Determinants of air pollution around schools and their solutions

Air pollution is not only a major factor affecting the health and well-being of children in schools, but also has a significant impact on the general population in urbanised areas. Increased levels of air pollution in urban environments, mainly caused by traffic, industrial activities and other human activities, have a negative impact on the health of the population, including adults, the elderly and people with various health problems. This problem is often associated with the following pollutants (see Table 1).

Table 1Main air pollutants and their impact on human health

Suspended particulate matter (PM) is emitted from many sources and is one of the most harmful pollutants to human health. They penetrate sensitive areas of the respiratory system and can cause or exacerbate cardiovascular and lung disease as well as cancer.	**Organic pollutants** such as benzo(a)pyrene (BaP) are released from fuel and waste combustion, industrial processes and solvent use. Substances such as hexachlorobenzene (HCB), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) can have a range of harmful effects on human health and ecosystems.
Ground-level ozone (O_3) is an air pollutant that damages human health, vegetation and materials. Ozone is formed when other pollutants react with sunlight.	**Heavy metals** such as lead and copper are toxic to ecosystems. They are mostly released during combustion and industrial activities. As well as polluting the air, they can accumulate in soil and sediment and bioaccumulate in food chains.
Oxides of nitrogen (NO_x) and oxides of sulphur (SO_x) are released when fuel is burned, for example in power stations or other industrial plants. They contribute to acidification and eutrophication of water and soil. When present in the air, they can cause health problems such as inflammation of the respiratory tract and impaired lung function.	**Ammonia (NH_3)** is released mainly from agricultural activities and contributes to both eutrophication and acidification of water and soil.

Source: European Environment Agency (2020)

This review text addresses the issue of improving air quality in urbanized environments around schools with a focus on children's exposure to air pollution, using findings from recent articles focused on this issue. It briefly discusses specific methods of measuring pollution that can be used or have already been used. It also outlines the determinants of air pollution and recommendations for mitigation measures.

Measuring air pollution

Measuring air quality in urban schools is key to assessing the exposure of students and school staff to various pollutants. These measurements are designed to identify and monitor concentrations of harmful pollutants such as nitrogen oxides (NO_2), sulphur oxides (SO_2), particulate matter ($PM_{2.5}$, PM_{10}), carbon monoxide (CO) and others that can have a negative impact on human health. Measurement of air pollution in urban school environments can be carried out in several ways and using different methods. Their use needs to be put in the context of the environment in which the air is being monitored, i.e. whether it is indoors or outdoors.

Satellite data

Satellite air quality measurement is a modern and efficient method of monitoring air pollution using satellites orbiting the Earth. These satellites are equipped with special sensors that can detect and monitor concentrations of pollutants in the air over different regions of the planet. They use various spectrometric and optical techniques to measure different components of the atmosphere. Their advantages include a wide geographical range and the ability to measure pollution on a global scale. They also allow monitoring of dynamics. Although satellite measurements provide valuable information, it should be stressed that this technology has some limitations, such as lower spatial resolution compared to other measurement methods. Satellite data usually cannot provide as detailed information at the local level as station sensors can. Satellite data has been used in research by, for example, Ung et al. (2021).

Biomonitoring

This approach uses monitoring of living organisms such as plants, animals or micro-organisms that respond in specific ways to harmful substances in their environment. Living organisms, whether they are lichens or woody plants (black poplar), have been used, for example, by Belguiduom et al. (2022) Giordano et al. (2021) and Levei et al. (2021).

Air quality measurement stations

Air quality stations are facilities that systematically monitor and collect data on the concentrations of pollutants in the atmosphere using a variety of sensors and analytical tools. The stations periodically collect air samples and subsequently analyse the pollutant content. The stations can be located in different types of locations such as urban centres, transport hubs, industrial zones, residential areas or rural areas. The location of the stations is strategically important to obtain the most accurate and representative air quality data.

Due to the nature of the information, the data is sent to central databases for subsequent processing. The resulting information is often made available to the public, who can then adapt their behaviour to minimise exposure to harmful substances. A concrete example is the *European Air Quality Index* (European Environment Agency, 2023), which provides a real-time display of air quality determined by an index calculated from the concentrations of five key pollutants. The data are also used to assess the achievement of public health objectives.

Mobile measurement

Portable air quality meters make it easier to monitor pollution at specific locations or around the school. These are mobile devices or vehicles that are equipped with sensors. The devices can be placed indoors or outdoors in schools. Another type is personal portable monitors, which Osborne et al. (2021) suggest are a suitable measurement method as they allow for the detection of differences between indoor and outdoor air quality. One of the pilot projects of public involvement in research, called community science, was presented in a 2022 paper (Ilie et al., 2022). The paper presents the involvement of high school students to collect data on individual exposure to $PM_{2.5}$ using individual monitoring devices. The research included the organization of workshops, training sessions and the implementation of thematic school projects. According to Osborne et al. (2021), there is a paucity of studies of this type to date.

Sources of pollution

Harmful substances are released into the atmosphere from a wide range of sources. According to the EEA (2019), they are among the main sources of pollution:

1. agricultural activities, which account for up to 90% of ammonia emissions and 80% of methane emissions,
2. energy production and distribution, from which approximately 60% of sulphur oxides originate,
3. natural phenomena, including volcanic eruptions and sandstorms,
4. Waste, landfill, coal mining and gas transfer are all significant sources of methane,
5. transport, with more than 40% of nitrogen oxide emissions coming from road transport, as well as 40% of primary PM emissions$_{2,5}$,
6. combustion of fuels in transport, heating of buildings, use of energy sources, etc. Businesses, public buildings and households contribute approximately 50% in the production of $PM_{2,5}$ and carbon monoxide.

Depending on the location and local conditions, these sources will manifest themselves at different intensities. The main determinants include the location of schools, the amount (lack) of green space around schools, traffic density and intensity, and topography and urban layout.

The most significant source of outdoor pollution in cities is traffic (Pearce et al., 2021). Schools are also very often located near busy roads; children spend a large proportion of their time in schools when traffic volumes are highest, exposing them to high concentrations of pollutants (Dadvand et al, 2015). Studies have shown a wide range of negative impacts on children's development, their health and the health of the general population, as well as on concentration and academic performance (e.g., Nikolic et al., 2014; Manisadilis et al., 2020).

In the context of transport, it should be noted that it is not just exhaust fumes that are involved. Moreover, their quantity is expected to decrease with the advent of electrification or the transition to hydrogen propulsion. This trend will not, however, reduce (and may even increase) pollution from non-driven components, be it brakes, tyres or road wear. Friction between brakes and wheels, or between wheels and the road, produces PM, and electric vehicles with heavy batteries may further increase this pollution due to their overall higher weight (Pearce et al., 2021).

Another important factor that affects the amount of particulate matter not only outdoors but also indoors, especially in schools, is the presence of playgrounds, the surface of which is predominantly made up of sand. Minguillón et al. (2015) looked at the effects of traffic and playground surfaces on air pollution. The PM_{10} concentrations found in one of the schools were mainly due to the sandy playground. The measured values were up to 25 times higher over the morning break, 57 times higher over the lunch break and 12 times higher after school compared to the average nighttime values. Thus, hourly concentrations of PM_{10} are even more than 50 times higher than the average nighttime values. This pollution decreases substantially as the distance of the school from the playground increases. The fact that mineral particles are carried by children into the classrooms and cause pollution indoors also plays an important role. To reduce these effects, the sand in playgrounds should be regularly replaced with clean, non-crushed sand. According to Rivas et al. (2018), this should occur every year or every two years. It should also be considered that atmospheric pollution accumulates in the sand and children's activities contribute to the reduction of mineral dust particles, which negatively affects PM levels over time$_{2,5}$.

Measures to improve air quality

Measures to improve air quality are outlined, for example, by the WHO (2022), which categorises them by sector, be it industry, energy, health services, transport or urban planning. For the latter, it lists activities that include improving the energy efficiency of buildings and creating more compact and greener cities.

However, across the literature, authors agree that the best way to reduce pollution is at the source (e.g., Hewitt et al., 2020; Pearce et al., 2021; Weber et al., 2014).

Green infrastructure, including planting trees, shrubs and herbs around schools, is considered in the literature as a suitable mechanism for mitigating air pollution (Kumar et al., 2020). In addition, there is evidence of positive effects not only on air quality, but also on reducing noise pollution and improving mental health (Coutts and Hahn, 2015).

Other options for action include:

1. modification of the urban environment, in particular the optimisation of the design of urban spaces around schools, including the creation of green barriers and modifications to the topography that can lead to improved airflow and reduced concentrations of pollutants,
2. Urban planning, i.e. active participation in planning and spatial development with a focus on reducing traffic pollution and creating healthier environments around schools (e.g. An et al., 2021; Osborne et al., 2021),
3. Technological innovation and the implementation of new technologies and monitoring systems to monitor air quality and identify pollution sources (e.g. Osborne et al., 2021),
4. health interventions, i.e., the provision of health services and interventions for children exposed to increased air pollution, including information on their health status (e.g., Ramírez et al., 2019),
5. education and awareness, involvement of schools, communities and local authorities in education programmes on issues and impacts on health and quality of life, and communication of specific actions at the individual level (e.g. Ramírez et al., 2019).[1]

Green infrastructure

Green infrastructure has received more attention than the others in terms of mitigation measures, as it plays a key role in improving environmental quality and human health. Studies focus on the importance of vegetation, such as green roofs, walls and tree planting, in capturing and reducing harmful emissions caused mainly by motor vehicle traffic.

The introduction of greenery is expected to reduce air pollution through both direct and indirect mechanisms, where the direct mechanism is the filtering effect of plants based on dry deposition of pollutants (particles and gases) through vents in the leaves or through deposition directly on the plant surface Indirectly, pollution can be reduced through the introduction of greenery by improving ventilation in the development, which will increase the rate of dispersion of pollutants (Dadvand et al., 2015).

As an example, an ecological study from Barcelona in 2008 (Franchini and Mannoucci, 2018) shows that trees and shrubs in Barcelona, after recalculation, sequestered 305.6 tonnes of pollutants (166 tonnes of PM_{10} , 73 tonnes of O_3 , 55 tonnes of NO_2 , 7 tonnes of SO_2 and 6 tonnes of CO), which in total corresponds to a monetised benefit to society of an estimated €1.1 million.

Nowak et al. (2006) looked at the potential use of trees in built-up areas for the purpose of reducing air pollution and improving air quality for various US cities. Pollution removal rates vary between cities

[1] Building on the measurements of Ilie et al. (2022), a campaign was implemented to target the dissemination of air pollution awareness in the local community, the development of a set of recommendations for local policy, and the creation of a platform for community engagement to further disseminate air pollution awareness and education.

depending on the amount of trees planted (more trees lead to more pollution removal), the amount of pollution concentration detected (higher detected pollution rates subsequently lead to higher pollution removal rates), the length of the deciduous tree season (longer seasons lead to more pollutant removal), the amount of precipitation (more precipitation leads to lower pollution removal rates through dry deposition), and other meteorological variables that affect transpiration and deposition rates. Nowak et al. (2006)

Although trees remove tons of pollutants each year, their overall contribution to improving urban air quality during the deciduous tree season averages less than 1% during the day and varies depending on local meteorological conditions and pollutant concentrations. More significant improvements in air quality were observed for PM, sulphur dioxide (SO_2) and ozone (O_3). Air quality also improves with higher tree cover and less variation in canopy height. Nowak et al. (2006)

The absorption and filtration of pollutants are supported by the different characteristics of tree species. Factors such as leaf size and branch density, as well as leaf surface, should be taken into account when selecting species. Densely hairy leaves trap significantly more particles compared to leaves that are scattered and smooth (Weber et al., 2014). A study by Nowak (2000, in Chaparro and Terradas, 2009) classifies plant species according to their ability to remove internal and external pollution (Table 2). This information is based on a study of the combined effects of absorption of various pollutants, VOC (volatile organic compound) emissions, and air temperature reductions by 242 species of mature trees (in U.S. urban settings). The "Total" column shows the rankings based on the individual effects of pollutants, which are put into context by estimating the costs of these pollutants to society.

Table 2: List of the most suitable tree species for improving air quality in the United States

Ozone	**Carbon monoxide**	**Total**
Tall elm Small-leaved lime tree Big-leaved beech White birch Lily of the valley tulip-flower American linden Beech forest Big leaf linden Paper birch	American linden Big-leaved beech Silver Lime Flying elm Beech forest White birch Lime green Tall elm Jinan bicuspid Lily of the valley tulip-flower	Tall elm Small-leaved lime tree Lily of the valley tulip-flower Big-leaved beech Big leaf linden White birch Beech forest American linden American elm Rock elm
Suspended particles	**Nitrogen oxides and sulphur oxides**	**Total**
Tall elm Plane maple Leyland's cypress Black walnut Small-leaved lime tree White fir tree Larch deciduous Red spruce	Tall elm Small-leaved lime tree Eastern Poplar Plane maple Lily of the valley tulip-flower Black walnut White birch Big-leaved beech	Small-leaved lime tree Silver Lime Paper birch Smooth ivy Ash tree Cedar elm Black birch Larch deciduous

Source: Chaparo and Terradas (2009), translated

Trees, although they have the potential to trap pollutants, can be counterproductive in some cases. This is particularly the case where there is dense development and limited space. In this case, trees can influence and limit airflow, creating places with limited air circulation (Weber et al., 2014).

However, in certain situations, it is the change in airflow that can reduce exposure to sources by up to 50%, as polluted air mixes with clean air (Pearce et al., 2021). It should also be remembered that some trees produce high levels of pollen and allergens, which can cause problems for allergy sufferers and people with health problems. This of course also applies to herbs.

In the context of green infrastructure, it is a common misconception that increasing vegetation reduces the concentration of ground-level pollutants in a linear fashion. Thus, due to the physical distance of vegetation from the pollution source, measured pollution values will always be non-zero (Hewitt et al., 2020).

The study by Weber et al. (2014) focuses on herbaceous plants growing around roads, as opposed to the more commonly studied woody plants. Herbs immobilize significant amounts of air pollution relevant to human health, and the greater diversity of vegetation acts as air filters. In general, all herbaceous plants trap PM to some degree. All herbs studied captured PM, but the amount of PM captured varied significantly depending on leaf characteristics and plant height. In addition, different plant species captured different sizes and types of PM. For this reason, it is advisable to maintain plant diversity along roadsides to capture as much PM as possible, with plants with densely hairy leaves capturing the most PM. Conversely, there was no significant difference between the amount of dust captured by perennials and grasses on green roofs.

The accumulated amount of PM depended significantly on the height of the plant sampled. Tall herbs with leaves growing regularly around the entire stem captured more PM than short ones. Thus, overall, more diverse vegetation with different height of growth and large leaf area can capture more pollution produced around roads.

Herbs in street corridors can complement the benefits of trees. The benefits and reasons for greater use of herbs for air quality improvement purposes compared to trees are:

1. Greater physical proximity to motor traffic and exposed pedestrians compared to tree canopy, which maximizes the immobilizing effect for pollutants.
2. Negligible or no effect on air exchange in street corridors,
3. replenishing woody plants by capturing PM that has been washed or fallen from trees,
4. less space-intensive, can be easily and quickly integrated into existing infrastructure in relation to local priorities (Weber et al., 2014).

Weber et al. (2014) identified Loelos's hawthorn, bird's-foot trefoil, common honeysuckle, white honeysuckle, common yarrow, grey honeysuckle, or little-leaved cinquefoil as suitable herbs.

A combination of trees with dense foliage and a variety of perennials or grasses can enhance the ability to capture and reduce pollutants around campuses. For schools, greenery is important in terms of both pollution diversion and also for achieving other health benefits such as improved behavioral development (Amoly et al., 2014) or improved academic achievement (Wu et al., 2014).

Conclusion

Air quality around schools is a critical factor for children's health, taking into account their exposure to pollution during their education. This problem is associated with various sources of pollution, including transport and industrial processes. Analysis shows that suspended particulate matter (PM), organic pollutants, ground-level ozone, heavy metals, nitrogen oxides and sulphur oxides are among the main pollutants affecting air quality. Air quality measurements using various methods such as satellite data, biomonitoring, air quality stations, and mobile measurements are key to monitoring school students' exposure to air pollution.

Traffic is a major source of pollution around schools, not only in the form of exhaust fumes but also through tyre and road wear. Sandy playgrounds in schoolyards can also be a significant source of pollution, contributing to high concentrations of suspended particulate matter.

To improve air quality around schools, it is recommended to implement measures such as planting green spaces, modifying the urban environment, technological innovations, health interventions and education. Green infrastructure such as trees and shrubs play a key role in reducing pollution and improving air quality. Studies show that trees have the ability to trap pollutants and contribute to overall air quality improvement. It is also important to select plant species appropriately taking into account their capacity to absorb and filter pollutants. The implementation of green infrastructure and changes to the built environment can have a significant positive impact on air quality and the health of children around schools, but the reduction of pollution at source is essential.

Sources

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