ASEAN Journal of Physical Education and Sport Science

Journal homepage: https://ejournal.bumipublikasinusantara.id/index.php/ajopess

Air Quality, Physical Activity, and Sustainable Urban Health: Implications for Physical Education, Sports Participation, and Social Equity

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ABSTRACT

This study examines how air quality affects physical activity, physical education, sports participation, public health, and social equity within sustainable urban development. A structured narrative review of literature published between 2020 and 2026 synthesized evidence on particulate matter, transport emissions, industrial pollution, vulnerable populations, and urban policy interventions. The findings show that poor air quality increases respiratory and cardiovascular risks and may reduce exercise tolerance and discourage outdoor activity, particularly among children, older adults, athletes, and low-income communities. The study provides an interdisciplinary framework linking air-quality management with physical education, sports science, urban health, and sustainable social development.

ARTICLE INFO

Article History:
Submitted/Received 15 Apr 2026
First Revised 12 Jul 2026
Accepted 27 Jul 2026
First Available online 02 Aug 2026
Publication Date 01 Sept 2026

Keywords:
Air quality;
Physical activity;
Physical education;
Social equity;
Urban sustainability.

1. INTRODUCTION

Air quality is a major determinant of public health, social well-being, and sustainable urban development. Exposure to fine particulate matter, nitrogen dioxide, sulfur dioxide, carbon monoxide, and ground-level ozone is associated with respiratory illness, cardiovascular disease, neurological impairment, cognitive decline, and premature mortality [1]. These health outcomes also have implications for physical education and sports science because safe participation in outdoor exercise depends on environmental conditions that support breathing, cardiovascular function, recovery, and sustained physical activity.

Physical education and sport are commonly promoted as strategies for improving fitness, mental health, social inclusion, and community well-being. However, polluted environments may reduce the safety and accessibility of outdoor physical activity. Children attending physical education classes, athletes training in urban areas, older adults participating in community exercise, and residents using public recreation spaces may be exposed to pollutants generated by traffic, industry, fossil-fuel combustion, and poorly regulated urban development. Air-quality management should therefore be considered part of the environmental foundation required for safe physical education and sports participation.

The effects of poor air quality are not distributed equally. Low-income communities and informal settlements frequently experience greater exposure because they are located near industrial areas, congested roads, poorly managed waste sites, and neighborhoods with limited green infrastructure [2-4]. These communities may also have fewer indoor sports facilities, limited healthcare access, and restricted opportunities to avoid polluted outdoor environments. Consequently, environmental inequality can become physical-activity inequality when disadvantaged populations are less able to participate safely in exercise, recreation, and community sport.

Children and adolescents are especially important within this discussion. Air pollution affects respiratory health, cognitive development, school attendance, and educational performance [5, 6]. Physical education classes often occur outdoors, where students may experience direct exposure during running, games, and other activities that increase ventilation. Although the reviewed literature primarily discusses health and social outcomes, its findings suggest that schools should consider air quality when planning outdoor physical education and sports programs.

Older adults and individuals with existing health conditions also experience elevated vulnerability. Recent evidence links air pollution with frailty, cognitive decline, reduced functional independence, and increased risks of chronic disease [7-10]. These outcomes can influence participation in walking, rehabilitation, adapted exercise, and community fitness programs. Sports-science and public-health interventions must therefore consider environmental exposure alongside exercise prescription and participant characteristics.

Urban sustainability policies can reduce these risks. Green infrastructure, sustainable transportation, clean energy, pollution monitoring, and inclusive urban planning can improve air quality while creating safer environments for walking, cycling, recreation, and organized sport [11-14]. Green spaces and pedestrian infrastructure may simultaneously support environmental quality, psychological well-being, and opportunities for physical activity.

Despite these connections, most air-quality research has focused on environmental measurement, epidemiology, emission control, and urban governance. Limited attention has

been given to the implications of polluted environments for physical education, sports participation, exercise accessibility, and community recreation. Similarly, sports-science discussions often emphasize training, performance, and health behaviour without fully considering air quality as an external determinant of safe participation.

This study aims to examine the relationship between air quality, physical activity, physical education, sports participation, public health, and social equity within sustainable urban development. Specifically, it evaluates how pollution affects vulnerable populations, identifies implications for outdoor exercise and educational sport, and examines how urban policy interventions can support healthier and more inclusive physical-activity environments. The novelty of this study lies in connecting air-quality governance with physical education and sports science. Rather than treating pollution solely as an environmental or medical issue, the study interprets clean air as an enabling condition for safe exercise, equitable sports participation, and sustainable community health. It also integrates environmental justice, public health, urban planning, and physical activity within one interdisciplinary framework.

2. LITERATURE REVIEW

2.1. Air Quality as a Determinant of Physical Activity

Air quality influences whether urban environments are suitable for outdoor movement, recreation, and exercise. Pollutants such as $PM_{2.5}$, PM_{10}, nitrogen dioxide, sulfur dioxide, carbon monoxide, and ozone are commonly used to assess environmental health risks [15]. These pollutants originate from transportation, industrial activity, energy generation, waste burning, and other urban sources. Physical activity increases breathing rate and the volume of inhaled air. Therefore, individuals exercising in polluted environments may receive greater pollutant exposure than sedentary individuals in the same location. The reviewed literature did not directly quantify exercise-specific pollutant inhalation; however, the reported respiratory, cardiovascular, and neurological effects demonstrate the relevance of air quality to physical-activity planning. Poor environmental conditions may also discourage outdoor participation. Communities experiencing heavy traffic, visible pollution, unpleasant odors, and limited green space may be less attractive for walking, cycling, school sport, or recreational exercise. Air quality therefore affects not only physiological safety but also the usability and perceived quality of public spaces.

2.2. Physical Education and School Environments

Schools are important settings for promoting lifelong physical activity. Physical education supports fitness, motor competence, teamwork, social interaction, and psychological well-being. However, outdoor classes may expose children to traffic-related and neighborhood pollution. Children are particularly vulnerable because their respiratory and neurological systems are still developing. Indoor and outdoor air pollution has been associated with respiratory illness, weakened immune function, developmental problems, and reduced well-being [5]. Prenatal and early-life environmental exposure may also influence cognitive and language development [6]. These findings have practical implications for schools. Physical education scheduling, outdoor-sport decisions, and facility planning should consider local air-quality conditions. Schools located near congested roads or industrial zones may require pollution monitoring, green barriers, flexible scheduling, or access to safer indoor environments. Air pollution may also affect education indirectly through illness-related absence and reduced cognitive performance. Students experiencing respiratory symptoms or

pollution-related fatigue may participate less consistently in physical education. Therefore, clean air supports both educational participation and physical development.

2.3. Sports Participation and Training Environments

Athletes and recreational participants often train outdoors for extended periods. Running, cycling, football, athletics, and other activities may occur near roadways or in densely populated urban areas. The environmental conditions surrounding sports facilities can therefore influence participant exposure. The reviewed literature provided limited sport-specific performance data. However, its evidence linking air pollution with cardiovascular disease, respiratory illness, neurological effects, and reduced quality of life indicates potential consequences for training safety and recovery. These implications should be tested directly in future sports-science studies. Sports organizations can respond by using air-quality information when scheduling training and competitions. Coaches and administrators may consider pollution levels, participant age, existing respiratory conditions, and activity intensity when determining whether outdoor sessions should proceed. Urban sport infrastructure should also be located with environmental safety in mind. Building sports grounds near high-emission corridors may increase exposure among participants. Integrating environmental assessment into sports-facility planning can therefore support safer and more sustainable participation.

2.4. Air Pollution, Public Health, and Functional Capacity

Air pollution is associated with respiratory infections, cardiovascular complications, neurological disorders, and weakened immune function [1, 7]. $PM_{2.5}$ can penetrate deeply into the lungs and enter the bloodstream, contributing to long-term physiological damage. Recent studies also connect pollution exposure with cognitive decline and frailty among older adults [7-10]. Frailty reduces mobility, strength, balance, and functional independence. These outcomes are directly relevant to adapted physical activity, rehabilitation, and community exercise. Pollution-related illness may also increase healthcare expenditure and reduce labour productivity. At the individual level, chronic illness can limit participation in exercise and recreation. At the community level, high health burdens may reduce investment in preventive physical-activity programs. Physical education and sports science should therefore treat environmental exposure as part of the broader context influencing health and functional performance.

2.5. Environmental Inequality and Unequal Access to Safe Exercise

Environmental inequality occurs when disadvantaged populations experience greater pollution exposure and fewer environmental benefits. Low-income neighborhoods often have heavier traffic, weaker regulation, limited green infrastructure, and reduced healthcare access [2-4]. These conditions can also restrict access to safe exercise environments. Wealthier communities may have indoor fitness facilities, greener neighborhoods, and greater ability to avoid polluted locations. By contrast, residents of informal settlements may depend on crowded roads, open spaces near industrial areas, or other environmentally unsafe locations for recreation. This creates a link between air-quality inequality and physical-activity inequality. Populations that would benefit most from affordable community exercise may face the greatest environmental barriers to participation. An environmental-justice approach requires that clean-air interventions prioritize highly exposed communities. It also requires equitable investment in parks, walking routes, cycling infrastructure, school sport facilities, and community recreation spaces.

2.6. Green Infrastructure and Active Urban Living

Green infrastructure includes parks, urban forests, ecological corridors, green roofs, and vegetated public spaces. These systems can contribute to pollution absorption, temperature regulation, biodiversity, psychological well-being, and urban resilience [11, 12]. From a physical-activity perspective, green spaces also provide locations for walking, running, informal play, physical education, and community sport. Their benefits therefore extend beyond environmental protection. However, access to green infrastructure is often unequal. Informal settlements and low-income neighborhoods may lack safe parks and recreational facilities. Sustainable urban planning must therefore consider both the distribution and quality of green spaces. Green infrastructure should not be treated as a complete substitute for emission reduction. Its role is complementary. Cleaner transportation, industrial regulation, and renewable energy remain essential for reducing pollution at its source.

2.7. Sustainable Transportation and Physical Activity

Transportation is a major source of urban air pollution. Fossil-fuel vehicles emit nitrogen oxides, particulate matter, and other pollutants that affect both environmental quality and public health. Sustainable transportation strategies include public-transit expansion, electric mobility, cycling infrastructure, pedestrian-friendly planning, and reduced dependence on private vehicles [13]. These strategies may generate dual benefits: lower emissions and greater opportunities for active transport. Walking and cycling can contribute to daily physical activity, but their health benefits depend partly on route safety and air quality. Active transport should therefore be supported by low-emission corridors, green buffers, and pollution-aware urban design. The connection between clean mobility and physical activity makes transportation policy relevant to both environmental sustainability and sports science.

2.8. Air-Quality Monitoring and Sport-Safety Decisions

GIS, satellite systems, and low-cost sensors increasingly support pollution monitoring and hotspot identification [14]. These technologies can improve environmental governance by providing more detailed information about local exposure. In physical education and sport, monitoring systems could support decisions about outdoor training, school activities, and public events. Local air-quality information may help teachers, coaches, athletes, and community organizers select safer times and locations. Community-based monitoring may be particularly valuable in neighborhoods not covered by official stations. Involving schools, universities, and sports organizations in data collection could also strengthen environmental awareness. However, monitoring alone does not reduce pollution. Data must be connected with practical action, public communication, and enforceable environmental policy.

2.9. Sustainable Development Goals and Physical Activity

Air-quality improvement supports several Sustainable Development Goals (SDGs). SDG 3 emphasizes health and well-being, while SDG 10 addresses inequality. SDG 11 focuses on sustainable cities and communities, and SDG 13 concerns climate action. Physical education and sport can contribute to health, inclusion, education, and community development. However, these benefits are difficult to realize when environmental conditions make outdoor participation unsafe. Clean-air policies can therefore support both sustainability and physical activity. Renewable energy, low-carbon transportation, green infrastructure, and equitable urban planning may reduce pollution while expanding opportunities for active living.

2.10. Research Gap and Conceptual Position

Existing literature provides strong evidence that air pollution affects health, inequality, cognition, urban livability, and sustainable development [1-15]. However, the relationship between air quality and physical education or sport participation remains less developed. Three gaps are particularly important. First, limited research has examined how air quality influences the delivery of school physical education. Second, sport-specific evidence concerning outdoor training, performance, and recovery is insufficient. Third, environmental-justice studies rarely connect pollution exposure with unequal access to safe physical activity. The present study addresses these gaps by interpreting air quality as an environmental determinant of physical activity and sports participation. **Figure 1** presents the conceptual relationship among urbanization, pollution, health risk, productivity loss, social inequality, and unsustainable development.

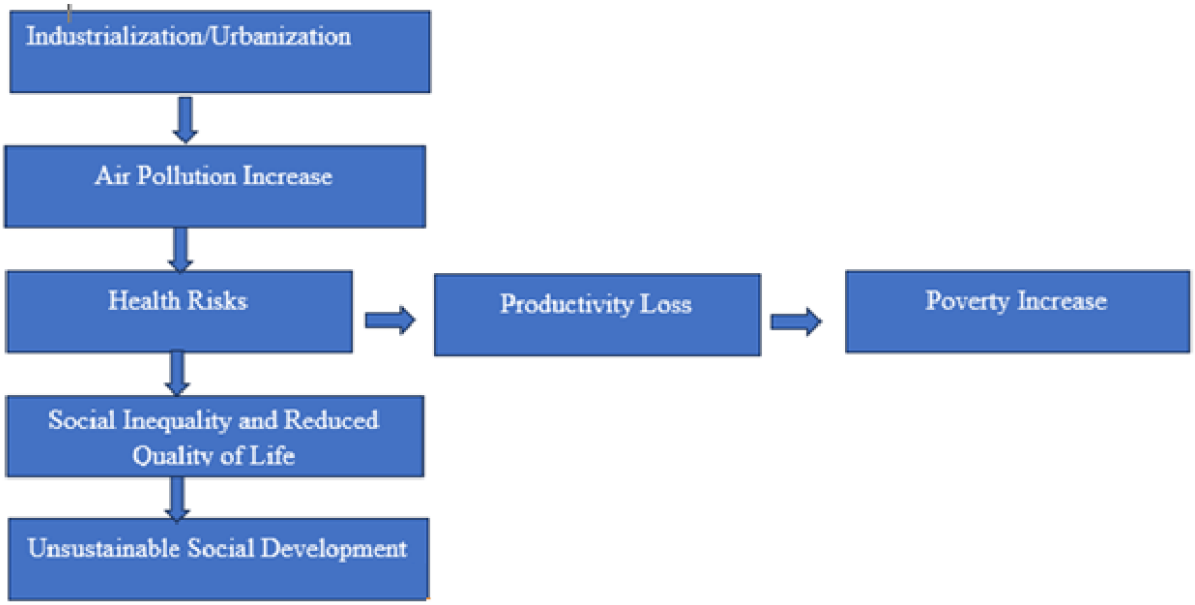

Figure 1. Conceptual relationship between air quality and sustainable social development.

As summarized in **Table 1**, the literature establishes strong connections among pollution, health, inequality, and urban sustainability. The present study extends this evidence by identifying its implications for physical education, sports participation, active living, and equitable access to safe exercise environments.

3. METHODS

This study employed a structured narrative review to examine the relationship between air quality, physical activity, physical education, sports participation, public health, social inequality, and sustainable urban development. This design was selected because the topic spans environmental science, public health, urban planning, social sustainability, and physical-activity research and therefore required an interdisciplinary synthesis. Relevant literature was identified through Scopus and Web of Science, supplemented by searches of publisher platforms, including ScienceDirect, SpringerLink, and MDPI. Search terms included combinations of *air quality*, *air pollution*, *$PM_{2.5}$*, *PM_{10}*, *nitrogen dioxide*, *sulfur dioxide*, *urban sustainability*, *physical activity*, *physical education*, *sports participation*, *public health*, *environmental justice*, *social inequality*, and *Sustainable Development Goals*. The wording and structure of the search terms were adapted to the requirements of each source.

Table 1. Synthesis of previous research and the research gap.

RESEARCH AREA	MAIN CONTRIBUTION	RELEVANCE TO PHYSICAL EDUCATION AND SPORT	REMAINING GAP
Air pollution and public health	Establishes links with respiratory, cardiovascular, neurological, and cognitive outcomes	Indicates potential risks for exercise participation and recovery	Limited direct exercise-specific analysis
Child health and development	Shows developmental and educational vulnerability	Relevant to school physical education and outdoor sport	Few studies examine PE scheduling or school exposure
Frailty and aging	Connects pollution with reduced functional independence	Relevant to rehabilitation and adapted physical activity	Limited intervention evidence
Environmental justice	Demonstrates unequal exposure among disadvantaged communities	Suggests unequal access to safe recreation and sport	Physical-activity inequality is rarely examined
Green infrastructure	Supports environmental quality and urban resilience	Provides spaces for walking, exercise, and community sport	Unequal access remains a major problem
Sustainable transportation	Reduces emissions and supports urban mobility	Can promote walking and cycling	Exposure along active-transport routes requires attention
Digital monitoring	Improves pollution surveillance and hotspot identification	Can support outdoor sport and PE decisions	Limited integration with sports administration
Present study	Integrates air quality, health, social equity, and urban sustainability	Positions clean air as an enabling condition for safe physical activity	Provides an interdisciplinary framework for physical education and sports science

Studies were considered relevant when they were published in English, appeared in peer-reviewed journals, and examined air quality in relation to public health, social sustainability, urban development, environmental justice, physical activity, education, or community well-being. Preference was given to Scopus-indexed publications. Studies were excluded when they did not address air quality or sustainable social outcomes, lacked sufficient methodological information, duplicated other records, or focused on environmental issues unrelated to human health, physical activity, or urban development.

Screening was conducted in stages. Titles and abstracts were first reviewed for relevance, followed by full-text assessment of the remaining publications. During full-text review, the inclusion and exclusion criteria shown in **Table 2** were applied consistently. Because numerical records for identification, duplicate removal, and exclusion were unavailable, the review reports the screening procedure descriptively rather than through a numerical flow diagram.

Information extracted from the selected studies included publication year, geographical setting, pollutant type, population group, health outcome, social-development dimension, urban-policy intervention, and implications for physical activity or sports participation. The evidence was then organized into six analytical themes: public health, social inequality,

physical activity and education, sustainable urban development, environmental justice and governance, and Sustainable Development Goals.

The extracted evidence was synthesized narratively. Quantitative findings reported in the original studies were retained where they clarified relationships involving pollution exposure, disease burden, frailty, cognitive performance, urban vulnerability, or social inequality. Because the reviewed literature used different research designs, pollutants, population groups, and outcome measures, no statistical meta-analysis was conducted.

The review also developed a conceptual interpretation linking urbanization and industrialization with pollution exposure, health risk, reduced physical-activity opportunities, productivity loss, social inequality, and unsustainable development. This relationship is presented in **Figure 1**. Policy pathways involving green energy, sustainable transportation, improved air quality, public health, and inclusive urban development are summarized in **Figure 2**. Because this study analysed published literature and did not involve direct human participation, ethical approval and informed consent were not required. **Table 2** summarizes the inclusion criteria used in the review.

Table 2. Inclusion criteria for the structured narrative review.

CRITERION	DESCRIPTION
Publication period	2020-2026
Source type	Peer-reviewed journal articles
Language	English
Research focus	Air quality, social sustainability, physical activity, public health, environmental justice, or urban development
Indexing	Scopus-indexed journals preferred
Population relevance	Children, adults, older adults, vulnerable communities, or urban populations
Outcome relevance	Health, cognition, physical activity, inequality, productivity, urban livability, or sustainability
Exclusion	Non-peer-reviewed sources, unrelated environmental topics, insufficient methodological detail, and duplicate studies

4. RESULTS AND DISCUSSION

The reviewed evidence shows that poor air quality affects more than respiratory health. It also influences cardiovascular function, cognition, frailty, educational participation, labour productivity, social inequality, urban livability, and access to safe physical activity. These effects are especially important for physical education and sports science because outdoor exercise increases ventilation and may increase pollutant intake when activities occur in contaminated environments.

4.1. Air Quality, Public Health, and Physical Capacity

Air pollution was consistently associated with respiratory, cardiovascular, neurological, and functional health risks. Fine particulate matter was particularly important because $PM_{2.5}$ can penetrate deeply into the lungs and enter the bloodstream, contributing to long-term physiological damage [16-18]. These health effects may reduce exercise tolerance, increase fatigue, and limit participation in physical activity, rehabilitation, and community sport. Children, older adults, and individuals with pre-existing conditions were identified as especially vulnerable. Indoor and outdoor pollution exposure among children was associated with respiratory illness, developmental problems, and reduced well-being [5]. Prenatal and

early-life exposure was also linked with cognitive and language outcomes, suggesting that environmental conditions may influence later educational and physical-development trajectories [6]. Among older adults, air pollution was associated with frailty, cognitive decline, and reduced functional independence [7-10]. Frailty affects strength, balance, mobility, and the ability to participate safely in exercise. These findings are relevant to adapted physical activity and geriatric sports science because environmental exposure may influence the effectiveness and accessibility of rehabilitation and community exercise programs. Recent evidence also linked $PM_{2.5}$ exposure with cognitive decline among middle-aged and older adults. Cognitive impairment can affect decision-making, movement control, and exercise adherence [18]. Therefore, air quality should be considered part of the environmental context in which physical-activity programs are designed [19].

4.2. Implications for Physical Education and School Sport

School-aged children may experience direct exposure to air pollution during outdoor physical education, games, and sports activities. This concern is especially important for schools located near congested roads, industrial areas, or densely populated urban zones. Pollution-related respiratory symptoms may reduce students' willingness or ability to participate in running, team games, and endurance activities. Illness-related absenteeism may also reduce continuity in physical education. Cognitive effects associated with pollution exposure may further influence attention, learning, and motor-skill acquisition. Physical education programs should therefore consider local environmental conditions when planning outdoor sessions. Teachers may need to adjust activity intensity, move sessions indoors, shorten exposure duration, or select safer times of day when pollution levels are lower. Schools located in high-exposure areas may also benefit from vegetative buffers, air-quality monitoring, and safer facility placement. However, the reviewed literature did not provide enough direct school-based evidence to establish specific air-quality thresholds for cancelling physical education classes. This remains an important research gap.

4.3. Sports Participation and Outdoor Training

Outdoor sports participants may inhale more polluted air because exercise increases breathing frequency and tidal volume. This is particularly relevant to running, cycling, football, athletics, and endurance activities conducted near traffic corridors or industrial zones. The reviewed studies did not directly quantify sport-specific changes in performance under polluted conditions. Nevertheless, the documented associations between pollution and respiratory disease, cardiovascular risk, cognitive decline, and frailty indicate plausible consequences for training quality and recovery [16-19]. Sports organizations should therefore consider air quality when scheduling outdoor training and competitions. Coaches and administrators may need to account for participant age, asthma, cardiovascular conditions, exercise intensity, temperature, and pollution level. Outdoor sport facilities should also be located away from major pollution sources whenever possible. The absence of direct performance data means that claims about reduced speed, endurance, reaction time, or competitive results should be made cautiously. Future sports-science studies should measure these outcomes directly.

4.4. Social Inequality and Unequal Access to Safe Physical Activity

Air pollution was not distributed equally across urban populations. Low-income communities, informal settlements, and marginalized groups frequently experienced higher

exposure because of proximity to industrial sites, heavy traffic, poorly regulated waste systems, and limited green infrastructure [2-4, 20]. These unequal exposure patterns can create physical-activity inequality. Residents of wealthier neighborhoods may have access to cleaner parks, indoor sports facilities, and safer walking or cycling routes. By contrast, disadvantaged communities may depend on polluted outdoor spaces for recreation and exercise. The reviewed evidence shows that pollution exposure can increase healthcare costs, reduce labour productivity, interrupt education, and reinforce poverty [20-22]. These effects may further reduce the time, resources, and health capacity available for physical activity.

Table 3 summarizes the major social and physical-activity consequences associated with poor air quality. As shown in Table 3, the consequences of air pollution extend beyond disease. They affect whether communities can participate safely and consistently in physical education, recreation, and sport.

Table 3. Major social and physical-activity impacts of poor air quality.

DIMENSION	MAIN IMPACT	IMPLICATION FOR PHYSICAL EDUCATION AND SPORT
Public health	Respiratory and cardiovascular disease	Reduced exercise tolerance and greater health risk
Cognitive health	Reduced concentration and cognitive performance	Possible effects on learning, motor instruction, and decision-making
Education	Absenteeism and reduced academic participation	Interrupted physical education and school sport
Economy	Lower labour productivity and increased healthcare expenditure	Reduced household capacity to support sport participation
Social equity	Higher exposure among vulnerable populations	Unequal access to safe exercise environments
Urban sustainability	Reduced livability and environmental quality	Less attractive and less usable public recreation space
Poverty	Rising medical costs and reduced income	Lower participation in organized sport and physical activity
Community well-being	Stress, reduced cohesion, and environmental insecurity	Lower engagement in outdoor recreation and community exercise

4.5. Conceptual Relationship between Air Quality and Sustainable Physical Activity

Figure 1 presents the conceptual relationship among urbanization, air pollution, health risk, productivity loss, social inequality, reduced quality of life, and unsustainable social development. Industrialization and urbanization contribute to increased air pollution. Pollution then produces health risks that can reduce productivity, increase poverty, intensify inequality, and lower quality of life. Within the present interpretation, these pathways also reduce opportunities for safe physical activity and sports participation. Health risks may directly restrict participation through illness, fatigue, respiratory limitation, or reduced mobility. Productivity losses and poverty may indirectly restrict participation by reducing household resources and access to sport facilities. Environmental inequality may further concentrate unsafe exercise conditions in disadvantaged communities. The figure therefore supports the argument that clean air is an enabling condition for sustainable physical activity. Physical education and sport cannot be separated from the environmental settings in which they occur.

4.6. Sustainable Urban Development and Air Quality

Sustainable urban development requires coordinated action across transportation, energy, land use, public health, recreation, and environmental governance. The reviewed literature shows that rapid urbanization without adequate environmental controls increases traffic emissions, industrial pollution, waste accumulation, and population exposure to particulate matter [23]. These conditions reduce urban livability and may also make outdoor physical activity less safe and less attractive. Green infrastructure contributes to pollution reduction, temperature regulation, psychological well-being, and community resilience [11, 12]. Parks, urban forests, green corridors, and vegetated school environments can also provide spaces for walking, running, physical education, informal play, and community sport. Their value therefore extends beyond ecological protection. However, the benefits of green infrastructure depend on equitable distribution. Low-income communities and informal settlements often have limited access to clean, safe, and well-maintained recreational spaces. Urban greening strategies should therefore prioritize highly exposed neighborhoods rather than concentrating environmental improvements in already advantaged areas. Transportation reform is equally important. Fossil-fuel-dependent vehicles contribute substantially to urban particulate matter and nitrogen oxide concentrations. Public transportation, electric mobility, pedestrian infrastructure, and protected cycling routes can reduce emissions while encouraging active transport [13]. These interventions can simultaneously support environmental quality and population-level physical activity.

4.7. Policy Pathways toward Sustainable Physical Activity

Figure 2 presents the policy pathway linking green-energy transition, cleaner transportation, improved air quality, better public health, inclusive social development, and sustainable cities. The clean-energy transition and cleaner transportation reduce urban emissions and improve air quality. Improved environmental conditions can then support public health by lowering pollution-related respiratory, cardiovascular, neurological, and functional risks. Within the physical education and sports-science interpretation, better air quality also supports safer school exercise, outdoor training, active transport, and community recreation. These benefits may contribute to more inclusive social development because vulnerable populations gain greater access to safe movement environments. The pathway should not be interpreted as automatic or strictly linear. Green-energy and transport reforms must be accompanied by equitable planning, community participation, monitoring, and enforcement. Without these elements, environmental improvements may not reach the neighborhoods experiencing the greatest exposure.

4.8. Green Infrastructure and Community Sport

Green spaces can support community sport by providing accessible settings for walking, running, games, cycling, and group exercise. They may also reduce heat exposure, improve psychological restoration, and strengthen social interaction. The reviewed evidence indicates that urban green infrastructure improves ecosystem services and resilience [11, 12]. These findings support the development of school grounds, public parks, greenways, and recreational corridors as components of both environmental and physical-activity policy. Nevertheless, green spaces cannot fully eliminate exposure when pollution sources remain uncontrolled. Vegetation may reduce localized pollution under certain conditions, but industrial emissions, traffic volume, and fossil-fuel use require direct regulation. Therefore, urban greening should complement rather than replace emission-reduction strategies. Future

studies should examine whether greener school and neighborhood environments increase physical-education participation, active transport, recreational activity, and community-sport attendance.

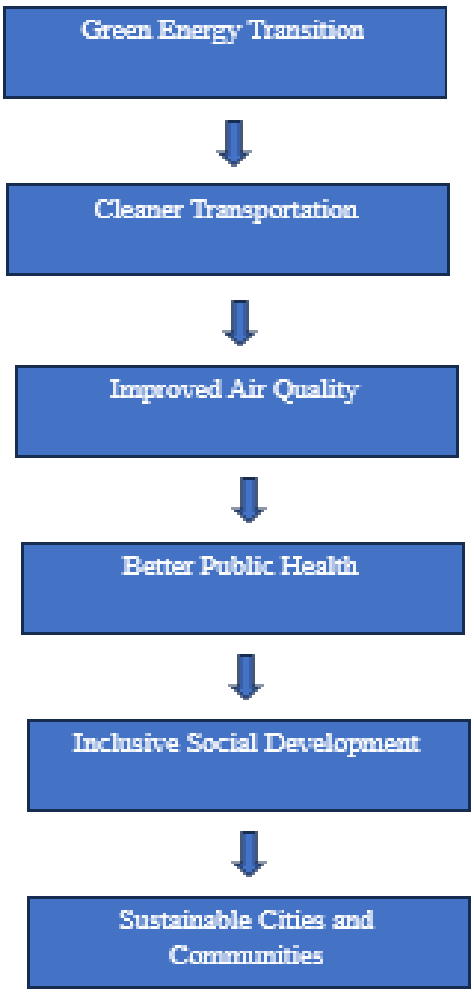

Figure 2. Integrated policy pathways linking clean energy, transportation, air quality, public health, and sustainable urban development.

4.9. Sustainable Transportation and Active Mobility

Sustainable transportation provides a direct connection between air-quality policy and physical activity. Public transit can reduce private vehicle use, while walking and cycling infrastructure can increase routine movement. The reviewed literature identifies transport reform as a central strategy for reducing urban emissions and supporting social inclusion [13, 24]. However, active transport routes must be designed carefully because cyclists and pedestrians may still experience high exposure when routes pass through congested corridors. Low-emission routes, green buffers, reduced traffic density, and real-time pollution information may improve the safety of active mobility. These measures are especially important for children travelling to school, recreational runners, cyclists, and individuals with respiratory conditions. Physical-activity promotion should therefore be coordinated with air-quality management. Encouraging outdoor exercise without addressing polluted environments may shift environmental risks onto participants.

4.10. Environmental Monitoring for Physical Education and Sport

Digital monitoring technologies can help schools, coaches, sports organizations, and local governments make safer activity decisions. GIS, satellite observations, fixed monitoring stations, and low-cost sensors can identify pollution hotspots and changes over time [14, 25]. Schools could use local air-quality information to adjust outdoor physical-education schedules. Sports organizations could apply similar information when planning training sessions, competitions, and community events. Such decisions may include modifying activity intensity, reducing session duration, changing location, or moving activities indoors. Community-based monitoring can also increase environmental awareness and participation. Schools, universities, sport clubs, and community groups may contribute to local data collection, particularly in areas not covered by official monitoring stations. However, monitoring systems require clear communication. Technical pollution data should be translated into understandable guidance for teachers, coaches, parents, athletes, and community participants.

4.11. Environmental Justice and Inclusive Sports Participation

Environmental justice requires the fair distribution of environmental benefits and burdens. In the context of physical activity, this principle means that all communities should have access to safe air, healthy recreation spaces, and suitable environments for sport. The reviewed studies show that low-income, minority, migrant, and informal-settlement populations frequently experience disproportionate pollution exposure [2-4, 20-22]. These same populations may have limited access to indoor facilities, organized sport, healthcare, and environmental information. As a result, air pollution can intensify existing inequalities in exercise participation. Individuals living in polluted neighborhoods may be advised to avoid outdoor activity but lack alternative locations. This creates a policy contradiction in which physical activity is promoted without ensuring safe environmental conditions.

Environmental-justice strategies should therefore include:

(i) pollution reduction in highly exposed neighborhoods;
(ii) equitable distribution of green and recreational infrastructure;
(iii) affordable access to indoor and outdoor sport facilities;
(iv) local air-quality monitoring near schools and sports grounds;
(v) community involvement in facility and transport planning.

These actions would connect environmental policy with inclusive physical education and sport development.

4.12. Air Pollution and SDGs

Air-quality improvement contributes directly to several SDGs. Poor air quality undermines SDG 3 by increasing disease burden and premature mortality. It also restricts opportunities for safe physical activity, which is an important component of preventive health. Pollution exposure threatens SDG 4 because illness, cognitive impairment, absenteeism, and unsafe school environments can reduce educational participation. Physical education may also be disrupted when outdoor conditions are unsuitable. Environmental inequality affects SDG 10 because disadvantaged communities experience higher exposure and fewer resources for avoiding polluted environments. Unequal access to safe exercise spaces represents an additional dimension of this inequality. Air-quality management supports SDG 11 through cleaner transport, green infrastructure, healthier public spaces, and more livable

communities. It also contributes to SDG 13 because many air pollutants and greenhouse gases share common sources, including fossil-fuel combustion and unsustainable transport systems. As summarized in **Table 4**, air-quality policy can support both environmental sustainability and physical-activity participation. The strongest benefits are likely to occur when pollution reduction is combined with inclusive recreation planning.

Table 4. Air quality, physical activity, and relevant SDGs.

SDGs	AIR-QUALITY RELATIONSHIP	PHYSICAL EDUCATION AND SPORTS IMPLICATION
SDG 3: Good Health and Well-being	Cleaner air reduces respiratory, cardiovascular, neurological, and functional risks	Supports safer exercise, rehabilitation, and community sport
SDG 4: Quality Education	Reduced pollution may improve attendance, cognition, and school well-being	Supports consistent physical education and school-sport participation
SDG 10: Reduced Inequalities	Equitable pollution reduction protects vulnerable communities	Reduces unequal access to safe physical-activity environments
SDG 11: Sustainable Cities and Communities	Green infrastructure and clean mobility improve urban livability	Expands opportunities for walking, cycling, recreation, and sport
SDG 13: Climate Action	Clean energy and low-carbon transport reduce shared pollution sources	Supports healthier and more resilient activity environments

4.13. Implications for Physical Education Practice

Physical-education programs should recognize air quality as an external safety condition. Teachers and school administrators should not rely only on temperature, rainfall, or facility availability when planning outdoor lessons.

Practical measures may include:

(i) checking local air-quality information before outdoor sessions;
(ii) scheduling activities during lower-pollution periods;
(iii) reducing prolonged high-intensity exercise during poor air-quality events;
(iv) using indoor spaces when exposure risks are elevated;
(v) monitoring students with asthma or cardiovascular conditions;
(vi) locating school sport facilities away from major traffic corridors;
(vii) increasing vegetation and green barriers around school grounds.

These recommendations are derived from the reviewed health and environmental evidence. The source literature does not establish universal sport-specific thresholds, so locally applicable public-health guidance remains necessary.

4.14. Implications for Sports Science and Athlete Health

Sports science should examine air pollution as an environmental factor that may affect training, recovery, and performance. The reviewed literature supports health-related concern but contains limited direct evidence concerning athletic outcomes. Future studies should measure pulmonary function, heart-rate response, oxygen uptake, perceived exertion, recovery, reaction time, and sport-specific performance under different pollution conditions. Research should also compare indoor and outdoor exposure and examine whether training

adaptations modify vulnerability. Athletes with asthma, allergies, cardiovascular conditions, or prolonged outdoor exposure may require particular attention. Coaches should integrate air-quality monitoring with training-load management rather than treating environmental conditions as separate from performance planning.

4.15. Integrated Policy Recommendations

The reviewed evidence supports an integrated approach rather than isolated environmental or sport policies. **Table 5** shows that clean-air policy, sport planning, education, transport, and urban design should be coordinated. Such integration can produce co-benefits for health, sustainability, and social inclusion.

Table 5. Integrated policy recommendations for air quality and physical activity.

POLICY AREA	RECOMMENDED ACTION	EXPECTED PHYSICAL-ACTIVITY BENEFIT
Air-quality regulation	Strengthen emission standards and enforcement	Reduces health risks during outdoor activity
School policy	Include air-quality checks in physical-education planning	Supports safer classes and school sport
Sports administration	Develop pollution-response protocols for training and events	Protects athletes and recreational participants
Sustainable transport	Expand low-emission public transport, walking, and cycling routes	Supports active mobility with lower exposure
Green infrastructure	Prioritize parks and green corridors in vulnerable communities	Improves equitable access to recreation
Monitoring technology	Install sensors near schools, parks, and sports grounds	Enables location- and time-sensitive decisions
Environmental justice	Target interventions toward highly exposed neighborhoods	Reduces inequalities in safe participation
Community engagement	Involve residents, schools, and clubs in planning and monitoring	Strengthens accountability and local ownership

4.16. Limitations and Future Research

This review was limited to literature published between 2020 and 2026 and may not represent all regions or population groups. Evidence from low-income regions remained comparatively limited because air-quality monitoring and research infrastructure were unevenly distributed. The included studies also used different pollutants, exposure periods, health outcomes, socioeconomic indicators, and study designs. This heterogeneity prevented statistical meta-analysis and limited direct comparison. A further limitation is that much of the reviewed evidence concerned public health and social sustainability rather than direct physical-education or sport outcomes. The implications for exercise participation were therefore partly interpretive and should be tested through targeted empirical research.

Future studies should examine:

(i) pollution exposure during physical-education classes;
(ii) outdoor athlete performance and recovery;
(iii) respiratory and cardiovascular responses during exercise;
(iv) pollution-related cancellation or modification of sports activities;
(v) differences between indoor and outdoor facilities;
(vi) access to safe exercise environments across socioeconomic groups;

(vii) the effect of green infrastructure on actual physical-activity participation;
(viii) the usefulness of real-time air-quality warnings for teachers and coaches.

Such research would provide a stronger empirical basis for integrating environmental conditions into physical education and sports science.

5. CONCLUSION

This review demonstrates that air quality is not only an environmental or public-health issue but also an important determinant of physical activity, physical education, sports participation, and sustainable urban development. The reviewed evidence consistently shows that exposure to air pollutants, particularly fine particulate matter and traffic-related emissions, increases respiratory, cardiovascular, neurological, and functional health risks. These adverse effects may reduce exercise capacity, discourage outdoor physical activity, and disproportionately affect vulnerable populations, including children, older adults, athletes, and residents of low-income communities. Consequently, environmental inequality can also become physical-activity inequality when access to safe and healthy exercise environments is unevenly distributed.

The study contributes to the literature by integrating environmental science, public health, social equity, urban planning, and physical education within a single interdisciplinary framework. It emphasizes that clean air should be recognized as a prerequisite for safe school physical education, community recreation, active transportation, and outdoor sports participation. Sustainable interventions—including cleaner transportation systems, green infrastructure, air-quality monitoring, and equitable urban planning—can simultaneously improve environmental quality and expand opportunities for healthy and inclusive physical activity. Future research should provide direct evidence on pollution exposure during exercise, evaluate sport-specific performance under different air-quality conditions, and develop practical guidelines for schools, coaches, urban planners, and policymakers to support safer physical activity and more sustainable communities.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

7. REFERENCES

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