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Health at Risk: Air Pollution and Urban Vulnerability - Perspectives in Light of the 2030 Agenda

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Abstract

This study explores the effects of industrialization and air pollution on public health, emphasizing disparities between national and international air quality standards. A qualitative, descriptive methodology was adopted through a bibliographic review of national and international literature published between 2005 and 2023, using databases such as LILACS and PubMed. Findings indicate that even in areas where pollutant levels meet legal thresholds, vulnerable populations still experience increased morbidity and mortality. The study compares air quality standards from the World Health Organization (WHO), the United States Environmental Protection Agency (EPA), and Brazil's National Environmental Council (CONAMA), revealing significant differences. The WHO, aligned with Sustainable Development Goals (SDGs) 3 and 13, recommends stricter limits to better protect human health, while national regulations remain more lenient. The research also addresses the importance of continuous environmental monitoring, emission control strategies, and the implementation of educational and policy actions. Finally, it underscores the need for individual, collective, and institutional responsibility in promoting environmental preservation, in line with the 2030 Agenda.

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1. Introduction

The acceleration of population growth began in the early 18th century, marked by the Industrial Revolution, which led to economic development and an increased demand for industrialized products. Consequently, there was also greater appropriation of natural resources. This development resulted in the concentration of populations in large cities, and under this perspective, environmental impacts increased rapidly. These impacts were characterized by the accumulation of pollutants in the atmosphere at levels sufficient to interfere with the safety and well-being of living organisms, being extremely harmful to flora and fauna on a global scale [1].

In parallel with the advance of industrialization and urbanization, society has experienced a growing awareness of the impacts of environmental pollution on human health. This movement has been accompanied by stronger commitment to environmental causes and by the reinforcement of oversight from competent regulatory bodies [2].

In this context, numerous toxicological and epidemiological studies have shown that even in environments where pollutant levels meet the standards established by governmental regulations, continuous exposure is associated with adverse health effects [2–4]. In more severe cases, such exposure may result in morbidity and mortality due to complications in the circulatory system, such

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as increased blood pressure, changes in coagulation, higher blood viscosity, and reduced heart rate variability, leading to greater risks for human health [3–5].

Certain population groups are particularly vulnerable. Older adults, whose recovery capacity is generally lower, experience intensified effects of pollution, such as a higher incidence of cardiovascular diseases (stroke and myocardial infarction), especially in those with pre-existing comorbidities. Pollution exposure can also contribute to cognitive decline, raising the risk of dementia and other neurodegenerative diseases, as well as reducing life expectancy in populations exposed over extended periods [3]. Children, on the other hand, due to their ongoing growth and development, are more susceptible to the effects of pollution, which may impair pulmonary and cognitive development, increase the risk of respiratory diseases such as asthma and bronchitis, and make them more prone to infections due to the immaturity of the immune system [2–6].

In large cities, air pollution has become an even more severe threat to population health, due to the accelerated growth of motor vehicle fleets, which, because of their enormous number, have become the main source of pollutant emissions in urban areas [7]. Poor air quality in these regions is widely associated with an increased prevalence of chronic respiratory diseases, such as asthma and chronic obstructive pulmonary disease (COPD), disproportionately affecting children and the elderly [2–6].

High population density in large urban centers also plays a significant role in the cause-and-effect relationship, creating a vicious cycle of pollutant emissions into the atmosphere. Given that, due to high density, enormous amounts of various pollutants are emitted within a limited area, many individuals in these same areas end up suffering health problems caused by the inhalation of the same pollutants [3,4,7].

Faced with this scenario, continuous monitoring of air quality becomes essential, through the systematic collection of data that makes it possible to assess atmospheric conditions at contrasting times and identify trends over time. Such information is fundamental for supporting control strategies, more effective environmental regulations, and the establishment of safe distances between populations and pollutant sources [8,9].

Thus, the impacts of air pollution highlight the importance of an interdisciplinary approach that integrates health, education, and the environment, as well as the formulation of public policies aimed at mitigating emissions, particularly in densely populated areas, to protect population health, reduce socio-environmental inequalities, and promote greater sanitary equity.

The objective of this study is to analyze the impacts of air pollution on health in vulnerable urban contexts, based on a bibliographic review and a comparative analysis of international and national air quality standards, discussing their implications in light of the 2030 Agenda and the integration of environmental education as a strategy for mitigation and awareness.

2. Materials and Methods

This study adopts a qualitative and descriptive approach, based on a bibliographic review of national and international scientific publications from 2005 to 2023, retrieved from databases such as LILACS and PubMed. The search employed the following descriptors combined with Boolean operators: "air pollution," "industrialization," "public health," "environmental impacts," "air quality," and "morbimortality." The research explores the association between exposure to pollutants ($PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, and O_3), with particular attention to vulnerable urban areas and the increasing prevalence of respiratory, cardiovascular, and neurological diseases. Additionally, a comparative analysis was conducted to examine air quality standards established by the World Health Organization (WHO), the United States Environmental Protection Agency (EPA), and Brazil's National Environmental Council (CONAMA), highlighting the differences between these regulatory frameworks. The study also reflects on Brazilian legal instruments—such as the National Environmental Education Policy (PNEA) and the Law of Guidelines and Bases of National Education (LDB)—to discuss the integration of environmental education into school curricula as a means of fostering socio-environmental awareness and promoting long-term behavioral change.

3. Results

ATMOSPHERIC POLLUTANTS: CLASSIFICATIONS, PERMITTED LIMITS, MONITORING OF POLLUTION SOURCES AND REGULATIONS

Air pollution releases toxic and breathable agents into the atmosphere, causing unpleasant odors, soot, and other particles that harm the respiratory system and blood circulation. The association of air pollution with various respiratory, cardiovascular, and neurological diseases, as well as with increased mortality among the elderly, has become increasingly common [3-510]. Air pollutants consist of a combination of elements, including particles such as particulate matter (PM) and gases released into the atmosphere by transportation, factories, power plants, and the burning of fossil fuels and biomass [11]. Such pollutants can be categorized into two forms: primary, which are emitted directly by sources in the environment, such as automobile exhaust gases, and secondary, which are pollutants that are formed through chemical or photochemical reactions between two or more pollutants or with the participation of normal constituents of the atmosphere, such as oxygen and water. The main primary pollutants include nitrogen oxides (NOx), sulfur dioxide (SO2), carbon monoxide (CO), and volatile organic compounds (VOCs) [11]. Nitrogen oxides are primarily generated by vehicles in traffic. A common pollutant in the atmosphere is particulate matter (PM), which can be of primary or secondary origin and is classified according to the size of its suspended particles. In the city of São Paulo, vehicles are responsible for 40% of PM emissions, in addition to other factors such as the resuspension of soil particles and the formation of secondary aerosols from industries and other pollution sources [11]. Pollutants can also be divided into two other classifications: pollutants from variable mobile sources and pollutants from continuous fixed sources: Mobile sources of contamination are motor vehicles, which are the main sources of pollutant emissions in urban areas, and fixed sources are industrial, mining and energy production activities, the combustion of fuels in companies and all those that allow a direct assessment at the source, since they are fixed in one place and occupy a relatively limited area [7]. In the case of motor vehicle emissions, in addition to the primary pollutants already mentioned, exhaust gases can also contain volatile organic compounds (VOCs), which are harmful to human health and contribute to the formation of tropospheric ozone, a secondary pollutant [9]. From stationary sources, emissions of sulfur dioxide and fine particulate matter can affect air quality in nearby areas, harming the health of residents [12].

The World Health Organization (WHO) has established limits considered safe for human health for some of these air pollutants in its air quality guidelines. These limits are more restrictive than those adopted by many countries and include: Fine particulate matter (PM2.5): daily limit of 15 μg/m³ and annual limit of 5 μg/m³; (PM10): daily limit of 45 μg/m³ and annual limit of 15 μg/m³; Nitrogen dioxide (NO2): daily limit of 25 μg/m³ and annual limit of 10 μg/m³; Sulfur dioxide (SO2): daily limit of 40 μg/m³. Regarding gases, the WHO establishes a maximum exposure limit of 4 ppm for carbon monoxide (CO) over an 8-hour average and a maximum exposure limit of 40 μg/m³ for sulfur dioxide (SO2) over a daily average [12].

However, the limits for gas and particulate matter pollution considered acceptable or harmful to public health vary according to each country's regulatory standards and are periodically updated based on new scientific research and epidemiological data on the effects of these substances on human health [12]. For example, the United States Environmental Protection Agency (EPA), responsible for protecting the environment and public health through the enforcement of laws and regulations related to air, water, and soil quality, has been instrumental in reducing air pollution in the United States in recent decades by establishing national limits for six air pollutants considered harmful to human health, known as "Criteria Air Pollutants." These pollutants include: Tropospheric ozone (O3): daily limit of 70 ppb (parts per billion) and an 8-hour average of 0.075 ppm; Fine particulate matter (PM2.5): daily limit of 35 μg/m³ and annual average of 12 μg/m³; Sulfur dioxide (SO2): daily limit of 75 ppb and annual average of 0.03 ppm; Nitrogen dioxide (NO2): hourly limit of 100 ppb and annual average of 53 ppb [13].

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In Brazil, Resolution No. 491 of November 19, 2018, of the National Environmental Council (CONAMA) establishes air quality standards and limits for some atmospheric pollutants, including: Sulfur dioxide (SO2): daily limit of 125 PI-1 mg/m³ and annual average of 40 PI-1 mg/m³; Total suspended particles (PST): daily limit of 240 µg/m³ and annual average of 80 µg/m³; Inhalable particulate matter (PM10): daily limit of 120 PI-1 mg/m³ and annual average of 40 PI-1 mg/m³ ; Inhalable fine particles (PM2.5): daily limit of 60 PI-1 mg/m³ and annual average of 20 PI-1 mg/ m3 [8]. However, the WHO does not establish a maximum exposure limit for carbon dioxide (CO2), as it is not considered an air pollutant directly toxic to humans. However, high concentrations of carbon dioxide may indicate the presence of other air pollutants, such as the burning of fossil fuels in vehicles and industries, which emit pollutants that are more harmful to human health [12,13].

The effects of inhalable particulate pollutant concentrations in the environment can manifest themselves in a variety of ways, ranging from impacts on population health to environmental damage through increased greenhouse gas emissions, climate change, and urban acid rain [7].

In this sense, the impacts of pollution on human health have been the focus of numerous toxicological and epidemiological studies. Some of these studies have shown that, although pollutant concentrations analyzed in some environments meet the standards established by local government regulations, continued exposure of the local population to these air pollutants is associated with a series of negative effects on human health, including an increased risk of cardiovascular, pulmonary, and cerebrovascular diseases [2-6].

The concentration of pollutants in the air, as well as their dispersion and transport, is the result of several factors, including not only emissions from sources, but also a set of physical and chemical processes in the atmosphere. These processes are caused by topographical and meteorological factors, such as pressure, temperature, humidity, and wind direction and speed [11].

Environmental monitoring is the assessment of basic information about a location's environmental situation. It serves as an important tool for monitoring whether the benefits proposed in the design and implementation of pollution control projects are actually occurring or whether adjustments to the methodology employed are needed. These data are essential for describing the current state of the environment, future trends in the potential for environmental resource recovery, and the performance of proposed interventions in meeting government parameters and standards [14]. Implementing environmental monitoring requires a prior assessment and selection of parameters that can qualitatively and quantitatively express the pollutants present at the location. This is done to determine the impact of these sources on air quality and, thus, evaluate the types of interventions necessary and possible to be implemented in that particular region [14,15]. Monitoring pollution sources, including qualitative and quantitative assessments of emissions and air quality analysis, is essential to determine the impact of these pollution sources on regional air quality and, thus, define an appropriate method for effective local pollutant control actions. However, studying the influence of local meteorological conditions on pollutant dispersion, analyzing regional meteorological variables such as temperature, wind speed, direction, and precipitation in the monitoring area, is essential for developing the desired dispersion simulations [2,3,11,15,16]

After collecting data on air pollutant concentrations and evaluating the short- and long-term averages obtained, a comparative analysis should be performed with the Resolution of the National Environmental Council (CONAMA) to identify the periods when air pollutants exceed the limits established by law and the possible causes [15]. It is also noteworthy that this monitoring network is an important control mechanism not only in the context of air quality degradation and environmental intervention projects, but also in the preparation of inventories to assess the effects of pollutants on human health [3,4,11,14,15]. Both monitoring and interventions depend on the source of pollution and the type of pollution observed. For example, gaseous emissions can be treated with a catalyst and a filter, or by replacing a chemical used in an industry with a less polluting one [3,14,15]. his section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

4. Discussion

THE IMPORTANCE OF ENVIRONMENTAL EDUCATION IN THE SCHOOL ENVIRONMENT

Environmental education in schools is an increasingly present topic on the global educational agenda to develop conscious citizens committed to environmental preservation. Education raises awareness of the importance of preserving nature, the need to reduce the impact of human activities on the planet, and the importance of adopting sustainable habits [17,18].

Thus, schools become a privileged space for the development of initiatives aimed at promoting environmental education. The goal is to teach students from an early age about the importance of caring for the environment and encourage the adoption of sustainable practices at home and in the community to develop conscious citizens committed to environmental preservation [17]. In Brazil, the National Environmental Education Policy (PNEA) establishes that environmental education must be an integrated educational practice at all levels of education, both formal and informal. Furthermore, the Law of Guidelines and Bases of National Education (LDB) also establishes the inclusion of environmental education as a cross-curricular theme in the curriculum [19,20,21,22].

Implementing environmental education in schools requires the involvement of the entire school community, from administration, teachers, students, and staff to parents and guardians. It's important that activities be developed in an interdisciplinary manner, involving various areas of knowledge and promoting students' awareness of the relationship between the environment and human activities [17,19,23].

Promoting environmental education in schools requires coordination between public education and environmental policies, teacher training, the development of teaching materials, and the development of pedagogical projects focused on the topic. Furthermore, it is important that activities be developed in a playful and participatory manner, encouraging critical reflection and the collective construction of knowledge [17,19,23].

Environmental education is a continuous and integrated process that aims to raise awareness about the importance of preserving and conserving natural resources, as well as promoting behavioral changes to build a more sustainable world. It should involve not only students, but also teachers, staff, and the community at large. This can be achieved through lectures, workshops, hands-on activities, and interdisciplinary projects that address topics such as global warming, air pollution, water conservation, and material recycling, among others [19,20,21,22].

Furthermore, environmental education should also focus on promoting citizenship and students' active participation in building a more just and sustainable society. It's important that students learn to critically analyze environmental information and make informed decisions about the environment [18,20,21,23].

According to Law 9.795/99, article 26 of the Guidelines and Bases of National Education (LDB), environmental education is a mandatory curricular component in all Brazilian schools, it must be present, in an articulated manner, at all levels of education. Therefore, it is important that schools and educators are trained to implement environmental education effectively and that the necessary resources are made available for this purpose [21,22].

5. Conclusions

We can conclude that high concentrations of atmospheric pollutants are extremely harmful to the environment, damaging flora and fauna, and posing a risk to human health. Environmental preservation is a collective responsibility that depends on the contribution of each individual.

Individual practices that contribute to the preservation and reduction of pollution.

1st - Plant a tree.

2nd - Place recyclable waste in the appropriate containers

3rd - Use energy-efficient appliances and light bulbs, which not only help reduce pollution but also lower your electricity bill.

4th - Avoid using plastics in your daily life, have a bag for shopping and always use the same one.

5th - Choose products and producers that don't destroy forests for food production. There is sufficient land for agricultural production, and preserving native forests ensures a more balanced rainfall pattern. Therefore, preservation improves productivity and production in our agricultural areas.

6th - Use your personal car as little as possible. Vehicles are the biggest cause of pollution worldwide. Prioritize public transportation or, whenever possible, cycling.

Collective actions for environmental preservation:

1st - Replacement of electrical energy sources with renewable energy (solar photovoltaic, wind, hydro).

2nd - Renewal of the entire public transport fleet with electric or biofuel-powered vehicles, which are less polluting compared to transport based on the internal combustion of fossil fuels.

3rd - Encouraging the distribution of the population over large areas (reducing population density) would reduce the local impact on air, land, and water pollution. Environmental education is a continuous and integrated process that aims to raise awareness of the importance of preserving and conserving natural resources, as well as promoting behavioral changes to build a more sustainable world [23]. In this context, in addition to the individual and collective actions mentioned above, it is essential that environmental education be incorporated into schools as part of the curriculum to promote citizenship and the active participation of students in building a more just and sustainable society. However, the most effective action a population can take to protect the environment on a large scale is to vote for government officials and parliamentarians who are sensitive to environmental issues and committed to promoting them. Once their candidates are in office, the public must remain vigilant, verifying what is actually being done regarding environmental preservation and the protection of green spaces in large cities.

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