Linking outdoor particulate pollution to children's negative experiences of their neighbourhoods: Findings from an interdisciplinary research project in Ankara

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Abstract
This study aimed to understand whether children living in neighbourhoods with higher particulate matter (PM) concentrations report more air pollution-related issues than children living in neighbourhoods with lower PM concentrations and whether these issues vary across neighbourhoods with different built environment characteristics. Data were drawn from participatory mapping activities with 9–14-year-old children living in eight neighbourhoods of Ankara, Türkiye, objectively analysed urban form characteristics of these neighbourhoods, and $PM_{2.5}$ and PM_{10} measurements in children's places in a heating and non-heating season. Results show that as the built environment characteristics and $PM_{2.5}$ and PM_{10} concentrations of children's neighbourhoods change, the proportions of air pollution-related issues reported by children alter.

Keywords: outdoor air pollution; particulate matter; children's place experiences; neighbourhood; participatory mapping

1. Introduction

Outdoor air pollution is a major threat to global public health, responsible for 4.2 million deaths worldwide in 2019 (World Health Organization, 2021). According to a report published by the World Health Organization (2018), roughly more than 90% of children under the age of 15 years breathe polluted air, affecting their health and well-being negatively. Children are particularly vulnerable due to their higher respiration rates, developing organs and proximity to ground-level pollutants. One major consequence of air pollution is asthma – a chronic inflammatory disease of the airways that usually develops in childhood (Graham, 2004; Hammad and Lambrecht, 2021; Vörös et al., 2019). Some other health impacts of air pollution to children are brain functioning problems (Markevych et al., 2021), issues related to skeletal growth (Sram et al., 2013), increased overweight and obesity (Zhou et al., 2021), increased susceptibility to respiratory infections (Krismanuel et al., 2024), and pneumonia (Nhung et al., 2017).

Additionally, prior research has shown strong associations between air pollution and academic success of children (Miller and Vela, 2013). Even the perception of polluted air may affect children's behaviour and well-being negatively (Chen et al., 2020).

There is a voluminous amount of literature linking built environment to air pollution in children's home and school neighbourhoods (Aydin and Severcan, 2024; Lim et al., 2017; Ortegon-Sanchez et al., 2021; Roche et al., 2024). A closer review of this literature shows that there are two groups of researchers concerned with these relationships. The first group, quantitative researchers, mainly consists of scientists affiliated with the departments of engineering, environmental sciences, and environmental epidemiology (see, e.g., Dadvand et al., 2015; Demirel et al., 2014; Lim et al., 2017; Mohai et al., 2011; Rivas et al., 2014). By objectively measuring outdoor air pollution and built environment, these scholars have largely questioned the physical environmental correlates of outdoor air pollution around children's homes and schools – e.g., living in an urban or rural area, traffic, building density, and neighbourhood greenness. The second group, qualitative researchers, is fewer in number compared to quantitative researchers and is mostly affiliated with the fields of sociology, psychology, and education (see, e.g., Börner et al., 2017; Duran, 2021; Manouchehri and Burns, 2023). The common characteristic of these scholars is that they have directly engaged children in research to understand whether young people perceive the environmental problems in their everyday environments (including air pollution) and the factors that affect children's perceptions. The self-reported data have been presented in qualitative, semi-qualitative or quantitative forms. In general, while these studies are exploratory in nature, their results can inform urban planning and design about how to design neighbourhoods with better air quality. Our review of the literature revealed that there is a lack of interdisciplinary research that bridges these two groups of researchers. Perhaps partly for this reason, we could not find any studies that linked children's negative place experiences regarding air pollution-related issues to the actual outdoor air quality levels of their neighbourhoods with varying built environment characteristics.

Drawing on an interdisciplinary, cross-sectional research project with a novel research design, this study aimed to understand whether children report more negative experiences about outdoor air pollution in school neighbourhoods with higher particulate matter ($PM_{2.5}$ and PM_{10}) concentrations. We also questioned whether these air pollution-related issues are related to the built environment. This study is important because finding a match between high levels of neighbourhood air pollution and a few negative outdoor experiences related to air quality can support the prior claims of qualitative researchers that there is a relationship between built environment, outdoor air pollution and outdoor place experiences of children (Börner et al., 2017). Furthermore, the results presented here may lead future studies to consider the reasons of a possible mismatch between children's negative place experiences related to outdoor air pollution and the actual air quality levels of children's neighbourhoods. They also pave the way for the creation of healthier environments for children.

The remainder of this paper is organised into three main parts. The next section provides a background information about the factors affecting PM concentrations and how these factors may affect children's place experiences. This is followed by the method and results section. The paper concludes with a discussion of the results, implications for urban planning and design, and limitations of the study.

2. Literature review

This section provides a brief summary of the literature relevant to this study.

2.1. *Factors that influence the level of $PM_{2.5}$ and PM_{10} concentrations*

PM (particulate matter), described as the mixture of solid particles and liquid droplets in the air, is one of the most serios air pollution problems in the world (Sun et al., 2014). PM is classified by particle size. Particles with size not exceeding 2.5 μm are known as $PM_{2.5}$ or "fine PM." $PM_{2.5}$ and smaller (ultra-fine particles) are known to be highly dangerous for children's health since they can penetrate deep into their lungs (Pope and Dockery, 2006). PM_{10} refers to particulate matter smaller than 10 μm in diameter.

The sources of PM can be human-made (e.g., transport- or industry-related) or natural (e.g., dust storms, volcanoes). It is commonly accepted that human-made (also called anthropogenic) sources are more important than natural sources in urban areas. Some common sources of $PM_{2.5}$ and PM_{10} in urban areas are related to industrial emissions, domestic heating, vehicle engines, and construction activities. PM_{10} mainly originates from soil dust resuspension, construction, non-exhaust vehicle emissions and industrial dusts, whereas $PM_{2.5}$ is largely derived from combustion processes (industrial combustion), mining and construction activities, fires or burning of the wood and transformation of gaseous species (Gugamsetty et al., 2012). The main sources of $PM_{2.5}$ and PM_{10} concentrations may vary from one city to another based on their characteristics. For example, Qin et al. (2006) found that in metropolitan New York City, most of the $PM_{2.5}$ concentrations derive from transport (e.g., diesel engines and trucks), whereas another study conducted in an industrialised region of China, Pearl River Delta Economic Zone, showed that the average concentrations of $PM_{2.5}$ in roadside and industrial areas are not significantly different (Wang et al., 2016). Some other studies argued that most of the PM in the atmosphere originates from the construction industry (Cheriyan et al., 2020).

The sources of PM in urban settings are often difficult to detect, posing challenges for urban planners aiming to design neighbourhoods with improved air quality. This difficulty stems partly from the complex nature of PM, which includes both anthropogenic, natural and biological particles such as dust and pollens (Ortega-Rosas et al., 2021). For example, research shows that living close to urban green areas on the one hand and to roads with heavy traffic may increase residents' PM exposure (Capone et al., 2023; McCarty and Kaza, 2015; Vörös et al., 2019). Elevated pollen concentrations may increase PM concentrations. In green open spaces located next to industrial areas, industry-related particles may attach to pollen surfaces, increasing green space users' PM exposure (Ortega-Rosas et al., 2021). However, there is also a great deal of literature showing how green open spaces play a key role in reducing PM concentrations in cities (Han et al., 2020).

Another reason is the complexity of the relationships among the variables. Existing findings regarding the role of built environment in PM concentrations are contradictory, and thus inconclusive. Multiple factors affect an individual's PM exposure: meteorological (e.g., temperature, humidity, wind), physical environmental (e.g., elevation of neighbourhoods, proximity to major roads and industrial facilities, morphology at various scales – like leaf morphology, clustering of the vegetation or land uses) and behavioural (e.g., time of place use, duration of exposure to transport-related pollution) (Adgate et al., 2002; Han et al., 2020; Ning et al., 2018; Qin et al., 2006; Zender-Swiercz et al., 2024). These factors are in relationship with one another, causing an individual's PM exposure to differ from one place or time to another.

Meteorological factors complicate the relationship between built environment and PM concentrations. Higher PM concentrations are linked to higher air temperatures, higher humidity, and lower wind speeds (Jayamurugan et al., 2013). Thus, one can observe different associations between green open spaces (or built-up areas) and PM in different seasons (Sabir et al., 2024). Certainly, the issue that particles can travel long distances with the wind (even from one country to another) makes it challenging for researchers to relate outdoor PM concentrations to a particular built environment variable (like presence of green spaces or traffic). In urban neighbourhoods, temperature and wind speeds can be affected by various built environment features – at meso-scale, e.g., building density, layout of the buildings, and neighbourhood greenness (Bonan, 2008; Spirn, 1987).

Neighbourhoods with higher building density are usually associated with more building surfaces, and thus higher thermal load (Chen et al., 2017). Scholars like Spirn (1987) and Makvandi et al. (2024) discuss how increased building density results in a decrease in air flow at the street level. On the other hand, some scholars linked built environment attributes like building density, street connectivity, land use mix and neighbourhood greenness to greater outdoor physical activity, and thus to lower transport-related PM concentrations (Frank et al., 2006) (for conflicting results, see, e.g., Zlatkovic et al., 2019, who showed that well-connected streets in neighbourhoods is associated with high traffic density, and thus lower air quality).

At the micro-scale, various urban design characteristics may affect PM concentrations. The size of green spaces and layout of planting in these areas (Qiu et al., 2018), and presence of land uses that generate vehicle traffic (e.g., commercial and educational areas, gas stations, bus station, and construction sites) (Razak et al., 2023; Yan et al., 2019; Yang et al., 2017) are some of the factors affecting PM. At certain hours of the day (like school/ business opening and closure hours), PM concentrations tend to increase around such land uses (Razak et al., 2023). Increased outdoor $PM_{2.5}$ and PM_{10} concentrations are also associated with proximity to waste dump sites (Chkwu Okeah et al., 2021; Jatau et al., 2024), wood and waste burning activities (Fuller et al., 2014; Mouganie et al., 2023), and outdoor smoking (Acevedo-Bolton et al., 2014).

2.2. *The role of air pollution in children's place experiences: What do we already know?*
Studies show that when children are asked about the problems of their neighbourhoods, they mention a variety of problems related to outdoor air quality: e.g., traffic-related pollution (Börner et al., 2017), industry-related pollution (Börner et al., 2017; Ozbil Torun et al., 2024), smelly trash cans (Loukaitou-Sideris, 2003), smoking (Duran, 2021; Pluhar et al., 2009), places with high pollen concentrations (Pluhar et al., 2009), and problems related to deforestation, urbanisation and replacement of urban green spaces with buildings (Duzenli et al., 2019). Although these problems are known to effect children's place experiences negatively, little is known whether children living in neighbourhoods with higher particulate matter (PM) concentrations report more air pollution-related issues than children living in neighbourhoods with lower PM concentrations, and whether these issues vary across neighbourhoods with different built environment characteristics. This paper aims to fill these gaps in the literature.

3. Method
This study was carried out in the capital of Türkiye, Ankara. Data were drawn from a larger-scale, interdisciplinary research project bringing together urban planners and designers, who were specialised in urban form analysis and children's geographies, environmental engineers specialised in air pollution, and paediatricians specialised in childhood asthma. Our method consisted of eight steps which are explained in the following eight subsections.

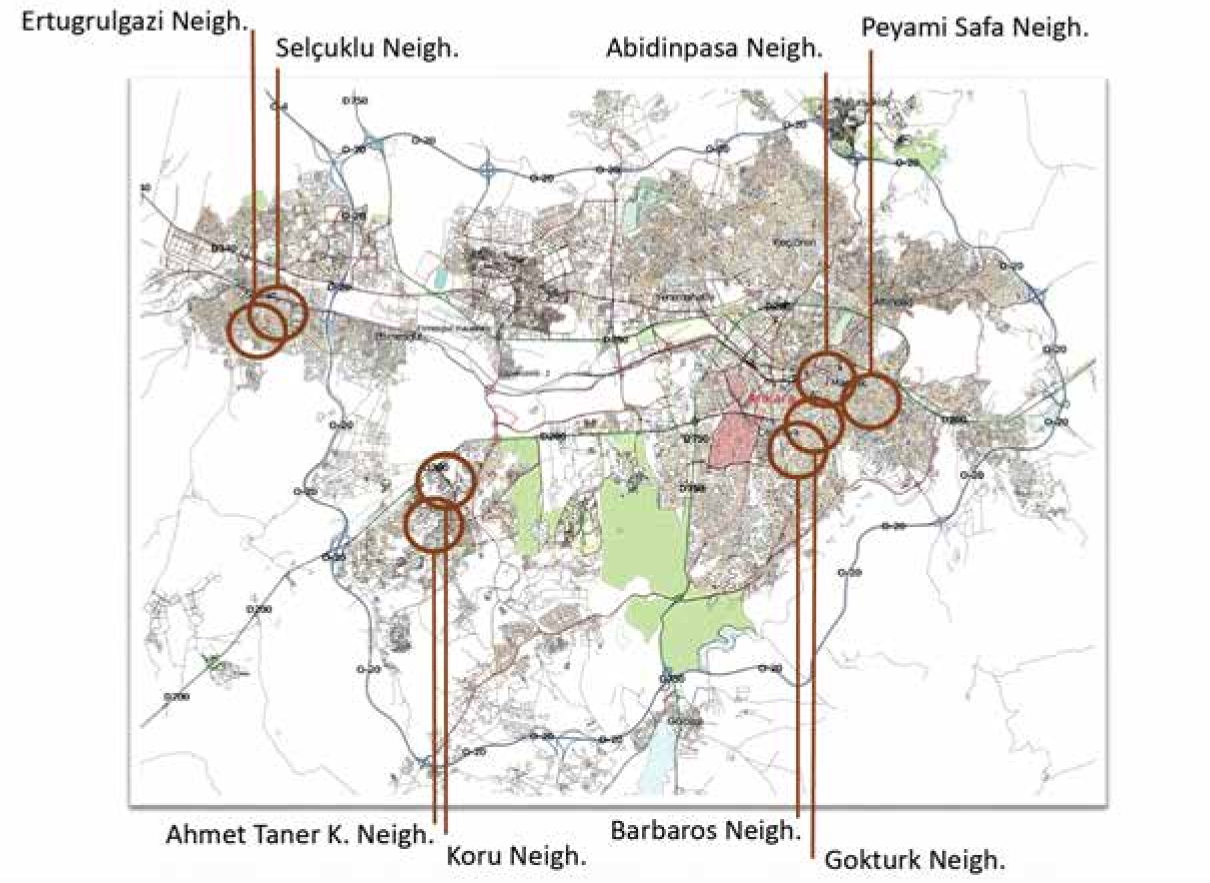


Figure 1. Location of the selected neighbourhoods.

3.1. *Site selection*
This study was conducted in eight neighbourhoods in Ankara: from Cankaya district: Gokturk, Barbaros, Koru and Ahmet Taner Kislali neighbourhoods, from Mamak district: Abidinpasa and Peyami Safa neighbourhoods, and from Sincan district: Selcuklu and Ertugrulgazi neighbourhoods. Figure 1 shows the location of these neighbourhoods in the city. Details of the site selection process can be found in Aydin (2023). All neighbourhoods differed in their built environment characteristics (e.g., proximity to industrial areas, forests, building density, land use mix, street connectivity, neighbourhood greenness, elevation, traffic) (*ibid.*)

3.2. *Investigation of the built environment characteristics of the selected sites*

Built environment characteristics of the selected sites were measured objectively using Geographic Information System (GIS) tools. The process consisted of several steps: (1) obtaining GIS data from the metropolitan municipality, (2) creating 800-meter buffers around all public schools located within the administrative borders of the selected neighbourhoods (these buffer areas represented school neighbourhood areas), (3) field observations to document the most recent land uses, building heights and building typologies in the school neighbourhoods, (4) updating the GIS data set based on the field notes, and (5) GIS-based analysis of built environment attributes of the selected neighbourhoods. Neighbourhood boundaries were defined by joining the boundaries of school neighbourhoods in each administrative area.

For the purpose of this study, we classified the selected neighbourhoods based on their land use mix and neighbourhood greenness. We selected these variables because previous studies have shown their association with PM and they were available in our data set. While our initial aim was to classify neighbourhoods based on some additional built environment variables like building density and proximity to industrial facilities, as we have shown in the following sections of this paper, children rarely mentioned such variables as problems in their neighbourhoods. We could not observe any difference between the average traffic density of the selected school neighbourhoods, which led us not to classify neighbourhoods based on this variable. However, in line with what Frank et al. (2006) suggested, we assumed that compared to children living in neighbourhoods with lower land use mix, children living in neighbourhoods with a higher land use mix would report less vehicle traffic issues.

Table 1. Built environment characteristics of the selected neighbourhoods.

Neighbourhood	Land use mix	Neighbourhood greenness
Barbaros	0.69	0.44
Gokturk	0.41	0.54
Koru	0.62	0.66
Ahmet Taner Kislali	0.52	0.68
Abidinpasa	0.50	0.47
Peyami Safa	0.37	0.44
Selcuklu	0.49	0.50
Ertugrulgazi	0.36	0.55

Land use mix, at the building level, was measured by the land use entropy score, indicating the level of land use diversity (Saelens et al., 2003). The index ranges from 0 to 1, where 1 refers to a perfect mix and 0 refers to a perfect homogeneity. Neighbourhood greenness was calculated by dividing the total area of permeable surfaces (softscapes) by the buffer area. Details of the analysis process can be found in the study of Aydin (2023). Table 1 shows the results of these analyses.

3.3. *Participant selection*

Child participants were selected in several stages. First, we selected all the public schools located inside the administrative boundaries of the chosen neighbourhoods. After obtaining the necessary ethical approvals from the university's ethics board and Ministry of Education, we went to the selected schools to distribute the consent forms and explain the study to 9–14-year-old children (third to eighth graders). Sixteen schools were visited for this purpose. All children who wanted to participate in the study and returned the parent-signed consent forms were accepted. This study is based on data drawn from participatory mapping activities with children.

3.4. *Participatory mapping activities with children*

Participatory mapping is a method used for linking children's views of their environments to specific geographical contexts (Ozbil Torun et al., 2024). In our study, we used this data collection technique for various reasons: e.g., to find out the most frequently used places of children so that these places can be used for measuring the outdoor PM concentrations in the further stages of our research, and to document children's negative places experiences. In total, 1687 children participated in participatory mapping activities.

The process started by grouping children into groups of 5-7 in the empty classrooms and conference rooms of the selected schools. Thereafter a trained moderator gave each group of children a 50x70cm poster, which consisted of a high-quality satellite image of the chosen school neighbourhoods and a blank map legend under it. This image showed an area within 800-meter radius of the school. Next, followed by a process where children were shown how to read satellite images, children were asked to pinpoint their homes and the places they frequent and like on the map. Two different procedures were used in this stage: while some participants were asked to explain their responses in detail (e.g., what they do in these places, why they like them) (n=881), others were not asked about such details because of the time restrictions (n=806). Finally, on another blank base map, children (n=1687) were asked to pinpoint the places they see problematic and/or dislike in their school neighbourhoods and discuss the reasons of their responses. Children used unique stickers when documenting their responses and recorded the meaning of each sticker in the legend (Figure 2). The whole process took about 1.5 hours.

Figure 2. Photographs from participatory mapping activities.

3.5. ***Data coding and analysis to define children's frequently used places***
We followed a five-step process for the selection of PM measurement sites. First, we digitised 1687 children's positive places in GIS. This process resulted in the coding of 8704 positive places in the selected neighbourhoods. Second, we deleted the overlapping points in ArcGIS to avoid repetition after transferring their content (e.g., how many children mentioned them) into the retained points. This reduced the total number of points into 2355. Third, we investigated the built environment characteristics (e.g., building density, street connectivity, land use mix, neighbourhood greenness, etc.) of the surrounding of these places to select the most spatially unique PM measurements sites in the following stages of the research. Fourth, after normalizing the data, we used a hierarchical cluster analysis to group children's places with similar built environment characteristics. Twenty clusters were produced for each neighbourhood. For clustering, we used Ward's method and squared Euclidian distance. Fifth, we selected the most frequently mentioned place/point from each cluster. Thus, from eight neighbourhoods, 160 points were selected for PM measurements. A range of places were selected such as neighbourhood parks, urban parks, school yards, streets with ground floor retail and home gardens.

3.6. ***$PM_{2.5}$ and PM_{10} measurements in children's frequently used places***
$PM_{2.5}$ and PM_{10} measurements were performed in the selected sites twice, one during heating season (March 22 – April 18, 2023, average temperature: 14.8 °C) and another during non-heating season (May 27 – June 15, 2023, average temperature: 20.95 °C). We used two DustTrak aerosol monitors (Model 8530), one for measuring $PM_{2.5}$ and the another for measuring PM_{10} concentrations. In each children's place, we zero calibrated the devices and concurrently carried out the PM measurements for 7 minutes at a height close to children's breathing height (Figure 3). We explained the details of this procedure elsewhere in another paper.

Figure 3. Photographs from $PM_{2.5}$ and PM_{10} measurements.

In our analysis, we considered the data obtained during the last 5 minutes of the PM measurements. Table 2 shows the average $PM_{2.5}$ and PM_{10} concentrations of each neighbourhood in different measurement periods. When presenting the results, the data obtained from Koru and Ahmet Taner Kislali neighbourhoods – two adjacently located neighbourhoods showing similar built environment characteristics – were merged for the reason we explained in next section.

Table 2. Average $PM_{2.5}$ and PM_{10} concentrations (µg/m^3) in the selected neighbourhoods.

Neighbourhoods	Heating season (March-April 2023)		Non-heating season (May-June 2023)	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Barbaros	26.547	24.179	42.421	48.295
Gokturk	20.274	19.158	48.905	58.863
Koru + Ahmer Taner K.	46.979	55.313	17.862	20.800
Abidinpasa	33.126	41.389	33.084	38.516
Peyami Safa	27.274	34.263	36.768	42.789
Selcuklu	48.480	47.130	22.550	25.720
Ertugrulgazi	64.863	72.800	18.032	21.168

Our findings indicate that $PM_{2.5}$ and PM_{10} concentrations diminished in peripheral neighbourhoods of Ankara (Koru, Ahmet Taner Kislali, Selcuklu, and Ertugrulgazi) while escalating in neighbourhoods near the city centre as temperatures rose. In heating season, $PM_{2.5}$ concentrations ranged from 20.27 µg/m^3 (in Gokturk) to 64.86 µg/m^3 (Ertugrulgazi); PM_{10} concentrations ranged from 19.16 µg/m^3 (Gokturk) to 72.80 µg/m^3 (Ertugrulgazi). In non-heating season, $PM_{2.5}$ concentrations ranged from 17.86 µg/m^3 (Koru and Ahmet Taner Kislali) to 48.90 µg/m^3 (Gokturk); PM_{10} concentrations ranged from 20.80 µg/m^3 (Koru and Ahmet Taner Kislali) to 58.86 µg/m^3 (Gokturk).

3.7. *Analysing children's negative places*

This process consisted of three stages. First, we digitised 1687 children's negative places in GIS, which resulted in the coding of 4171 places in eight neighbourhoods. The distribution of these places across Barbaros, Gokturk, Abidinpasa, Peyami Safa, Koru and Ahmet Taner Kislali, Selcuklu and Ertugrulgazi neighbourhoods were 370, 640, 644, 457, 335, 906 and 819 respectively. In each of these places, children mentioned one problem related to that site (e.g., "*there are gangs here*", "*There is no traffic light in this street junction*", "*there are people burning coal here*", "*there is too much traffic in this street with high vehicle exhaust*"); our GIS data set included these statements. Thereafter we exported this data set to MAXQDA, a content analysis software.

While reviewing children's explanations of their experiences, we categorised these issues based on their themes. To this end, we used a thematic content analysis method to analyse children's statements.

Our findings indicate that six main themes emerged from the data set, one of which pertains to air quality. Out of 4171 issues mentioned by children, 1378 issues were in this category. We revealed 10 sub-categories under the air quality theme. Table 3 presents the distribution of these 1378 issues across these 10 sub-themes and neighbourhoods. Because of the low number of participants in Koru neighbourhood (n=22 children), for the purpose of this study, we merged the data obtained from Koru and Ahmet Taner Kislali neighbourhoods – two adjacently located neighbourhoods showing similar built environment characteristics. This table shows that, in Abidinpasa neighbourhood, 249 children mentioned 179 air quality-related problems in their school neighbourhoods, which corresponds to around 27.8% of all the problems mentioned. Out of 644 mentioned issues in this neighbourhood, 35 (5.4%) were in the category of places with lack of vegetation. Children mentioned various problems related to air quality, including transport- and construction-related air pollution issues, places with smelly trashes and smokers, and places where tree cutting activities take place. These results are in line with most previous research (e.g., Börner et al., 2017; Duran, 2021; Loukaitou-Sideris, 2003; Pluhar et al., 2009). Our results also suggest that neighbourhood characteristics may play a role in the issues mentioned by children. For example, compared to children living far from construction sites, more children mentioned construction related issues in the neighbourhood that gives an edge to construction sites (i.e., Ertugrulgazi).

Table 3. The number and frequency of outdoor air quality-related issues in the selected neighbourhoods.

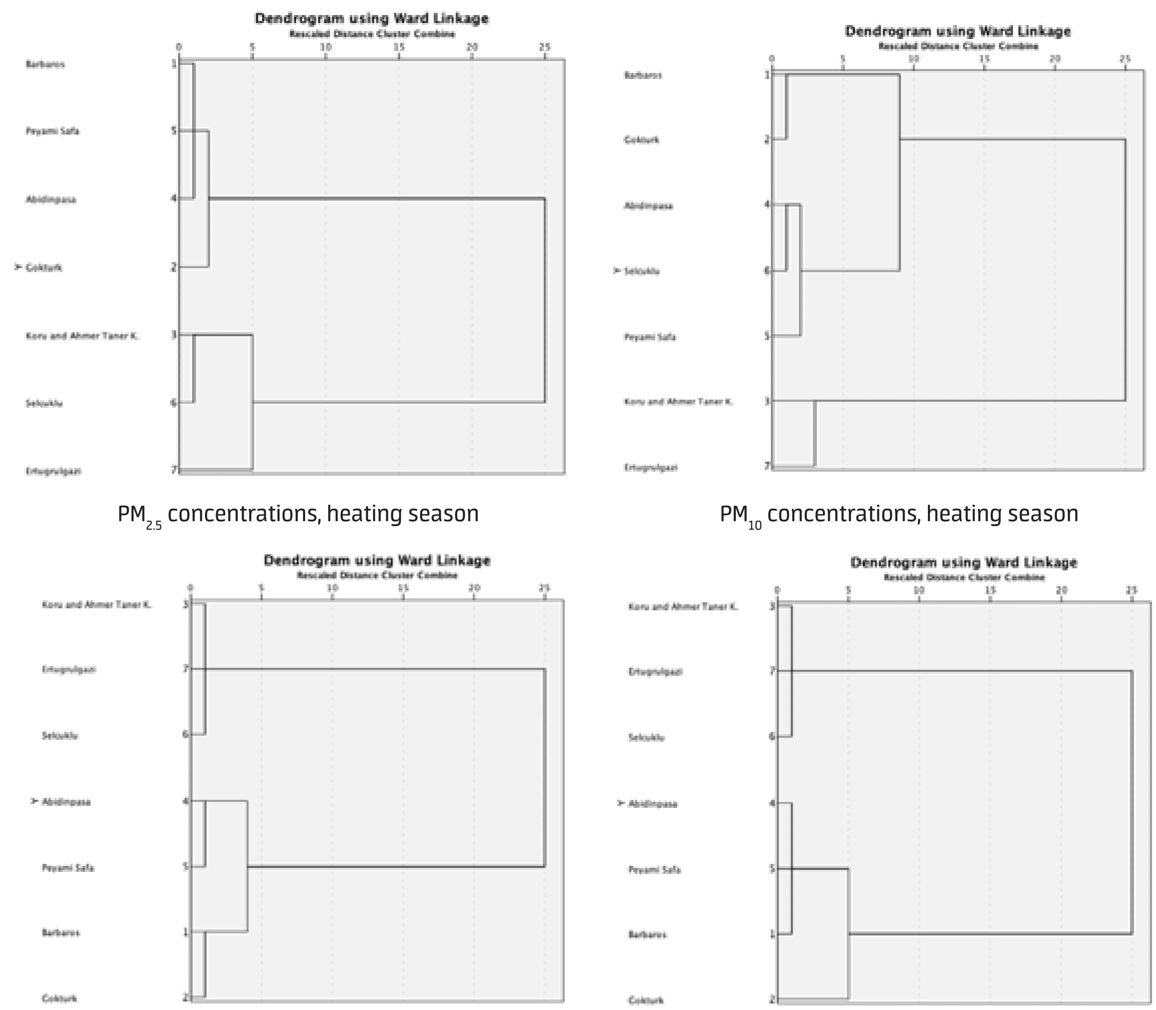
	Neighbourhoods						
	Gokturk	Barbaros	Abidin.	Peyami S.	Koru+Ah	Selcuklu	Ertugrul.
	181 child.	172 child.	249 child.	415 child.	109 child.	299 child.	262 child.
Themes	n, (%)	n, (%)	n, (%)	n, (%)	n, (%)	n, (%)	n, (%)
Places with lack of vegetation	30 (4.7%)	2 (0.5%)	35 (5.4%)	5 (1.1%)	33 (9.8%)	26 (2.9%)	9 (1.1%)
Highly urbanised places	–	–	–	–	–	7 (0.8%)	–
Places with high traffic volume / the problem of exhaust gas in streets	55 (8.6%)	99 (26.7%)	76 (11.8%)	42 (9.2%)	57 (17.0%)	64 (7.1%)	62 (7.6%)
Places with smelly trashes	68 (10.6%)	70 (18.9%)	37 (5.7%)	55 (12.0%)	113(33.7%)	93 (10.3%)	71 (%8.7)
Places with smok-ers	1 (0.1%)	8 (2.2%)	7 (1.1%)	13 (2.8%)	–	5 (0.6%)	9 (1.1%)
Places where coal burning activi-ties take place	8 (1.2%)	–	–	–	–	2 (0.2%)	–
Places where peo-ple burn fire	13 (2.0%)	–	1 (0.1%)	–	2 (0.6%)	10 (1.1%)	–
Places where tree cutting activities take place	1 (0.1%)	–	–	–	2 (0.6%)	–	–
Places where con-struction/ dem-olition activities take place	–	–	–	–	–	2 (0.2%)	12 (1.5%)
Places with poor air quality with unspecified reasons	27 (4.2%)	24 (6.5%)	23 (3.6%)	24 (5.2%)	2 (0.6%)	20 (2.2%)	53 (6.5%)
Total	203 (31.7%)	203(54.9%)	179(27.8%)	139(30.4%)	209(62.4%)	229(25.3%)	216 (26.4%)

3.8. ***Statistical analysis***

To respond the first research question, whether children report more negative experiences about outdoor air pollution in school neighbourhoods with higher particulate matter ($PM_{2.5}$ and PM_{10}) concentrations, we first grouped school neighbourhoods based on their average PM concentrations. Thereafter, we re-categorised the data presented in Table 3 according to our proposed new classification. To achieve the former step, we used a hierarchical cluster analysis based on Ward's method and squared Euclidian distances. As Figure 4 shows, with one exception (i.e., the clustering of the neighbourhoods based on PM_{10} concentrations in heating season), in all cases, the neighbourhoods located in the periphery and inner-city of Ankara were in separate clusters.

To respond the second research question, whether the air pollution-related issues mentioned by children are related to the built environment characteristics of their neighbourhoods, we first grouped school neighbourhoods based on their land use mix and neighbourhood greenness. Next, we re-categorised the data presented in Table 3 according to our proposed new classification. Figure 5 shows how the neighbourhoods in each cluster differed based on their built environment characteristics.

In all analysis, comparisons were made between two groups (e.g., neighbourhoods with lower $PM_{2.5}$ concentrations and higher $PM_{2.5}$ concentrations in heating season). Since the number of children were different in each cluster, we compared the percentage distribution of the air quality-related problems rather than using t-test.



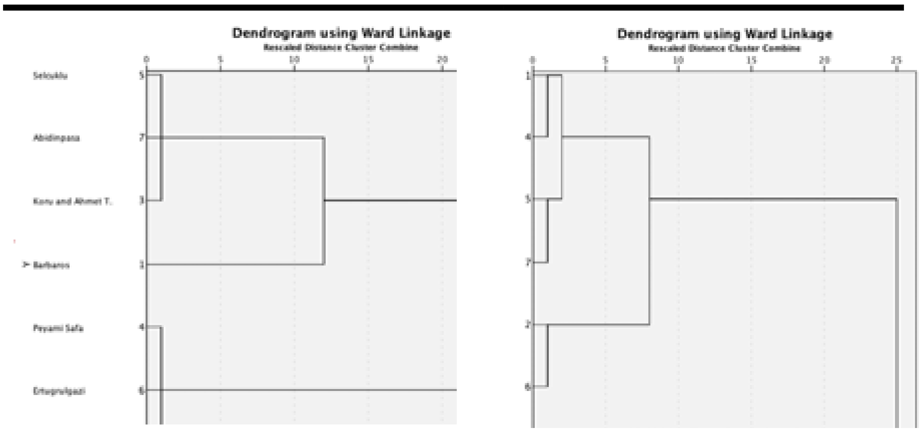
$PM_{2.5}$ concentrations, heating season

PM_{10} concentrations, heating season

$PM_{2.5}$ concentrations, non-heating season

PM_{10} concentrations, non-heating season

Figure 4. Dendograms showing the clustering of neighbourhoods for different PM types and PM measurement periods.



Land use mix | Neighbourhood greenness

Figure 5. Dendograms showing the clustering of neighbourhoods based on their built environment characteristics.

4. Results

4.1. *Children's air pollution-related experiences and PM concentrations of their neighbourhoods in different seasons*

In heating season, children living in neighbourhoods with higher $PM_{2.5}$ concentrations did not report more outdoor air pollution-related issues than children living in neighbourhoods with lower $PM_{2.5}$ concentrations (31.4% versus 34.3%), which is an unexpected finding (see Table 4). However, as expected, children living in neighbourhoods with higher PM_{10} concentrations reported more air pollution-related issues than children living in neighbourhoods with lower PM_{10} concentrations (36.8% versus 31.6%). The responses of children in Selcuklu neighbourhood were influential in this outcome as this neighbourhood was in different neighbourhood clusters in heating season. As Table 3 shows, different from the children in other neighbourhoods, more children in Selcuklu reported issues related to high levels of urbanisation. This neighbourhood is also known with its closeness to polluting industrial facilities and construction sites (Aydin, 2023).

Table 4. The number and frequency of outdoor air quality-related issues in neighbourhoods with lower and higher $PM_{2.5}$ and PM_{10} concentrations in heating season

Themes	Neighbourhoods with lower $PM_{2.5}$ concentrations (N=2111 issues) n (%)	Neighbourhoods with higher $PM_{2.5}$ concentrations (N=2060 issues) n (%)	Neighbourhoods with lower PM_{10} concentrations (N=3017) n (%)	Neighbourhoods with higher PM_{10} concentrations (N=1154) n (%)
Places with lack of vegetation	72 (3.4%)	68 (3.3%)	98 (3.2%)	42 (3.6%)
Highly urbanised places	–	7 (0.3%)	7 (0.2%)	–
Places with high traffic volume / the problem of exhaust gas in streets	272 (12.9%)	183 (8.8%)	336 (11.1%)	119 (10.3%)
Places with smelly trashes	230 (10.9%)	277 (13.3%)	323 (10.7%)	184 (15.9%)
Places with smokers	29 (1.4%)	14 (0.7%)	34 (1.1%)	9 (0.8%)
Places where coal burning activities take place	8 (0.4%)	2 (0.1%)	10 (0.3%)	–

Places where people burn fire	14 (0.6%)	12 (0.6%)	24 (0.8%)	2 (0.2%)
Places where tree cutting activities take place	1 (0.04%)	2 (0.1%)	1 (0.03%)	2 (0.2%)
Places where construction/ demolition activities take place	–	14 (0.7%)	2 (0.06%)	12 (1.0%)
Places with poor air quality with unspecified reasons	98 (4.6%)	75 (3.6%)	118 (3.9%)	55 (4.7%)
Total	724 (34.3%)	654 (31.4%)	953 (31.6%)	425 (36.8%)

As expected, in non-heating season, children living in neighbourhoods with higher $PM_{2.5}$ and PM_{10} concentrations reported more outdoor air pollution-related issues than children living in neighbourhoods having lower $PM_{2.5}$ and PM_{10} concentrations (results were the same for $PM_{2.5}$ and PM_{10} based comparisons: 33.3% versus 31.4%) (see Table 5).

Table 5. The number and frequency of outdoor air quality-related issues in neighbourhoods with lower and higher $PM_{2.5}$ and PM_{10} concentrations in non-heating season

Themes	Neighbourhoods with lower $PM_{2.5}$ concentrations (N=2060 issues) n (%)	Neighbourhoods with higher $PM_{2.5}$ concentrations (N=2111 issues) n (%)	Neighbourhoods with lower PM_{10} concentrations (N=2060 issues) n (%)	Neighbourhoods with higher PM_{10} concentrations (N=2111 issues) n (%)
Places with lack of vegetation	68 (3.3%)	72 (3.4%)	68 (3.3%)	72 (3.4%)
Highly urbanised places	7 (0.3%)	–	7 (0.3%)	–
Places with high traffic volume / the problem of exhaust gas in streets	183 (8.8%)	272 (12.9%)	183 (8.8%)	272 (12.9%)
Places with smelly trashes	277 (13.3%)	230 (10.9%)	277 (13.3%)	230 (10.9%)
Places with smokers	14 (0.7%)	29 (1.4%)	14 (0.7%)	29 (1.4%)
Places where coal burning activities take place	2 (0.1%)	8 (0.4%)	2 (0.1%)	8 (0.4%)
Places where people burn fire	12 (0.6%)	14 (0.6%)	12 (0.6%)	14 (0.6%)
Places where tree cutting activities take place	2 (0.1%)	1 (0.04%)	2 (0.1%)	1 (0.04%)
Places where construction/ demolition activities take place	14 (0.7%)	–	14 (0.7%)	–
Places with poor air quality with unspecified reasons	75 (3.6%)	98 (4.6%)	75 (3.6%)	98 (4.6%)
Total	654 (31.4%)	724 (34.3%)	654 (31.4%)	724 (34.3%)

4.2. *Children's air pollution-related experiences and the built environment characteristics of their neighbourhoods*

Our results show that compared to children living in neighbourhoods with lower land use mix, more children living in neighbourhoods with higher land use mix reported traffic density and vehicle exhaust-related pollution issues (13.1% versus 8.3%) (see Table 6). Additionally, we observed more smelly trash related issues in neighbourhoods with high land use diversity than to neighbourhoods with less land use diversity (13.9% versus 10.1%).

Compared to children living in greener neighbourhoods (i.e., Koru and Ahmet Taner Kislali) more children living in less green neighbourhoods mentioned a general air quality problem in their neighbourhood environments (4.5% versus 0.6%). However, we found that compared to children living in less green neighbourhoods, more children living in highly green neighbourhoods mentioned places with lack of vegetation.

Table 6. The number and frequency of outdoor air quality-related issues in neighbourhoods with lower and higher $PM_{2.5}$ and PM_{10} concentrations in non-heating season

Themes	Neighbourhoods with lower land use mix (N=1916 issues) n (%)	Neighbourhoods with higher land use mix (N=2255 issues) n (%)	Neighbourhoods with lower neighbourhood greenness (N=3836 issues) n (%)	Neighbourhoods with higher neighbourhood greenness (N=335 issues) n (%)
Places with lack of vegetation	44 (2.3%)	96 (4.3%)	107 (2.8%)	33 (9.8%)
Highly urbanised places	-	7 (0.3%)	7 (0.2%)	-
Places with high traffic volume / the problem of exhaust gas in streets	159 (8.3%)	296 (13.1%)	398 (10.4%)	57 (17.0%)
Places with smelly trashes	194 (10.1%)	313 (13.9%)	394 (10.3%)	113 (33.7%)
Places with smokers	23 (1.2%)	20 (0.9%)	43 (1.1%)	-
Places where coal burning activities take place	8 (0.4%)	2 (0.09%)	10 (0.3%)	-
Places where people burn fire	13 (0.7%)	13 (0.6%)	24 (0.6%)	2 (0.6%)
Places where tree cutting activities take place	1 (0.05%)	2 (0.09%)	1 (0.02%)	2 (0.6%)
Places where construction/ demolition activities take place	12 (0.6%)	2 (0.09%)	14 (0.4%)	-
Places with poor air quality with unspecified reasons	104 (5.4%)	69 (3.1%)	171 (4.5%)	2 (0.6%)
Total	558 (29.1%)	820 (36.4%)	1169 (30.5%)	209 (62.4%)

5. Discussion and conclusion

We found that inner- and outer-city neighbourhoods had significantly different levels of $PM_{2.5}$ and PM_{10} concentrations, which shows the role of built environment in affecting PM concentrations. In a non-heating season, high $PM_{2.5}$ and PM_{10} concentrations in inner-city neighbourhoods can be attributed to factors such as high building density (and thus, increased heat islands) and low green spaces in these areas (Chen et al., 2017; McCarty and Kaza, 2015). Contrarily, low $PM_{2.5}$ and PM_{10} concentrations in peripheral neighbourhoods can be attributed to the presence of greenery and high air circulation (Han et al., 2020). Seasonal variations in PM concentrations in neighbourhoods can be attributed to many factors, such as reduced industrial activity and domestic heating in summer seasons (Sabir et al., 2024) and neighbourhood location. These factors may explain the seasonal variation in PM concentrations observed in peripheral neighbourhoods adjacent to construction sites and forests (which cool down the air).

Our results support the prior claims of qualitative researchers that there is a relationship between built environment, outdoor air pollution and outdoor place experiences of children. Children reported more negative experiences about outdoor air pollution in school neighbourhoods with higher $PM_{2.5}$ and PM_{10} concentrations in the non-heating season; different and conflicting results are obtained in the heating season for $PM_{2.5}$ and PM_{10} concentrations. This difference in the PM concentrations triggers the following question: Whether children, who participate in participatory mapping activities, are more likely to report issues that are experienced in particular weather conditions? Certainly, one may argue that children are more likely to use outdoor environments in warmer seasons than in a winter season (see Buck et al., 2015). Thus, the results that we presented here for the non-heating season may be more reliable than those presented for the heating season if children's voices are shaped largely by their place experiences. Truly, multiple factors may affect children's perceptions of and ideas about their environments, including shared experiences within the family (Demirkaya et al., 2024). As in all cross-sectional studies, causal inference is limited in our research. Future studies can map children's neighbourhood experiences in different seasons.

In this study, we could not observe any industry-related air pollution issues mentioned by children. Likewise, while the density of the selected neighbourhoods significantly varied from one neighbourhood to another, as Table 3 shows, except for a few children in Selcuklu, none of the children in other neighbourhoods mentioned a problem related to high urbanisation rates. Furthermore, while the neighbourhood greenness values significantly differed across the selected neighbourhoods, lack of vegetation was mostly mentioned as a problem by the children living in the greenest neighbourhoods. One explanation to these findings could be that children's negative place experiences are more likely to be affected by factors that are physically and visually accessible to and that can be easily perceived and grasped by children. For example, in our study, none of the selected neighbourhoods included industrial areas. Another explanation could be that some children might have internalised the problems of their neighbourhoods, leading them to no longer view the drawbacks of their environments, such as the lack of green open spaces in highly dense neighbourhoods, as problems.

We found that compared to children living in neighbourhoods with lower land use mix, more children living in neighbourhoods with higher land use diversity reported traffic density and traffic-related pollution issues. While this result is in line with the findings of Ding and Zhao (2011), who linked places with high land use mix to high traffic density, it is contrary to what Frank et al. (2006) suggested: increasing the land use mix promotes walking behaviour in residents and decreases vehicle traffic. Since this study did not consider traffic density as an explanatory variable and since various contextual factors may affect PM concentrations, future research should investigate the associations between built environment and PM concentrations in the selected neighbourhoods. Future research should also place greater emphasis in conducting longitudinal and control-group studies.

Despite these limitations, the results of this research may provide helpful insights for urban planners to elaborate tailored and context-specific interventions to create healthier environments for children. Since the proportions of air pollution-related issues experienced by children change from one neighbourhood to another depending on their PM and built environment characteristics, our results show the need for targeted interventions and policies to address these issues.

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