough University, Loughborough, UK

[q] Stockholm Environment Institute, University of York, YO10 5NG, UK

*Corresponding author, heather.price@stir.ac.uk; Biological and Environmental Sciences, University of Stirling, Stirling, FK9 4LA, UK

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Abstract

Air pollution is a key contributor to poor respiratory health, particularly for those susceptible to its effects, such as adolescents whose lungs are still developing. Better understanding of the lived experiences of air pollution and lung health can support the design of policies and other interventions to improve health. The aim of this study was to explore adolescents' lived experiences of breathing, lung health and air pollution in Nairobi, Kenya. We focused on adolescents who had reported respiratory symptoms and were attending schools in an informal settlement (Mukuru (*n*=22)) and an adjacent more affluent area (Buruburu (*n*=16)). We took a mixed-methods approach, combining video-recorded walking interviews with route tracking (GPS) and particulate pollution ($PM_{2.5}$) measurements along the route. Participants took the interviewer to a space they found it harder to breathe and a space where they found it easier to breathe. Though both settlements had relatively high levels of $PM_{2.5}$, Mukuru had more 'hotspots' of $PM_{2.5}$, highlighting exposure inequalities for Nairobi residents. There was no significant difference in $PM_{2.5}$ between spaces considered by interviewees as easier or harder to breathe in. Harder to breathe locations limited people's activities within those spaces. The concept of 'breathing well' went beyond air quality, encompassing cleanliness, population and building density and presence of vegetation, offering potential for urban planning to support better lung health. Avoidance behaviours (for example walking faster) were a common way to reduce exposures. To supplement individual action, policies to reduce place-based inequalities and improve respiratory health for all are urgently needed.

Keywords

Air pollution; Lung health; Human exposure; Young people; Risk perception; Exposure inequality; Health-protective behaviour

1. Introduction

Air pollution is a major public health concern (Holgate, 2022). Exposure to air pollution increases the risk of developing lung diseases and aggravates established disease for example asthma and chronic obstructive pulmonary disease (COPD) (Glenn et al., 2022; Manisalidis et al., 2020). The health impacts associated with air pollution are evident at each life stage: pregnancy and birth (for example foetal development, low birth weight), from birth to adolescence (for example asthma, lung growth) and adulthood (for example premature death, COPD, stroke) (Fuller et al., 2023; Royal College of Physicians, 2025). Adolescence, defined by the World Health Organization (WHO) as a life stage between the ages of 10 and 19 (WHO, 2024a), is a key phase of life linking childhood to adulthood. Adolescents are at increased risk from air pollution compared to adults due to their physiology, with their lungs and other vital organs still developing (Health Effects Institute, 2024; Kurt et al., 2016; WHO, 2024b).

Many people living in Low- and Middle-Income Countries (LMICs) experience a 'double burden' of air pollution exposure, with high concentrations of outdoor air pollution from sources including waste burning, traffic and industry, and high concentrations of indoor air pollution from use of solid fuels for cooking and infiltration of pollutants from outside (Chan et al., 2020; Health Effects Institute, 2024; Khaltaev & Axelrod, 2024). Consequently, those living in LMICs commonly experience the largest health impacts associated with air pollution exposures (Badida et al., 2023; Landrigan et al., 2018; Masekela & Vanker, 2020; Meme et al., 2023). Within LMICs, residents of informal settlements - characterised by widespread poverty, densely packed poor-quality housing and lack of access to basic infrastructure (including electricity, clean water, sanitation, waste management) - experience some of the highest concentrations of air pollution and associated health impacts (Corburn & Sverdlik, 2018, Meme et al., 2023). However, there is a lack of air pollution data specifically in informal settlements, but also in LMICs more generally (Pinder et al., 2019).

Understanding people's perceptions of air pollution is important because they can impact health independent of actual exposures through the perceived exposure (for example smell). The perceived exposure triggers stress-induced physiological activity, such as anxiety and annoyance, as a protective mechanism (Orru et al., 2018; Sucker et al., 2008). Perceptions of air pollution can also potentially be leveraged to yield support for policies promoting clean air (Dons et al., 2018) and can shape protective actions taken to reduce exposures, for example moving away from sources of air pollution (Noël et al., 2022; Saksena, 2011). If air pollution risks are underestimated, people may not enact behaviours that can help to reduce their exposures (Noël et al., 2021). Therefore, it is crucial to understand what people think about the air they breathe. However, previous work on perceptions of air pollution and lung health is relatively sparse, particularly for LMICs such as Kenya (with notable exceptions; Egondi et al., 2013; Muindi et al., 2014). We also know very little about how public perceptions of air quality relate to measured air pollution concentrations (Reames & Bravo, 2019). However, if there is a 'perception gap', i.e., a mismatch between people's perceptions of air pollution and scientifically measured air pollution (in either direction) this can create problems, for example, in policymaking for improved air quality (Muindi et al., 2014; Noël et al., 2021), thus warranting further investigation.

Breathing air into lungs connects the external environment to the internal environment of the body (Oxley & Russell, 2020). Breathing is the key way air pollutants enter the body and cause harm, but its consideration is often missing in studies of air pollution (Garnett, 2020). Activities that induce higher breathing rates, such as running or hard manual labour, will lead to higher doses of air pollutants reaching the lungs. Our aim was to explore adolescents' lived experiences of breathing, lung health and air pollution in two adjacent but contrasting settings; an informal settlement (Mukuru) and a more affluent neighbourhood (Buruburu) in Nairobi, Kenya. To do this, we combined participant-led geo-located videoed walking interviews with $PM_{2.5}$ concentration measurements during the interviews. This approach allowed us to go beyond using bodies as structures on which sensors can be placed (Allen, 2020), to also concurrently explore the embodiment of air and intake of air pollution through breathing.

2. Methods

This work was undertaken as part of a wider study called [redacted], that aimed to understand whether children living in informal settlements are at increased risk of asthma by comparing two settlements in Nairobi, Kenya. [Redacted] is described in detail elsewhere [redacted]. Ethical approval for the study was provided by the [redacted] and the [redacted]. Interviewees' parents gave their informed consent for their children to participate in the interviews and the adolescents assented before the interviews commenced.

2.1 Study areas

Within Nairobi, the study was undertaken in two contrasting settings; Mukuru informal settlement and the more affluent Buruburu. Over 70% of Kenya's urban dwellers live in informal settlements (Murumba & Pashayan, 2024). Mukuru is one of the largest in Nairobi and is surrounded by Nairobi's major industrial area. It is home to an estimated 100,000 households with a high density of approximately 240 homes per acre (Corburn et al., 2017). Most Mukuru residents are tenants facing numerous daily risks and challenges, such as accessing sufficient food, accessing clean drinking water and safe sanitation facilities and environmental pollution (Corburn et al., 2022). Buruburu is a nearby middle-class medium density residential area to the north of Mukuru, separated from it by an industrial area and a major road. In contrast to Mukuru it is a planned owner-occupied neighbourhood, established in the 1970s and 1980s (Meme et al., 2023).

2.2 Selection of interviewees

Interviewees were selected from adolescents attending schools in Mukuru or Buruburu who had taken part in the [redacted] study [redacted] by completing a respiratory symptom questionnaire and undergoing lung function testing (spirometry) (n=1277 in Mukuru and n=1096 in Buruburu, aged 4-18). Our original target population for the current study were adolescents from this group aged 15-18 with abnormal lung function and associated respiratory symptoms (for example wheeze in the last year), but due to low numbers of children aged 15-18 with abnormal lung function, the research population was broadened to include [redacted] study participants aged 13-18 who had experienced wheeze in the past year irrespective of measured lung function. Some interviewees were aged over 18 years when the interviews took place, mainly because of a 14 month suspension due to COVID-19, separating the respiratory survey (January and February 2020) and the walking interviews (November and December 2021).

2.3 Data collection

We undertook interviewee-led geo-located walking interviews alongside $PM_{2.5}$ exposure measurements along the routes taken. Walking interviews are a powerful method for exploring the relationship between people and the spaces they inhabit (Adams et al., 2022; Evans & Jones, 2011). For our study, making the interviews mobile was intended to enable a more natural conversation between interviewer and interviewee, generate place-based conversation, and position the interviewee as the 'expert' in their experiences of their local areas. The walking route was defined by the interviewee. They were asked (in advance, for logistical and safety reasons) where in their community they found it easier to breathe and where they found it harder to breathe. During the interview they took the interviewer to each of these locations by walking through their communities. During these walks, interviewees were asked about their experiences of their community, lung health, and air pollution. While interviews followed a semi-structured design (see Supplementary Material 1 for the topic guide), interviews took the form of a conversation, with specific questions asked depending on what was seen, heard and smelt on the journey. For instance, if they passed a street food vendor using wood fuel for cooking, the interviewer would ask the interviewee for their thoughts about that.

The interviews were audio and visual recorded using a GoPro HERO10 worn by the interviewer using a chest strap, with a separate audio recorder (Sony recorder ICD-UX533) used for backup and to support transcription where interviews were undertaken in busy, noisy places. Interviews were undertaken in Swahili, English, Sheng (Swahili and English slang) or a combination of these. The route was recorded using the Global Positioning System (GPS) Renkforce GT-730FL-S, and exposure to $PM_{2.5}$ measured and logged every 2-minutes using a calibrated PurpleAir PA-II-SD (PurpleAir Ltd, Draper, UT, USA) attached to a backpack worn by a fieldworker who accompanied the interviewer. Timestamps on all equipment were aligned before starting data collection.

Practical, safety and ethical factors were taken into consideration before and during the interviews (Kinney, 2017). Interviews were undertaken by a trained local research assistant (CW), supported by a trained fieldworker who carried the air quality monitoring equipment and made observations along the route. They were joined by a community representative who provided prior information about the route (for example whether certain paths were passable), as well as security and local knowledge. Importantly, the community representative also signalled to others that we had community buy-in and approval for the research activity. Interviews were only undertaken in daylight hours when young adults would normally be using the spaces we were visiting and only when conditions (such as weather) were suitable.

2.4 Data analysis

Recorded interviews were transcribed by professional Kenya-based transcribers. Reflexive thematic analysis, based on Braun and Clarke's six phase approach (Braun & Clarke, 2006, 2022), was used to explore patterns of meaning across the interviews. Such an approach fits with the lead author's ontological and epistemological stances of critical realism and contextualism, enabling us to explore and give voice to the lived experiences of young people while situating their experiences within wider socio-cultural discourses. Our reflexive thematic approach allowed the analysis to be inductively driven and enabled the identification of both semantic and latent meanings within the dataset. Transcribed interviews were uploaded to NVivo v20 for analysis. HP led the reflexive thematic analysis (see positionality statement in Supplementary Material 2). A systematic and iterative approach to coding and theme generation by HP was supplemented by discussion of initial and refined themes with SW. Interviewees are identified in the results by their gender, age, location of interview and an identifying number.

For spatial mapping of interview routes, the data from the GPS and PurpleAir were merged using the timestamps of each measurement. More detail on how this was done can be found in Supplementary material 3, alongside details about the calibrations that were applied to the air pollution data.

Places people associated with being 'harder' or 'easier to breathe' were coded into representative microenvironments using the interview transcripts, associated visual information from the GoPro HERO10 and based upon the research team's experiences in both communities. Statistical analysis (Mann Whitney U test) was undertaken in IBM SPSS Statistics (version 29).

3. Results

In total, 38 interviews were conducted with young people in Mukuru and Buruburu (Table 1; see Supplementary Material 4 for full interviewee list). Slightly more females than males participated in Mukuru (55% female), while there was an even split in Buruburu. The mean age (17 years) was identical for young people in both settlements, though the age range was larger for interviewees in Mukuru than Buruburu. The mean length of interviews was 29 minutes in Mukuru and 23 minutes in Buruburu, which may be related to the geographic scale of the settlements and/or the population densities (i.e., ease of movement through the areas).

Table 1: Demographics of the interviewees.

	Mukuru	Buruburu
Number of interviewees	22	16
Gender		
Female n (%)	12 (55%)	8 (50%)
Male n (%)	10 (45%)	8 (50%)
Mean age (range)	17 (13 - 20)*	17 (15 - 19)
Mean interview length in minutes (range)	29 minutes (16 - 58)	23 minutes (13 - 35)

* the age of one Mukuru interviewee was unknown, so this is the mean of known age interviewees (*n*=21).

Five themes were developed through analysis of the walking interview transcripts (Table 2).

Table 2: Descriptions of the themes constructed from the walking interviews.

Theme name	Theme description
Air pollution changes over space and time	This theme describes the various ways that interviewees expressed that air pollution changes over space and time, often as something moving from one place to another.
Breathing easy is a holistic feeling created by a space	This theme explores how breathing easy goes beyond clean air, incorporating a range of physical, emotional and social factors experienced in a location.
There's lots you can't do in spaces where it's harder to breathe	This theme explores the idea that harder to breathe locations are limiting, preventing you from doing the things you need to do or the things you enjoy doing.
Them (and us)	This theme explores the 'othering' of polluters and polluted places.
People need to be kept separate from air pollution	This theme explores the actions taken by interviewees to keep themselves or others apart from air pollution to help to minimise health impacts.

The theme '*Air pollution changes over space and time*' explores the transient nature of air pollution as expressed by interviewees. Interviewees described how air pollution changed over space and time in response to two main factors. First, air pollution-creating activities, such as waste burning or emissions from industry, were not constant, but rather occurred at specific times. Second, interviewees described how air pollution would move from one place to another, often dispersed through the air by the wind. The home, usually described as somewhere where breathing was easier, could also be infiltrated by air pollution, meaning nowhere was fully safe all the time.

"So this here now is the place where they burn those tyres and now the air enters into the houses" (Male, 15, Mukuru [Interviewee 20]).

Air pollution was not just something external, but rather interviewees also described how air pollution could move into the body and cause harm.

"When maybe I breathe it in, the lungs may absorb that smoke" (Male, 18, Mukuru [Interviewee 34]).

"…that smoke goes to your lungs and it coats your lungs" (Male, 17, Buruburu [Interviewee 17]).

For one interviewee, air pollution took on an anthropomorphised and sinister character with intent to harm.

"…when I pass there I feel like that smoke can affect me, it wants to affect me" (Female, 13, Mukuru [Interviewee 1]).

This meant that for many there were no places which were always free from air pollution, but rather spaces would be easy to breathe in on some occasions and not on others.

The theme *'Breathing easy is a holistic feeling created by a space'* explores the multidimensional factors that together combined to make a space easier or harder to breathe in for interviewees. Perceived good air quality was a consistent factor that contributed to people being able to breathe easily in a space, and was often determined by what people smelt, saw, heard and felt. Easier to breathe locations were sometimes considered to be pollution-free, with nothing contributing pollution into the air. However, the ability to breathe well went far beyond air quality alone, with other key aspects of the microenvironment creating a feeling for people when they spent time there. Spaces where people found it easier to breathe were often described as clean, spacious, had few buildings and people, with trees and vegetation and were peaceful.

"The school has a lot of trees. It has fresh air because of the trees and we are not that squeezed. The houses are far from each other. No congestion, so there is good air" (Female, 16, Burburu [Interviewee 7]).

"Here you see the environment is green, the tarmacked roads are clean… and even the people around here are calm" (Male, 17, Buruburu [Interviewee 12]).

In contrast, places where people found it harder to breathe were considered dirty (for example featuring waste and insects) and congested with buildings and people.

"You cannot breathe because there is smoke there…You feel dizzy 'cause you know smoke too is not good. It's like the air is so stuffy. Actually so stuffy. And you know you are all overcrowded there and there is no way you can get free circulation of air" (Female, 18, Buruburu [Interviewee 4]).

"You can stay and after like five minutes you feel a funny smell, you feel there is waste all around, and there are those … what is their name?.... houseflies flying there. Yes. You feel just the environment is dirty" (Female, age unknown, Mukuru [Interviewee 36]).

Together, these factors created feelings within particular spaces that were either positive (easier to breathe in) or negative (harder to breathe in).

There was a more varied selection of easier to breathe than harder to breathe microenvironments (Table 3).

Table 3: Local microenvironments where young people found it easier or harder to breathe. The location (Mukuru or Buruburu) was where the interview took place (with *n* referring to the number of participants from each community that selected that microenvironment). Of the potential *n*=76 microenvironments (each of 38 interviewees naming an easier to breathe location and a harder to breathe location), *n*=9 were missing $PM_{2.5}$ data due to instrument malfunction or operator error and a further *n*=5 were unclassifiable by microenvironment. $PM_{2.5}$ measurements at easier to breathe or harder to breathe locations are 'spot' measurements and represent a 'moment in time' at that location. Each measurement at a location was a two-minute average.

Microenvironment	Mukuru *n*	Mukuru mean $PM_{2.5}$ ($\mu g/m^3$)	Buruburu *n*	Buruburu mean $PM_{2.5}$ ($\mu g/m^3$)

Easier to breathe	Residential area	9	34.6	4	14.9
	Street	3	24.5	2	15.0
	Football/ playing field	1	17.0	3	16.9
	Open space (with trees)	3	19.3	1	5.4
	Outside school (grounds)	1	28.2	2	14.9
	Open space (no trees)	2	12.4	0	-
	Inside home	0	-	1	7.9
	Other indoor spaces	1	19.4	0	-
	All 'easier to breathe' microenvironments		**22.2**		**12.5**
Harder to breathe	Street	3	35.9	8	19.2
'Harder to breathe'	River/ drainage channel	10	33.6	0	-
	Open space (for informal dumping)	2	31.8	2	17.5
	Residential area	2	12.0	0	-
	Inside school	0	-	2	11.5
	All 'harder to breathe' microenvironments		**28.3**		**16.0**

Many microenvironments were selected only as easier or harder to breathe spaces (including harder to breathe: river/ drainage channel, open space (for informal dumping) and easier to breathe: football/ playing field, open space (with trees)). However, some microenvironments (for example street and residential areas) were selected by different interviewees as places they found it easier to breathe and places they found it harder to breathe. A number of the residential areas were located near to an interviewee's home, for example in their compound/garden. In these cases, these microenvironments were always considered easier to breathe locations.

For harder to breathe locations there were broad similarities between the microenvironments selected by interviewees in Mukuru and Buruburu, with some key differences. There were no

river / drainage channels selected in Buruburu, whereas in Mukuru these represented 59% of selected microenvironments. Streets were more commonly selected as harder to breathe locations by interviewees in Buruburu (67%) than Mukuru (18%). Residential areas were selected as a harder to breathe location by two interviewees in Mukuru (12%), but not in Buruburu, while indoor school microenvironments were selected by two interviewees in Buruburu (17%), but not in Mukuru. This last finding may be linked to some of the Buruburu interviewees boarding at their schools. For easier to breathe locations, residential areas were more commonly selected by interviewees in Mukuru (45%) than Buruburu (31%). Open space (with trees) and open space (more generally) were both more commonly selected by interviewees in Mukuru.

Even when the microenvironment type and designation (easier or harder to breathe) was the same for interviewees in Mukuru and Buruburu, how that microenvironment looked in practice was often very different (Figure 1). For example, residential areas which were easier to breathe in were much more open and spacious in Buruburu. The football/playing fields selected as easier to breathe by interviewees in Mukuru were covered in soil, while the same spaces in Buruburu were at least partly grass-covered (reducing dust resuspension).

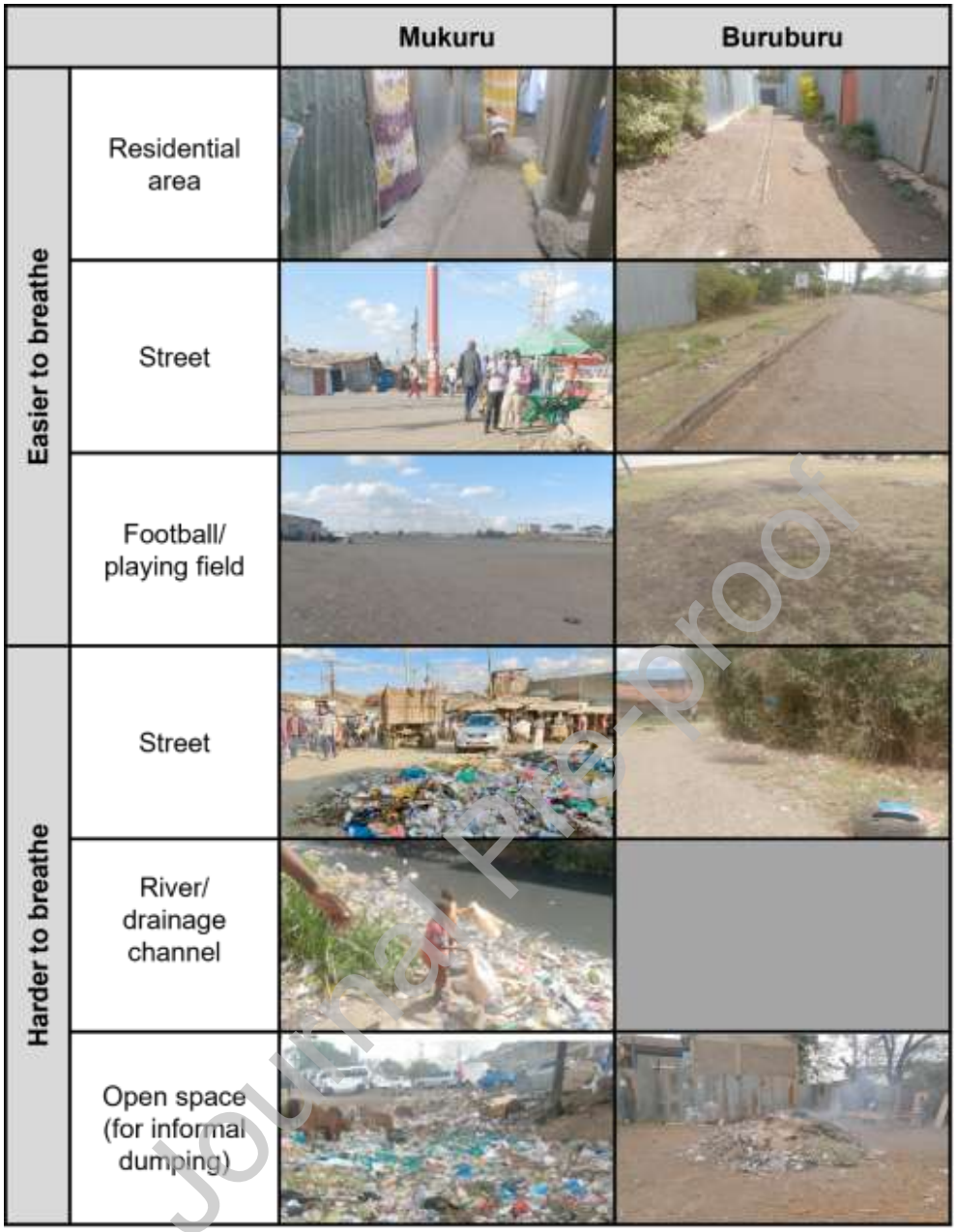

Figure 1: GoPro 'stills' taken from the walking interview videos exemplifying some of the most common 'easier to breathe' and 'harder to breathe' microenvironments selected by young people in Mukuru and Buruburu. No Buruburu interviewees selected river/drainage channel, hence this has been left blank.

Mean $PM_{2.5}$ concentrations for all locations selected as easier or harder to breathe were higher for interviewees in Mukuru than Buruburu. The mean $PM_{2.5}$ concentration for the harder to breathe locations identified in Buruburu (16.0 $\mu g/m^3$) was lower than the average $PM_{2.5}$ concentration for the easier to breathe locations in Mukuru (22.2 $\mu g/m^3$). However, the differences in $PM_{2.5}$ concentrations measured in locations selected as easier to breathe or

harder to breathe in neither Mukuru or Buruburu were statistically significant (Mann Whitney U test - Mukuru: $U = 193$, $z = -.457$, $p = .648$, Buruburu: $U = 70$, $z = -.744$, $p = .479$).

Four interviewees selected indoor microenvironments as locations they found it easier to breathe (n=1 in Mukuru and n=1 in Buruburu) or harder to breathe (n=2 in Buruburu). The mean $PM_{2.5}$ concentration for indoor microenvironments (12.6 µg/m^3 for n=4) was lower than the mean $PM_{2.5}$ concentration for outdoor microenvironments (24.3 µg/m^3 for n=58), though sample sizes for the indoor microenvironments were small.

The theme '*There's lots you can't do in spaces where it's harder to breathe'* explores the various ways that spaces that were more difficult to breathe in limited the activities that interviewees would undertake in them. This was often described in terms of a comparison between what they could do in easier to breathe spaces and what they could not do in the harder to breathe space. Harder to breathe spaces were described as places that you did not want to spend a long time in and where you could not relax. Interviewees also described how these spaces were not conducive to running, dancing, singing, listening to music, studying, eating, sleeping, spending time with friends and other activities they usually filled their time with.

"I can sing and I normally sing in church… In the other place [harder to breathe location], you find that I give out bass… They say that songs should not be sung in bass" (Male, 19, Mukuru [Interviewee 27]).

"There [harder to breathe location] you see you can't find a place to just sit down somewhere and talk… Because of that bad smell you don't want that and even the flies can disturb you" (Male, 17, Buruburu [Interviewee 17]).

The theme '*Them (and us)*' explores the many ways that interviewees set themselves or their communities apart from other people and places within or outwith their community. This frequently played out as the 'others' being the polluters (other residents or industries), with the interviewee (or their friends and family members) as the receptors of that pollution. The use of 'they', 'them' or 'these ones' was commonly used by interviewees to create this separation, with polluters sometimes described as being ignorant or lazy.

"They used to burn waste here but it brought issues… Like issues of violence in the area… It brought a lot of issues" (Male, 19, Buruburu [Interviewee 15]).

"These ones, I don't see them being bothered" (Male, 15, Mukuru [Interviewee 3]).

While some air pollution-creating activities were widespread (and perhaps carried out by the interviewee also), smoking (of cigarettes or bhang [cannabis]) was rare among interviewees. Interviewees expressed disdain for the practice of smoking and for those that smoked.

"Eh, Smoking! That is someone looking for death" (Male, 19, Buruburu [Interviewee 13]).

"Smoking also contributes... in fact we have visited at the right time, around four o'clock many youths come to smoke from there, around our home. They smoke bhang (Female, 20, Mukuru [Interviewee 33]).

Within this theme there was also a distinction made between Mukuru and more affluent parts of Nairobi, such as the town centre in terms of the likelihood of government action to address air quality.

"When you look like in town [central Nairobi] because it is a town centre the government will play big part in cleaning up, but here because here it is a slum and is high populated you find no one consider that here also there is a need to be cleaned for the people to have a clean air" (Female, 20, Mukuru [Interviewee 33]).

The theme '*Them (and us)*' also explored the idea that air pollution was worse somewhere else when compared to the area around interviewees' homes. For interviewees in Buruburu, informal settlements (including specifically Mukuru) were frequently highlighted as having higher air pollution. For interviewees in Mukuru, air pollution was frequently highlighted as being higher in other informal settlements, such as Kiambiu or Kibera, or in other parts of Mukuru. Even if air pollution was observed close to home by interviewees, air quality was usually considered to be better at home than in other places that interviewees were aware of. Linked to this, people explained that air pollution was something that you had to get used to in and around your home, meaning you did not notice it (or its effects on your health). However, if you left and came back, you would notice it again. Some interviewees described how getting used to air pollution masks it, normalising breathing dirty air and the associated health impacts.

"You can't live where there is bad smell. For example, let's say you are coming from another place…that's when you will smell it. But when you just stay within, you won't know you just get used to it. But let's say if I go to South B or C and come back…you will be like 'how is this place smelling?'" (Male, 17, Mukuru [Interviewee 28]).

"He [the Chief] mostly has some visitors from outside who mostly like to come here and tour and this smoke affects them. Last time we had some foreigners complaining that the air was dirty, so the chief prohibited that [waste burning]" (Male, 18, Buruburu [Interviewee 19]).

"I do tell those children; 'don't you feel that smell coming from the cigarette that your father smokes'… So now the elder sister says that she is used to it" (Female, 13, Mukuru [Interviewee 1]).

Most of the walks exhibited variation in $PM_{2.5}$ concentration along the route (Figure 2), with the magnitude of the differences larger for interviewees undertaking walks in Mukuru. Considering all the $PM_{2.5}$ data collected during the walking interviews (Figure 3; see supplementary material 3 (Figure S4) for details on the number of measurements averaged to develop each pixel in the figure), hotspots (red squares) emerged at two sites in Mukuru. The hotspot in the east is at the site of an abandoned quarry that is used as a dumping area by residents, while the hotspot in the west is a garbage collection area used for the recycling of cartons and plastics where burning of waste is common. Other slightly less polluted hotspots across Mukuru and (to a lesser extent) in Buruburu (darker orange shades in Figure 3) include other waste burning sites, areas with a high concentration of food vendors (for example fish frying, maize roasting), roads and industries.

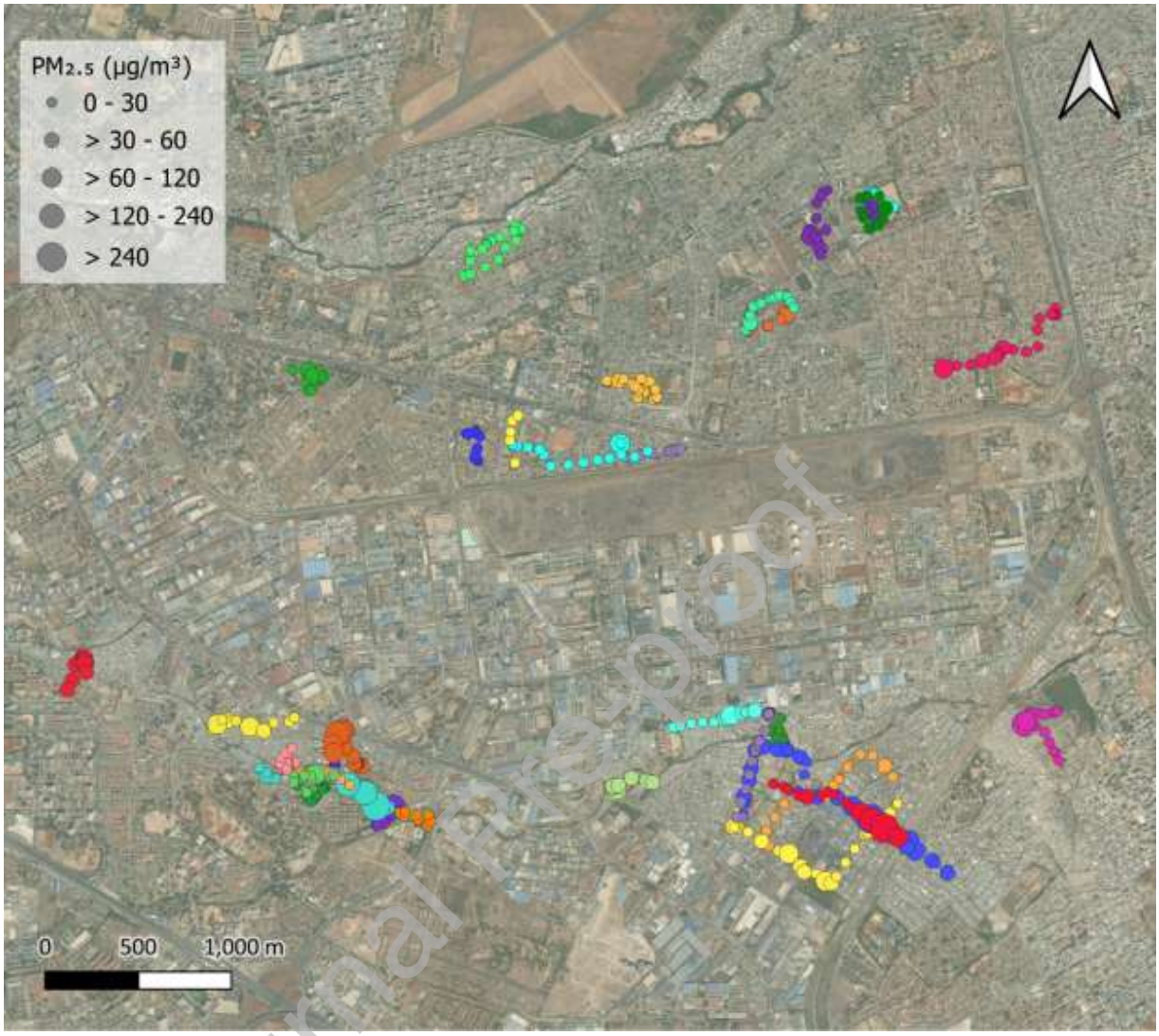

Figure 2: Exposure to $PM_{2.5}$ during 36 walking interviews with interviewees in Mukuru (bottom half of map) and Buruburu (top half of map). Data are missing for 2 interviewees (one was missing $PM_{2.5}$ data entirely and for one the $PM_{2.5}$ data and GPS data were temporally misaligned). $PM_{2.5}$ concentration is shown by the circle size (see key), and the colour denotes separate walks.

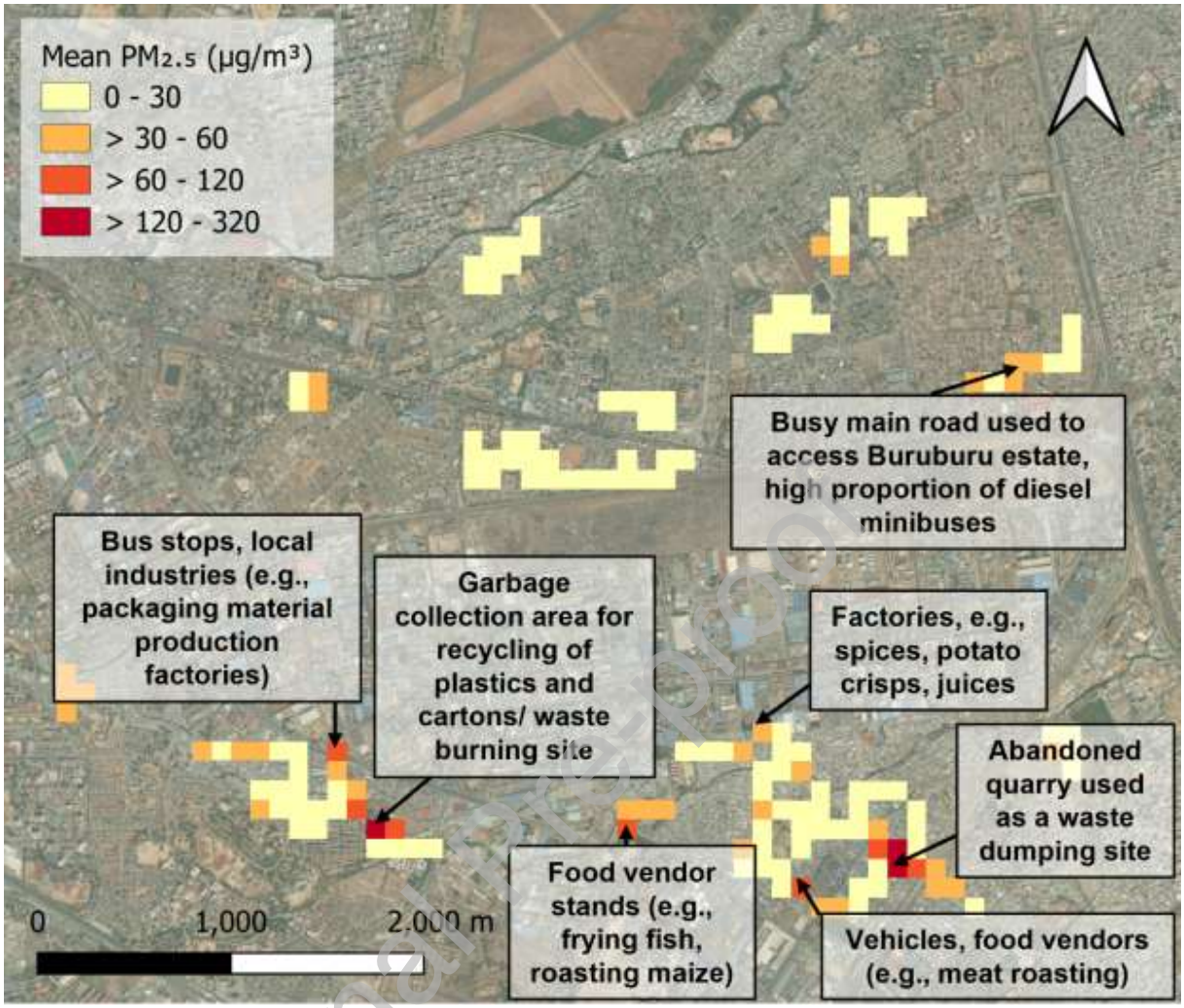

Figure 3: Measured $PM_{2.5}$ concentrations averaged across 36 walking interviews for 100m grid cells in Mukuru (bottom half of map) and Buruburu (top half of map) with potential source information added where known. Data missing for 2 walking interviews (see Figure 2 caption for more details).

The theme '*People need to be kept separate from air pollution'* explored a core idea expressed in various ways that air pollution affected people when they were close to it and people needed to be kept apart from where air pollution was.

"When I get close to it, it affects me" (Female, 17, Mukuru [Interviewee 22]).

"It is built with…iron sheet cause if it was open the smoke would just be going everywhere so they are trying to contain the smoke" (Female, 17, Buruburu [Interviewee 5]).

In Buruburu, several interviewees described how school staff tried to protect them from air pollution while burning waste in school grounds through choice of both the location and timing of the waste burning. Sometimes this worked, but other times the attempts to separate young

people from air pollution were less successful. However, in all cases this highlighted the thought and care that school staff were perceived to have for young people attending the school.

"The rubbish that we take from our class dustbin, sometimes from the dormitories and the rubbish that is not needed in the compost heap is usually dumped there and then it is burnt. Right now they are burning a small supply of it. There is a time they will burn a lot of it but when we are in the comfort of where it can't affect us (Female, 17, Buruburu [Interviewee 5]).

"…and for the trash no one usually goes there cause it's at the far end of the school so I don't think it really affects anyone" (Female, 16, Buruburu [Interviewee 8]).

This idea of protection of others by separating people from air pollution was also observed in some households, where actions were taken to protect those who were more vulnerable to air pollution, for example, by avoiding more polluting fuels.

This theme also explored individual actions (behaviour changes) that could be taken to avoid air pollution, since the onus was often on the person affected to remove themselves from the air pollution, rather than reducing the air pollution itself. Interviewees described how some routes or community spaces were avoided by those vulnerable to air pollution. Others described how they moved quickly through spaces with perceived high air pollution, held their breath, wore a mask or covered their nose.

"I don't pass here often. Because of that air. Just the way that air is you still don't want to breathe in that air" (Male, 17, Buruburu [Interviewee 17]).

"I can't breathe in the air because I know it is made up of intoxicated gases. So, I have to hold my breath. Then when I reach at a further distance a little bit then I take my normal breathing" (Female, 17, Mukuru [Interviewee 26]).

For some, a more permanent solution to separating from air pollution was needed, namely moving away from communities perceived as having very high levels of air pollution.

"...nowadays you can find people moving away from Bahati since it has become polluted" (Male, 18, Burburu [Interviewee 19]).

4. Discussion

4.1 Comparing perceptions to measurements of air pollution

$PM_{2.5}$ changed over space and time across our study areas (Figure 2, Figure 3), and indeed a key theme identified from the transcripts was *Air pollution as a moving smoke cloud*, highlighting that interviewees were aware that air pollution was spatiotemporally variable. People commonly associated air pollution with sights and smells as in previous work (for example McCarron et al., 2024a). This reliance on the senses can limit the identification of some important invisible sources of air pollution, such as carbon monoxide, which can reach high levels in these sorts of settlements (Orina et al., 2024).

Our $PM_{2.5}$ measurements (Figure 3) showed more 'hotspots' of air pollution in Mukuru compared to Buruburu. This fits with the findings from the wider [redacted] study (with a separate air

pollution dataset) [redacted] where measured $PM_{2.5}$ significantly differed between Mukuru and Buruburu, with significantly more wheezing and asthma in Mukuru. In this walking interview study, there were no significant differences in $PM_{2.5}$ measurements in easier to breathe compared to harder to breathe spaces in either Buruburu or Mukuru. This is probably related to the number of measurements included in the analysis. Past work attempting to explore the relationship between perceived and scientifically measured air pollution are mixed. Dons et al. (2018) found that higher concentrations of NO_2 (but not $PM_{2.5}$) at home were correlated with increased concern about air pollution for residents of seven European cities. However, Boso et al. (2022) found no correlation between perceived and objectively measured air pollution in two Chilean cities. Similarly, Brody et al. (2004) found that in Texas, USA, perceptions of air quality were not significantly correlated with measurements of air pollution. Here, our results align with Boso et al. (2022) and Brody et al. (2004), though it is worth emphasising that for our interviewees breathing easy went beyond air pollution alone (see section 4.4) and longer-term measurements in these spaces may have led to different conclusions on the link between easier breathing and lower air pollution levels (see section 4.5). Risk perception is known to have an important role in encouraging people to take action to minimise health effects (McCarron et al., 2023; Noël et al., 2022; Saksena, 2011), and so perceptions of breathing spaces could help interviewees manage their exposure risks if the protective behaviours they take are effective (see section 4.3).

The 'neighbourhood halo effect', where perceived air quality is better close to home (Bickerstaff & Walker, 2001; Hofflinger et al., 2019), manifested in our study within the interview theme *Them and Us*. Interviewees perceived locations outside of their communities to have poorer air quality than theirs. For interviewees in Buruburu, this was commonly informal settlements (including Mukuru), while for interviewees in Mukuru, other informal settlements were perceived to have poorer air quality than Mukuru. However, it is unclear whether this reflects perceptions relating to air quality or rather arises from wider reputations (i.e. factors beyond air quality such as crime or poverty) of the other neighbourhoods (King, 2015). The 'neighbourhood halo effect' also manifested as interviewees not selecting their home environment as a place they found it harder to breathe, though this finding could also have been related to study design (see section 4.5).

4.2 'Harder to breathe' spaces limit people's activities

Breath and breathing connect people with the environment they are situated within (Górska, 2021; Oxley & Russell, 2020), and spaces perceived as harder to breathe in limited the ways in which interviewees wanted to, and were able to, use these spaces. Interviewees described how they avoided or limited their time in harder to breathe spaces and described the range of activities (such as sleeping, eating, spending time with friends) they were prevented from undertaking there. Our interviewees were selected because in our initial [redacted] questionnaire [redacted]Click or tap here to enter text. they said that they experienced wheeze, a symptom consistent with asthma in adolescents of this age, though were not necessarily diagnosed with a medical condition that would precipitate such symptoms. Previous studies focused on adolescents with asthma have similarly described how the disease prevented people from doing things that they wanted to do (Gabe et al., 2002; Wildhaber et al., 2012).

4.3 Strategies to reduce exposure to air pollution

The theme *People need to be kept separate from air pollution* explored the various actions that interviewees took to keep themselves or others apart from air pollution to minimise health

impacts. Behaviours were predominantly avoidance behaviours, rather than contributing behaviours (such as stopping waste burning) or supportive behaviours (such as civil engagement) (Riley et al., 2021). Avoidance behaviours included creating physical or temporal space between people and air pollution (such as burning waste at night when people are not around), creating a barrier between people and air pollution (such as covering your face with cloth as you pass through) or minimising exposures by reducing the time you spend in proximity to air pollution (such as walking fast along a busy road).

Measured $PM_{2.5}$ concentrations were visually higher in Mukuru than Buruburu (Figure 3). This means that ultimately, in Mukuru, options for people to reduce exposures or 'clean their breathing spaces' are more limited (Garnett & Bhatnagar, 2022), evidencing an environmental injustice (Vaz et al., 2017). People's continued breathing of air that is heavily polluted could be considered 'slow violence' (Nixon, 2013), described as a violence that occurs 'gradually and out of sight', such as climate change, deforestation and air pollution. As a term, 'slow violence' can help to shed light on the 'hidden brutality of certain spaces' (Davies, 2018), such as those identified by our interviewees as harder to breathe in. In contrast to Nixon (2013), and aligned with Davies (2022), in Nairobi, the threat was not 'out of sight' to interviewees, but instead visible through their lived experiences of air pollution and lung health i.e., their identification of harder to breathe spaces and sources of air pollution, or sometimes actually visible due to the high concentrations experienced. However, breathing is political (Górska, 2021), and such experiences are often 'out of sight' to policy makers and others in power who have the potential to improve air pollution-related health, but instead sustain the embedded geographies of pollution (Davies, 2022; Dewan & Sibilia, 2024). This was noted by our interviewees in their comparisons of how the government took action to address air pollution in 'town' (central Nairobi), but not in their communities. This, in turn, reinforces the need for people, particularly those susceptible to the health impacts of air pollution (such as our interviewees), to rely on individual action (i.e. avoidance behaviours) to reduce respiratory health impacts. It also emphasises the importance of creating spaces for those in power to hear about the lived experiences of those experiencing poor air quality (see, for example, West et al., 2021).

4.4 Making spaces in Nairobi easier to breathe in

Various factors contributed to an area being perceived as easier to breathe in (i.e., good air quality/ low or no air pollution sources, clean, spacious, sparsely populated, low building density, trees and vegetation, peaceful and calm) or harder to breathe in (i.e., poor air quality, dirty, densely populated, high building density). How well people felt that they could breathe in a space was multidimensional, encompassing the various sensorial experiences of a space (Ngo et al., 2017; Noël et al., 2021). As in Day's study (2007) in London, UK, for our interviewees air pollution was one facet of the various physical, emotional and social characteristics of spaces that together combined to create a positive or negative association with the space in relation to breathing. This finding provides insights for what could support, from a health promotion perspective, a more 'therapeutic landscape' (Gesler, 1992), i.e., in this case places which promote healing and better health. A focus on therapeutic landscapes in relation to people's 'everyday geographies' (i.e. the socio-spatial spaces in which people spend time) (Mossabir et al., 2021) could support the creation of more spaces that people find it easier to breathe in. As already highlighted, perceptions of air pollution can impact health irrespective of objectively measured air pollution (Dons et al., 2018; Orru et al., 2018). Improving the aforementioned qualities of Nairobi's spaces, for example planting trees, could therefore benefit health through perceived (rather than, or in addition to, actual) improvements in air quality.

4.5 Limitations and methodological reflections

The use of walking interviews in this study - in comparison to, for example, standard static interviews – enabled in-depth place-based discussions around the experiences people have in those spaces (including the air they breathe) and the impacts these spaces have on their lung health. Combining walking interviews with other data types (i.e., video, GPS route tracking, $PM_{2.5}$ measurements) enabled us to go beyond learning about lived experiences, to also identify potential air pollution sources along the walking routes and compare perceptions of air quality with scientifically measured air quality (albeit for a single air pollutant, $PM_{2.5}$). Future studies could take this a step further, using air pollution data to help inform air quality discussions (for example to support behaviour change) in the various micro-environments where people spend their time.

Despite its strengths, our approach also had limitations, and we hope that our methodological reflections can help others to optimise the design of their studies in the future. Measurements of air quality during the walking interviews just capture that moment in time (see Table 3), and as the locations were identified by interviewees in advance, the $PM_{2.5}$ measurements do not necessarily reflect those lived experiences. Further, we selected and measured only one pollutant ($PM_{2.5}$). $PM_{2.5}$ varies significantly in terms of its physical and chemical properties, meaning it could be a sub-fraction of $PM_{2.5}$ (for example, from one particular source), or another air pollutant altogether, driving the perception response. Longer-term monitoring at selected sites, for a wider range of air pollutants, would better support conclusions on whether harder to breathe' locations had the highest levels of air pollution.

Few of the microenvironments chosen by our interviewees were indoors, which may be because we did not explicitly state that spaces could be indoors or outdoors. People might implicitly think we mean outdoor environments, as air pollution is often perceived to be an outdoor problem (Kim et al., 2019; McCarron et al., 2024b). In future studies the potential to include indoor *or* outdoor spaces should be explicitly highlighted to interviewees before they select their sites.

Though we video recorded the walking interviews for later analysis (for example identification of air pollution sources along the route for comparing to $PM_{2.5}$ concentrations), sometimes sources were not visible on the video, meaning another field visit was required to produce the sources shown in Figure 3. It would have saved time if one of the research assistants had identified key air pollution sources during the walking interviews.

Future projects may want to consider the high levels of staffing required to conduct fieldwork of this kind safely and accurately. We took safeguarding seriously, including scoping routes in advance and having a community representative accompany our two members of staff. This is very important when working in such settings but does have resourcing implications.

We purposely structured the interview (see Supplementary material 1) to avoid directing people towards air pollution in their identifications of easier and harder to breathe spaces, however the participant information sheets outlined the full purpose of the study and so this could have impacted the responses given by interviewees.

Finally, this study was undertaken in the wake of the COVID-19 pandemic. This will have likely impacted the ways that interviewees viewed breathing and air pollution, for example it is likely that much of the mention of using masks as a protective mechanism was due to people's experiences of COVID-19. This context needs to be considered in the interpretation of findings.

5. Conclusion

This study set out to explore adolescents' lived experiences of breathing, lung health and air pollution in Nairobi, Kenya. We found that: 1) Breathing well is multidimensional, encompassing various physical, emotional and social characteristics of spaces; 2) There was no statistically significant difference in measured $PM_{2.5}$ concentrations between easier to breathe and harder to breathe spaces in either community; 3) People can do more in places where they find it easier to breathe, while harder to breathe spaces limit activity; 4) Mukuru (informal settlement) had more 'hotspots' of $PM_{2.5}$ air pollution compared to Buruburu (the more affluent settlement), highlighting inequalities in $PM_{2.5}$ exposure and people's potential to reduce exposures through behavioural changes.

Our study suggests that breathing well in a space can be supported by addressing a range of place-based factors. These include cleanliness through improved sanitation and waste management, urban planning to reduce building density and increase green spaces and air quality. All participants described the 'avoidance' behaviours that they took to try to reduce exposure to air pollution (for example walking quickly or not visiting specific areas), but interviewees very rarely outlined 'contributing' behaviours (for example not burning waste) or 'supportive' behaviours (for example civic engagement) they undertook. Identifying mechanisms to support 'contributing' and 'supportive' behaviours, in addition to more top-down policy-driven action to address air quality and improve people's breathing, would support air pollution exposure reductions and improve health and wellbeing in Kenya.

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[Redacted]. For the purpose of open access, the author has applied a CC BY public copyright licence (where permitted by UKRI, 'Open Government Licence' or 'CC BY-ND public copyright licence may be stated instead) to any Author Accepted Manuscript version arising'.

Data availability

Data will be made available on request.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: