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Ecological Situation of the Regions and Problems of Population Health

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Abstract

This study investigates the impact of environmental conditions on population health and mortality rates in the Republic of Uzbekistan, focusing on the city of Samarkand. A mixed-methods approach was employed, integrating statistical analysis with a sociological survey. Quantitative data were derived from national statistics and official health reports, and analyzed using correlation and regression methods to determine associations between atmospheric emissions and disease incidence. Forecasting was conducted using exponential smoothing to project trends in pollution levels. The sociological component involved a purposive survey of 315 respondents from three ecologically diverse districts, capturing public perceptions of environmental quality and its health implications. The results revealed a statistically significant correlation between elevated air pollution and increased rates of respiratory, cardiovascular, and immune-related diseases. The findings emphasize that environmental degradation, particularly air pollution, contributes directly to adverse health outcomes and higher mortality rates. Based on these results, the study proposes targeted policy recommendations, including modernization of industrial infrastructure, promotion of green urban initiatives, and strengthened environmental governance to mitigate pollution and safeguard public health.

Keywords

Atmospheric air; Mortality rate; Population health level; Urbanization; Diseases

Introduction

The deteriorating ecological conditions in certain regions and their impact on public health represent one of the most pressing challenges in the context of rapid environmental degradation. Air, water and soil pollution caused by urbanisation and industrialisation are becoming significant factors that harm public health. The number of diseases caused by environmental factors is increasing every year, which requires new approaches to analysing and studying these processes. The study of such interrelationships is critical for the development of new, effective ways and strategies to preserve public health and minimise the negative impact of urbanisation.

In their paper, Barvaiz and Kumar (2020) investigated the use of plant barriers to reduce air pollution in urban settings and provided practical recommendations for selecting appropriate plant species for such barriers. In particular, the authors recommended the use of plant species with dense foliage and a high ability to absorb harmful substances. The scientists emphasised that plant barriers can significantly reduce air pollution levels due to the ability of plants to trap dust particles.

Iravani and Rao (2020) considered the principles of New Urbanism regarding the level of public health, in particular, the negative impact of a polluted environment on the quality of life, as well as the well-being of the population in general. Hu et al. (2024) studied the principles and approaches to urban planning, particularly the integration of urban planning strategies in the context of environmental, social and economic aspects. The authors analysed how urbanisation affects the development of modern cities and the importance of creating a convenient, sustainable, environmentally friendly and safe urban space. In their study, Degirmenchi *et al.* (2021) emphasised policy measures that may include regulating building codes, encouraging the use of green roofs, natural cooling systems and other environmental initiatives. The involvement of the population in environmental activities, particularly through policy measures, contributes to the formation of environmental awareness and leads to a better environmental condition of a certain region in the future, as part of the population has an awareness of some threats and effects of a polluted environment on their health. In addition, Degirmenchi *et al*. (2021) showed that the population living near chemical plants is 2-4 times more likely to suffer from diseases of the circulatory system, in particular myocardial infarction.

Environmental pollution negatively affects the general level of health and mortality of the population. In particular, Qu *et al*. (2024) studied the effect of air pollution on mortality caused by cardiopulmonary and cerebrovascular diseases in Shenyang, China. It was found that continuously circulating harmful substances in the air, such as fine particulate matter, significantly increased the rate of respiratory and cardiovascular diseases. Holst *et al*. (2020) investigated the presence of environmental air pollutants and family factors on the likelihood of developing asthma and persistent wheezing in children. The authors investigated the effects of air pollution, particularly nitrogen dioxide and particulate matter, which can cause the development of respiratory disease in children. Numerous family factors were also taken into account, including parental smoking, genetic predisposition to respiratory disease, and living conditions. The analyses showed that children who live in regions with fairly high levels of air pollutants are more likely to have persistent wheezing or a diagnosis of asthma than children who live in areas with lower concentrations of pollutants.

This study aimed to substantiate the influence of polluted air on the environment in general, on the mortality rate and health level of the population of the Republic of Uzbekistan, in particular, the city of Samarkand. This study aimed to examine the impact of air pollution on the environment and, more specifically, on the mortality rate and public health in the Republic of Uzbekistan, with a particular focus on the city of Samarkand. The specific objectives of the study are:

1. To study the impact of the development of the urbanisation process in the context of historical discourse and to trace its influence on the environmental condition of the city.
2. To analyse the relationship between environmental pollution and public health outcomes, particularly by evaluating statistical data on the incidence and mortality rates associated with cardiovascular, circulatory, and respiratory diseases.
3. To determine the relationship between the number and main types of diseases of the population and harmful substances that are emitted into the atmosphere.

Methodology

This study employed a mixed-methods approach, integrating statistical analysis with a sociological survey to assess the impact of environmental conditions on public health in Samarkand, Uzbekistan. Quantitative data were sourced from the Statistics Agency under the President of the Republic of Uzbekistan (2023), supplemented by policy and legal frameworks,[1] including the Decree of the President No. DP-60 (2022), the Law "On the Protection of Atmospheric Air" (1996), and WHO (2023) reports. These sources formed the foundation for assessing pollution trends and health outcomes.

A stratified purposive sampling strategy was used to ensure representation across distinct ecological zones of Samarkand. Three districts — Kimyogarlar, Farhod, and Hishrau — were selected based on their contrasting ecological profiles and varying degrees of industrial activity, population density, and infrastructural development. These areas were chosen to reflect differing environmental and socio-economic conditions that could influence public health outcomes. Within each district, respondents were recruited through targeted sampling at medical institutions such as family clinics and hospitals. Within these zones, 315 respondents were surveyed during November–December 2022 in medical facilities, including family clinics and hospitals. They were selected using non-probability purposive sampling, prioritising accessibility and environmental representativeness rather than statistical randomness. This non-probability sampling approach prioritised environmental diversity and respondent accessibility but may limit the generalizability of results beyond urban Samarkand. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. A study was approved by the Ethics Commission of the National University of Uzbekistan named after Mirzo Ulugbek, No. 5236-C. Based on 5 questions, the responses of the respondents were obtained and summarised (Appendix 1).

[1] Law of the Republic of Uzbekistan No. 353-I "On the Protection of Atmospheric Air". (1996). Online: https://lex.uz/acts/58400; Law of the Republic of Uzbekistan No. ZRU-393 "On the Sanitary and Epidemiological Well-Being of the Population". (2015). Online: https://lex.uz/mact/2732584

The quantitative component involved correlation and regression analyses to examine relationships between air pollution indicators and morbidity/mortality rates. The strength and direction of correlations were interpreted using the Cheddock scale. A key limitation noted was the presence of some inverse correlations (e.g., between emissions and mortality), potentially due to unaccounted confounding factors or measurement biases in reported data.

To forecast future pollution trends, single exponential smoothing was applied with a smoothing parameter $\alpha = 0.3$. This method was selected for its computational simplicity and suitability for datasets with moderate variability, where recent observations are assumed to carry more predictive weight than distant ones. Exponential smoothing was preferred over more complex models such as ARIMA due to the limited length and volatility of the available time series, as well as the practical need to provide transparent and interpretable results for policymakers and a non-technical audience. Although no formal model comparison was conducted, the choice of exponential smoothing reflects its proven reliability in short-term forecasting under conditions of limited data regularity. The exponential mean is calculated using the recurrence formula (1):

$$\mathrm{St} = \alpha \times \mathrm{Yt} + (1-\alpha)\mathrm{St} - 1, \quad (1)$$

where St is the value of exponential averaging at a specific moment of time t; St-1 is the value of exponential averaging at a specific moment of time (t=1); Yt is the value of the exponential process at the moment of time t; α is the weight of the ttt-th value of the dynamic series (or smoothing parameter).

The Student’s t-distribution table was used to construct 95% confidence intervals around the forecasted values. This approach enabled the estimation of the range within which future pollution levels are likely to fall, providing a measure of statistical uncertainty. The use of the Student’s table thus served as a tool for assessing the precision and reliability of the forecasted indicators.

Even though the study provides valuable insights into the relationship between environmental pollution and the health status of the population of Samarkand, several methodological points should be noted. The sociological study involved 315 respondents from three districts - Kimyogarlar, Farhod and Khishrau - which, while informative, cannot fully reflect the diversity of the city's population and environmental conditions. As a result, generalization of the findings to the broader urban context may be limited. In addition, the study relies mainly on self-reported data on environmental perceptions and health impacts, which may be influenced by individual biases or memory limitations. Lack of validation through clinical or environmental monitoring data may affect the accuracy of some observations. Regarding prediction, the use of exponential smoothing (with $\alpha = 0.3$) was not compared with alternative statistical models such as ARIMA, which may offer more reliable predictions. Finally, some correlation results, including negative associations between emissions and specific health indicators, contradict the overall findings, indicating the need for further clarification or additional analysis in future studies.

Results and Discussion

Urbanization as a Process. Geographical and Ecological Environment of Samarkand

Urbanisation has emerged as a defining force of the 21st century, shaping not only the spatial and economic development of cities but also influencing public health outcomes. In the context of Uzbekistan, and particularly Samarkand, the urbanisation process is characterised by the rapid expansion of residential and industrial zones, increased population density, and intensified demand for infrastructure and services (Ma *et al.*, 2024). These developments mirror broader global patterns, yet they also manifest in specific environmental pressures, including deteriorating air quality, insufficient waste management, and increased emissions from transport and industry. Such ecological challenges have direct implications for the health of urban populations, as seen in the rising incidence of respiratory and cardiovascular diseases in Samarkand. Therefore, understanding the urbanisation process in Uzbekistan requires both a recognition of its global drivers and a nuanced analysis of its localised environmental and public health impacts.

Urbanization is marked by population density, economic diversification, and infrastructure development (Wang *et al.*, 2024). While cities serve as engines of productivity, they generate significant ecological footprints. Urban planning models—such as expansion, compact city frameworks, and mixed-use development—aim to address spatial and resource challenges. Sustainable design emphasises efficient land use, renewable energy integration, and green spaces to enhance resilience to climate change (Teleagă, 2020). Urbanisation significantly impacts biodiversity and resource quality (Stenin, Drozdovych and Soldatova, 2020), altering local climates via the urban heat island effect and disrupting hydrological cycles (Turemuratov *et al.*, 2024). Green infrastructure—urban forests, green roofs, and sustainable drainage—mitigates these effects by enhancing biodiversity, reducing heat, and improving air quality (Fedonyuk *et al*., 2020).

In Uzbekistan, cities like Tashkent, Samarkand, and Bukhara function as cultural and industrial centres. However, rapid urban growth stresses infrastructure and environmental sustainability. Urban expansion leads to ecosystem degradation and biodiversity loss through habitat destruction (Rexhepi *et al.*, 2024; Skliar *et al.*, 2024). Rising urban populations increase demand for water, energy, and raw materials, surpassing ecosystems' regenerative capacity. Many megacities face drinking water shortages (Asgerov *et al.*, 2022; Doroshkevich *et al.*, 2017), while growing energy needs drive up carbon emissions and contribute to climate change.

Environmental pollution is concentrated in cities, with air, soil, and water contamination from vehicles and industries (Fedoniuk *et al.*, 2021; Kaldybaev *et al.*, 2024). Air pollution in megacities frequently exceeds safety norms, harming public health and increasing respiratory and cardiovascular disease risks. Urban agglomerations also produce substantial waste, including municipal solid, plastic, and electronic waste, which is often disposed of in environmentally non-compliant ways. These materials accumulate in landfills, slowly decomposing and contaminating soil and groundwater (Mustafayeva and Tagiyev, 2023; Ongayev *et al.*, 2024). Poor waste management and insufficient recycling exacerbate the growth of toxic landfills.

Urbanisation further contributes to climate change through the urban heat island effect, where city temperatures surpass those of surrounding rural areas due to the heat-absorbing properties of urban infrastructure. This raises energy demands for cooling and increases greenhouse gas emissions. Environmental pollution is a central challenge of the 21st century. The UN emphasises sustainable urban development through Goal 11 of the 2030 Agenda: "Ensure that cities and human settlements are inclusive, safe, resilient and environmentally sustainable" (WHO, 2018). In response, global efforts support eco-friendly urban development via international initiatives, technological innovation, and public awareness. Priorities include promoting sustainable urban planning, enhancing environmental education, strengthening cooperation with ecological organisations, and improving social and health infrastructure to foster holistic well-being in urban environments.

The Republic of Uzbekistan is introducing numerous reforms to improve environmental conditions and promote environmental protection, initiating further improvements in the health of the population, and modernising the medical system, which in the long term will lead to a potential reduction in the growing groups and types of diseases. In particular, the New Uzbekistan Development Strategy for 2022-2026 sets important tasks in the 80th goal: protection of ecology and environment, improvement of ecological conditions of cities and regions, implementation of the national project "Green Region". Organisation of 'public parks' in cities and regional centres for every 50-100 thousand people.[2] The environmental condition of the Republic of Uzbekistan, namely the city of Samarkand, is a complex problem requiring interaction between economic, infrastructural and natural factors. Population growth and economic development create additional pressure on the ecosystem, but the introduction of modern technologies and environmentally oriented solutions can contribute to improving the situation, preserving the numerous natural resources and cultural and artistic heritage of the city for future generations (Tryhuba *et al.*, 2022).

To improve the environmental situation in the Republic of Uzbekistan, in particular in the city of Samarkand, it is important to develop a system of effective management of natural resources and introduce innovative technologies to reduce the use of chemical fertilisers in agriculture (Pinchoff, Mills, Balk, 2020). The development of eco-transportation, in particular the transition to electric transport and the development of public transport, will have an impact on reducing air pollution. There is also a need for an efficient waste management pathway that will ensure a reduction in litter accumulation and impact on soils. The development of plantations, in particular the creation of green barriers that would improve air quality and serve as natural sound insulation, is also important. Tong (2024) also highlighted this in his work, that the establishment of green barriers is an integral part of green city development strategies. These barriers aim to enhance living conditions and mitigate the negative impacts of urban environments on surrounding ecosystems. Green barriers such as street trees, forest plantations, green roofs and living fences are important components in reducing air pollution, improving microclimate conditions and enhancing biodiversity in urban areas (Shahini *et al.*, 2022). Popescu et al. (2024) noted that a very important advantage of green barriers is their ability to adsorb and filter harmful substances from the air. Plants absorb harmful substances such as

[2] Decree of the President of the Republic of Uzbekistan No. DP-60 "On the Development Strategy of the New Uzbekistan for 2022-2026". (2022). Online: https://lex.uz/docs/-5841063

carbon dioxide, nitrogen oxides and dust through their leaves and roots. This process helps to reduce negative impacts and improve air quality, which directly affects the health of residents.

Green barriers are also components of microclimate stabilisation. They reduce summer temperatures by creating natural shade and cooling the air through photosynthesis and evaporation, which is particularly important in urbanised areas where temperature fluctuations can be significant due to paved surfaces and limited green space. In their study, Peng *et al*. (2024) also emphasised that several important aspects should be taken into consideration when selecting plants for green barriers. It is important to choose species with well-developed foliage and dense crowns that have a high potential to filter and adsorb harmful substances. Plants should be adapted to stressful conditions such as pollution, lack of water and high temperatures, which are common in cities. The choice of plants should also be based on the climatic characteristics of the particular region. Due to its environmental and social benefits, the creation of green barriers in urban environments is a strategically important step towards sustainable development.

The 2022–2026 Development Strategy of New Uzbekistan explicitly emphasises environmental protection, reduction of emissions, and improvement of urban living conditions through initiatives such as the "Green Region" project and the establishment of public parks for every 50–100 thousand residents. Within this framework, industrial modernisation should prioritise energy efficiency upgrades and emissions control in sectors with the highest pollution output, particularly chemical and textile industries concentrated in urban areas. Feasibility studies indicate that retrofitting industrial facilities in Samarkand would require both domestic investment and international partnerships, particularly under the UN’s Sustainable Development Agenda 2030. Similarly, the implementation of green barriers, such as roadside plantations and urban green corridors, must consider local climatic conditions, plant species adapted to semi-arid environments, and the availability of irrigation resources. Cost-effective solutions include the expansion of the existing "Yashil Makon" (Green Space) initiative, which supports mass tree planting and public engagement. These measures are not only environmentally beneficial but also socially inclusive, as they align with broader national goals of improving public health, urban resilience, and ecological awareness.

In parallel, urbanisation creates a certain noise background. Noise affects the human body in different ways. In urbanisation, noise pollution increases significantly due to transport, construction work, industry and domestic sources. Noise exposure in urban areas often reaches levels that negatively affect the ecological balance and human health, in particular the cardiovascular system, mental health, and cognitive development in children. Similar results were obtained by Welch *et al*. (2023). Noise pollution in urban settings is classified as one of the aspects affecting quality of life, as high noise levels contribute to anxiety, stress, sleep disorders and even depression. Constant exposure to noise levels above 70 decibels contributes to an increased likelihood of cardiovascular disease. Exposure to noise increases heart rate acceleration and decreases heart rate variability, resulting in constant stress on the cardiovascular system. The same findings were noted by Radun *et al.* (2022), although the authors in their study focused more on examining the relationship between noise and anxiety in the population. The most important aspect of the effects of noise on the body is sleep disturbance. Noise-induced sleep disturbances significantly affect a person's general well-being and lead to impaired performance, increased irritability and impaired concentration. Noise pollution at night causes involuntary body reactions that promote the release of stress hormones, specifically cortisol, adrenaline. Sleep disturbances can have long-term consequences, among which are the risk of hypertension, heart attacks and strokes. Tong *et al.* (2023) emphasised the detrimental effect of noise on sleep quality, which is confirmed by the results obtained.

In addition to physical effects, noise is a serious factor that disturbs the psycho-emotional state of a person. This was written about by Ventriglio *et al*. (2020). The authors paid more attention to the impact of noise on mental well-being, describing its association with increased anxiety, depression, and irritability. Their study highlights that constant noise exposure negatively affects sleep and increases chronic stress, creating a vicious cycle where deterioration in psycho-emotional well-being leads to additional vulnerability to noise. Constant noise creates stressful conditions, reduces cognitive function and impairs overall psychological comfort. From an environmental perspective, noise pollution disrupts the ecosystem balance in cities. In addition to humans, animals, including birds and insects, which are very important in urban environments, react to noise pollution. The same results were achieved in the study by Qu *et al*. (2024). Noise alters the natural behavioural responses and communication cycles of some species, which can lead to a decline in their populations. Since cities are complex ecosystems, a disturbance of equilibrium in one ecosystem element caused by noise can have a cascading effect on all other components.

Installing sound-absorbing materials, creating green spaces that serve as a natural barrier to sound, and zoning cities so that noise sources are located away from residential areas can be effective methods of noise reduction. An important role is also played by informing citizens about the impact of increased noise levels on well-being and ways to minimise their negative impact in the modern urban environment. Similarly, Choi *et al*. (2023) noted that effective noise management in urban environments involves an integrated approach involving both architectural solutions and public participation. Thus, long-term exposure to noise increases the risks of cardiovascular, nervous and endocrine system disorders, causes psychological disorders and affects the well-being of the population. Consequently, reducing noise levels in urban areas is important to improve the overall health and lifestyle of residents.

The Impact of a Polluted Environment on the Level of Public Health

The city of Samarkand is located in the south-eastern part of the modern Republic of Uzbekistan. The city has long served as the most important centre on the Great Silk Road, connecting China with Europe, which contributed to the active development of industry. Samarkand not only played a key role in trade, but was also an important cultural and educational centre. Due to its fortunate location, the city became a meeting place for different cultures and civilisations, which facilitated the transfer of knowledge and ideas. The climate in Samarkand is characterised by hot, rather arid summers and cold winters. The average temperature reaches +35°C in summer and can drop to -10°C in winter. These climatic features are important for the lifestyle of the city's inhabitants and for the environment, and can influence various aspects of urban development and economy. The area of Samarkand city (land area) is 0.12

thousand square kilometres, and the population is 570.4 thousand people (according to the Statistics Agency under the President of the Republic of Uzbekistan (n. d.), as of 1 October 2022), which is 14% of the region’s share.

Intensive anthropogenic activity of the city has influenced the ecological component of the settlement. Significant level of industrial development, numerical concentration of population, prevalence of construction and transport modes of transport contribute to the increase of pressure on the environment and, accordingly, changes in microclimate.

The modern infrastructure of Samarkand consists of transport, industrial and agricultural sectors, which ensure the economic stability of the city. However, the presence of outdated technologies in the industrial and agricultural sectors contributes to the increasing pressure on the ecological system. The main sources of pollution are motor vehicle emissions, industrial enterprises and excessive use of pesticides in agriculture. In addition, the city of Samarkand has an underdeveloped waste management system, which contributes to the accumulation of rubbish and pollution of soil and water sources. The Zeravshan River remains the main source of water supply for Samarkand, but its ecological condition is deteriorating due to overexploitation and pollution by agricultural chemicals. Babakhulov *et al*. (2022) also noted that over-exploitation of water resources, as well as pollution from agricultural practices, lead to deterioration of water resources and a decrease in biodiversity in the region. Water levels in the Zeravshan River are gradually declining, leading to droughts and water shortages for urban and agricultural needs. Samarkand also faces air pollution problems, particularly due to dust storms typical of the region, as well as emissions from cars and industrial plants. The concentration of particulate matter in the air is high, which negatively affects the health of the city's residents, particularly contributing to respiratory diseases.

Medico-geographical assessment is an important component for analysing the relationship between the level of health and mortality of the population and the ecological state of the environment. This type of assessment identifies the role of geographical, climatic and environmental factors in morbidity and health. In the city of Samarkand, the medico-geographical assessment was based on the analysis of data from 12 family clinics in the locality.

In the process of the study, all classes and types of diseases and the general level of health of the population were analysed, taking into account data from the World Health Organisation annual reports (2023). For example, while the incidence rate in 2014 was 483.6 cases per 1,000 individuals, it increased to 594.3 in 2018 and reached 1,184.3 cases per 10,000 individuals in 2021. This adjusted denominator reflects a more plausible scale for population-level morbidity, indicating a substantial rise in disease incidence over time. It is important to note that the rate of circulatory system diseases among the population of Samarkand also demonstrated a sharp increase, from 7.6 cases per 1,000 individuals in 2014 to 51.5 cases per 10,000 individuals in 2021, highlighting the growing burden of cardiovascular conditions potentially linked to environmental factors.

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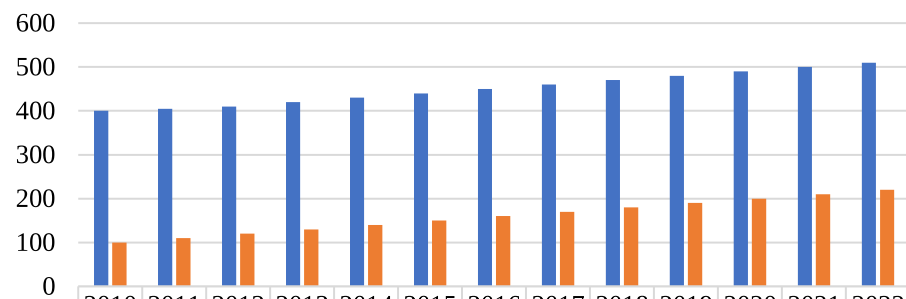
During the implementation of the study, it was noted that respiratory diseases are the most frequent in the total morbidity of the population of Samarkand city. The respiratory system is key in protecting the organism from certain factors that may contribute to the deterioration of the general health of the person, in particular from the impact of the polluted environment, and, accordingly, the state of the respiratory system is a key role in the context of the general level of health of the population. In addition, there is an increasing trend in respiratory pathologies in 2022: while in 2010 there were 78.1 cases per 1000 people, in 2021 there were 138.8 cases per 1000 people (Figure 1).



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Incidence of respiratory system diseases in Samarkand region	400	405	410	420	430	440	450	460	470	480	490	500	510
Incidence of respiratory system diseases in Samarkand city	100	110	120	130	140	150	160	170	180	190	200	210	220

Figure 1: Number of cases of respiratory diseases in the Samarkand region, in particular in the city of Samarkand (per 1000 population) [*Source*: Statistics Agency under the President of the Republic of Uzbekistan (2023)]

Respiratory diseases can be caused by various factors, including air pollution, climate change and local environmental conditions. It is noted that the air quality in Samarkand is worse than in other regions of the country, which has a significant negative impact on the health status of the population. Thus, the study indicated a link between high levels of particulate matter in the air and deterioration of the respiratory system. In general, the climatic condition of the region favours the increased occurrence of allergic reactions and chronic diseases of the respiratory system. Hot and dry seasons, typical for the city of Samarkand, lead to an increase in dust in the air, which is an important factor in increasing the risk of diseases of the respiratory system.

Thus, the number of cases of respiratory diseases is increasing every year. This process indicates the presence of serious problems related to the quality of atmospheric air, climatic features of the region, lifestyle of the population and accessibility of medical care.

Along with the spread of respiratory diseases, there is a clear increase in cases of diseases of the circulatory system. While in 2014 the rate was 7.6 cases per 1000 population, in 2021 it was 51.5 cases per 1000 population. The rapid development of diseases of the circulatory system covers a wide range of pathologies, including

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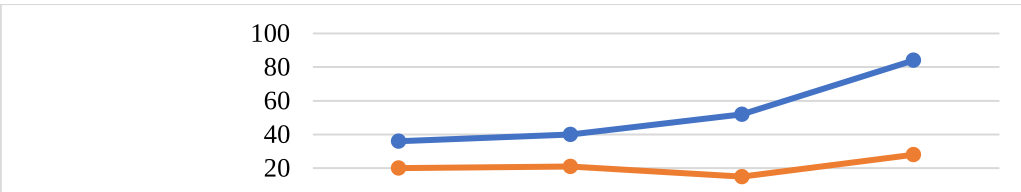
arterial hypertension, atherosclerosis, myocardial infarctions and strokes. These diseases are an important part of the epidemiological burden on the population and are often accompanied by increased mortality and disability.

An important aspect that contributes to the spread of circulatory diseases is environmental pollution, in particular emissions of harmful substances such as PM2.5 and PM10 particles, which have a significant impact on the development of cardiovascular diseases. High levels of harmful substances in the air, observed in the city of Samarkand, can lead to inflammatory processes in blood vessels, which significantly increase the likelihood of developing cardiovascular pathologies such as atherosclerosis. This was also written about by Nesterova *et al*. (2020). The climatic conditions of the region are important in the process of forming the epidemiological situation. Hot and dry climates can contribute to dehydration, which further increases the risk of cardiovascular diseases. In hot conditions, blood thickens, which increases the load on the heart and can lead to thrombosis (Figure 2).



	2005	2010	2015	2020
Samarkand region	36	40	52	84
Samarkand city	20	21	15	28

Figure 2: The number of cases of diseases of the circulatory system in the Samarkand region, in particular in the city of Samarkand (per 1000 population) [*Source*: Statistics Agency under the President of the Republic of Uzbekistan (2023)]

Atmospheric air pollution, noise, vibrations, and living conditions of a large part of the population, as well as a list of other factors, have an impact on the general state of the cardiovascular system and, accordingly, increase the risk of developing such diseases. In general, cardiovascular diseases are now considered to be one of the largest causes of death in humans. Similarly, Rajput *et al*. (2024) noted the magnitude of cardiovascular disease. The World Health Organisation (2018) estimated that cardiovascular disease is the cause of death for about 16 million people in the world, accounting for 31% of all deaths annually. The increase in risk factors in the modern urban space is responsible for the increase in the incidence of cardiovascular diseases, as environmental pollution, particularly atmospheric air pollution, is linked to the possibility of risk of these diseases directly.

During the study, analyses were conducted to identify correlations between environmental factors and the incidence of diseases within the population. A linear correlation coefficient was used. The linear correlation coefficient can have values from -1 to +1; respectively, the relationships between characteristics can be strong (close) or weak. Their criteria are assessed using the Cheddock scale: $0.1<|r_{xy}|<0.3$ –

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weak; $0.3<|rxy|<0.5$ – moderate; $0.5<|rxy|<0.7$ – marked; $0.7<|rxy|<0.9$ – high; $0.9<|rxy|<1$ – very high (Table 1).

Table 1: Correlation matrix

	Y	Y_1	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Y	1								
Y_1	0.742	1							
X_1	-0.388	-0.035	1						
X_2	-0.682	-0.397	0.072	1					
X_3	-0.246	-0.305	0.161	-0.263	1				
X_4	-0.605	-0.463	0.334	0.121	-0.008	1			
X_5	-0.739	-0.423	0.072	0.925	-0.053	0.127	1		
X_6	-0.674	-0.441	0.504	0.401	0.332	0.375	0.378	1	
X_7	-0.845	-0.551	0.397	0.742	0.129	0.377	0.729	0.845	1

Note: Y – Total emissions (thousands of tons); Y_1 – Emissions from mobile sources (thousands of tons); X_1 – Mortality (per 1000 people); X_2 – Respiratory diseases (per 1000 people); X_3 – Neoplasms (per 1000 people); X_4 – Eating disorders and metabolic disorders, as well as diseases of the endocrine system (per 1000 people); X_5 – Diseases of the hematopoietic organs and blood, certain disorders related to the immune mechanism (per 1000 people); X_6 – Diseases of the cardiovascular system (per 1000 people); X_7 – General morbidity (per 1000 people).

Table 1 summarises the overall correlation between the factors obtained (Table 2). The presented correlation matrix shows that there is a relationship between respiratory diseases (X_2) and harmful substances in the atmosphere, diseases related to the endocrine system (X_4), as well as harmful substances emitted into the atmosphere, heart diseases and the same factor (Y). There is also an association between cardiovascular diseases and immune system diseases (X_5), air pollutants (Y) and cardiovascular diseases (X_6), and air pollutants (Y) and general morbidity (X_7). These results support the existence of an association between these factors.

Table 2: Correlation between selected factors

No.	*Factors*	*Correlation coefficient*	*Significance*	*Confidence interval for r*
1	Y and X_1	-0.388	not significant	(-1;0.351)
2	Y and X_2	-0.682	significant	(-1;-0.086)
3	Y and X_3	-0.246	not significant	(-1;0.395)
4	Y and X_4	-0.605	significant	(-1;-0.225)
5	Y and X_5	-0.739	significant	(-1;-0.11)
6	Y and X_6	-0.674	significant	(-1;-0.0147)
7	Y and X_7	-0.845	significant	(-1;-0.279)

It is also evident that there is no connection between harmful substances (Y) emitted into the atmosphere, mortality rate (X_1) and neoplasms (X_3). For forecasting purposes, an exponential smoothing method was applied, calculated using the recursive formula (1), as presented in table 3. The initial value S_0 was taken as the arithmetic mean of the first five values in the time series:

$S_0 = (42.81 + 42.382 + 42.959 + 42.81 + 42.074)/5 = 42.61.$

Table 3: Forecast data using exponential smoothing

t	*y*	S_t	*Formula*	$(y\text{-}S_t)^2$
2010	42.81	42.749	$(1-0.3)*42.81+0.3*42.61$	0.00371
2011	42.382	42.492	$(1-0.3)*42.382+0.3*42.75$	0.0121
2012	42.959	42.819	$(1-0.3)*42.959+0.3*42.49$	0.0196
2013	42.81	42.813	$(1-0.3)*42.81+0.3*42.82$	0.0000
2014	42.074	42.296	$(1-0.3)*42.074+0.3*42.81$	0.0491
2015	41.711	41.886	$(1-0.3)*41.711+0.3*42.3$	0.0308
2016	42.476	42.299	$(1-0.3)*42.476+0.3*41.89$	0.0313
2017	42.034	42.114	$(1-0.3)*42.034+0.3*42.3$	0.00633
2018	41.834	41.918	$(1-0.3)*41.834+0.3*42.11$	0.00703
2019	40.161	40.688	$(1-0.3)*40.161+0.3*41.92$	0.278
2020	38.773	39.348	$(1-0.3)*38.773+0.3*40.69$	0.33
2021	38.46	38.726	$(1-0.3)*38.46+0.3*39.35$	0.0709
2022	38.39	38.491	$(1-0.3)*38.39+0.3*38.73$	0.0102

The smoothing method in the context of forecasting takes into account the effect of harmful emissions much better than the methods used in regression analysis. The equation is as follows (2):

$$S(t+1) = S(t)(1-\alpha) + \alpha Y(t), \tag{2}$$

where S(t) is the forecast made at time t; S(t+1) influences the forecast for a certain period that immediately follows time t.

$$S\,(13+1) = 38.491(1-0.3) + 0.3 * 38.39 = 38.461.$$

Formula for calculating standard error (3):

$$e_t\sqrt{\frac{\sum(y_i - S_{i-1})^2}{n-1}}, \tag{3}$$

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Where *i*=(t-2, t).

$$e_t\sqrt{\frac{0.849}{13-1}} = 0.266.$$

Linear equation: y = bt + ay = bt + a. The parameters of the equation are found using the least squares method. The system of least squares equations (4, 5):

$$\mathrm{an} + \mathrm{b}\sum \mathrm{t} = \sum \mathrm{y}, \tag{4}$$

$$\mathrm{a}\sum \mathrm{t} + \mathrm{b}\sum \mathrm{t}^2 = \sum \mathrm{yt}. \tag{5}$$

For the research data, the system of equations has the following form:

$$13\mathrm{a} + 26208\mathrm{b} = 536.87,$$
$$26208\mathrm{a} + 52835510\mathrm{b} = 1082267.01.$$

From the first equation, it is worth expressing a and substituting it into the next equation. It is: a=827.516; b=-0.39. The tendency of the equation:

$$\mathrm{y} = -0.39 \times \mathrm{t} + 827.516.$$

The root-mean-square error of the predicted indicator (5, 6) is being determined:

$$\mathrm{Uy} = \mathrm{y}_{\mathrm{n+L}} \pm \mathrm{K}, \tag{5}$$

$$\mathrm{K} - \mathrm{t_a} \times \mathrm{S_y} \times \sqrt{1 + \frac{1}{\mathrm{n}} + \frac{3(\mathrm{n}+2\mathrm{L}-1)^2}{\mathrm{n}(\mathrm{n}^2-1)}}, \tag{6}$$

where L is the period of reference; yn+L is the point forecast for the model at the (n+L)-th moment in time; n is the number of observations in the time series; Sy is the standard error of the predicted indicator; T_{table} – the tabular value of the student's criterion for the significance level α and for the number of degrees of freedom equal to n – 2. Using the Student's table, we find T_{table} (7):

$$\mathrm{Ttable}(\mathrm{n} - \mathrm{m} - 1; \alpha/2) = (7; 0.05) = 2.593. \tag{7}$$

Point forecast: t=2023: y(2023)=-0.39*2023+827.516=38.57:

$$\mathrm{K}_1 = 2.593 \times 0.85\sqrt{1 + \frac{1}{13} + \frac{3(13+2\times1-1)^2}{13(13^2-1)}} = 2.56,$$
$$38.57 - 2.56 = 36.01;\ 38.57 + 2.56 = 41.13.$$

Interval forecast: t=2023: (36.01;41.13).
Point forecast: t=2024: y(2024)=-0.39×2024+827.516=38.18:

$$\mathrm{K}_2 = 2.593 \times 0.85\sqrt{1 + \frac{1}{13} + \frac{3(13+2\times2-1)^2}{13(13^2-1)}} = 2.64,$$
$$38.18 - 2.64 = 35.54;\ 38.18 + 2.64 = 40.82.$$

Interval forecast: t=2024: (35.54;40.82).
Point forecast: t=2025: y(2025)=-0.39×2025+827.516=37.79:

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$$K_3 = 2.593 \times 0.85\sqrt{1 + \frac{1}{13} + \frac{3(13+2\times 3-1)^2}{13(13^2-1)}} = 2.73,$$
$$37.79 - 2.73 = 35.06;\ 37.79 + 2.73 = 40.52.$$

Interval forecast: t=2025: (35.06;40.52).
Point forecast: t=2026: y(2026)=-0.39×026+827.516=37.4.

$$K_4 = 2.593 \times 0.85\sqrt{1 + \frac{1}{13} + \frac{3(13+2\times 4-1)^2}{13(13^2-1)}} = 2.82,$$
$$37.4 - 2.82 = 34.58;\ 37.4 + 2.82 = 40.22.$$

Interval forecast: t=2026: (34.58;40.22).
Point forecast: t=2027: y(2027)=-0.39×2027+827.516=37.01.

$$K_5 = 2.593 \times 0.85\sqrt{1 + \frac{1}{13} + \frac{3(13+2\times 5-1)^2}{13(13^2-1)}} = 2.92,$$
$$37.01 - 2.92 = 34.09;\ 37.01 + 2.92 = 39.93.$$

Interval forecast: t=2027: (34.09;39.93) (Table 4).

Table 4: A forecast of harmful substances expected to be emitted into the atmosphere of Samarkand, developed for the period up to 2027, which may be emitted into the atmospheric air of the city of Samarkand for the period up to 2027

Years	*Forecast*	*Linear trend*	*Interval forecast*
2023	38.57	38.546	(36.01;41.13)
2024	38.18	38.156	(35.54;40.82)
2025	37.79	37.766	(35.06;40.52)
2026	37.4	37.376	(34.58;40.22)
2027	37.01	36.986	(34.09;39.93)

In this case, for each time t, the average value of Y decreases by 0.39 units. Based on this trend, it can be concluded that there is a consistent decline in Y over the study period. The regression equation estimates obtained are deemed suitable for forecasting future values of variable Y. The least squares method provides accurate parameter estimates, which improve the quality of forecasts and provide a basis for making informed decisions to control variable Y.

A sociological survey conducted in November-December 2022 in Samarkand city and three subordinate settlements — Kimyogarlar, Farhod and Khishrau (Sulim), was aimed at studying the perception of residents of different districts of the city about the environmental situation, and the impact of environmental pollution on their health. The results of the survey showed that residents have an idea about the environmental situation in their neighbourhood. However, the majority of respondents (45%) receive insufficient information, which indicates ineffective communication between the authorities and residents and, in general, a lack of awareness of existing sources of information (Figure 3). Growing awareness can be a powerful incentive to improve the environmental situation.

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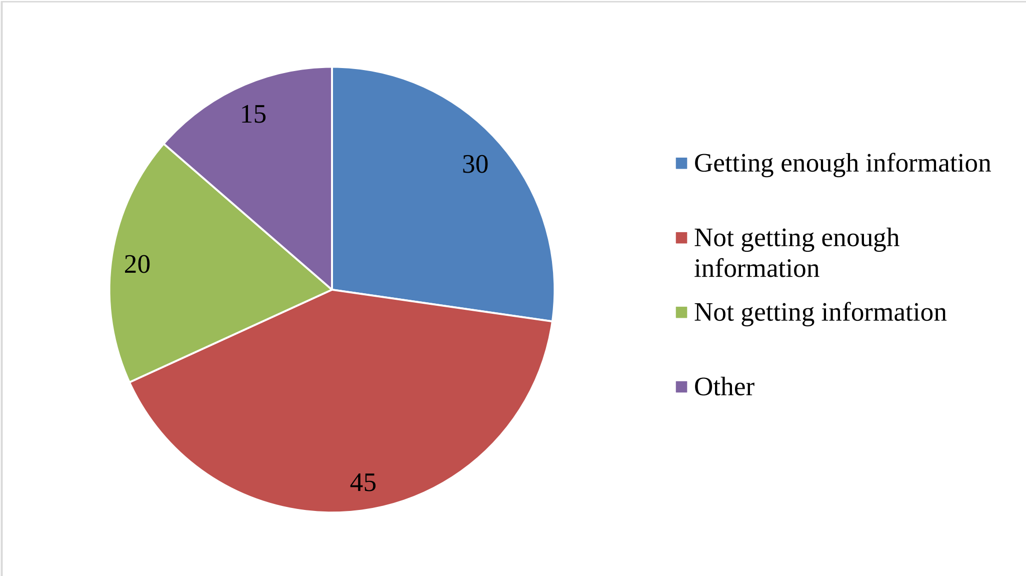

Figure 3: Obtaining information about the environmental situation

The air quality assessment showed that 10% of respondents rated the air quality as very good, while 25% thought that the air was bad. This result indicates that the population is aware of the level of air pollution, therefore, the satisfactory assessment (45%) indicates that there is a huge room for improvement, especially in the context of increasing pollution levels (Figure 4).

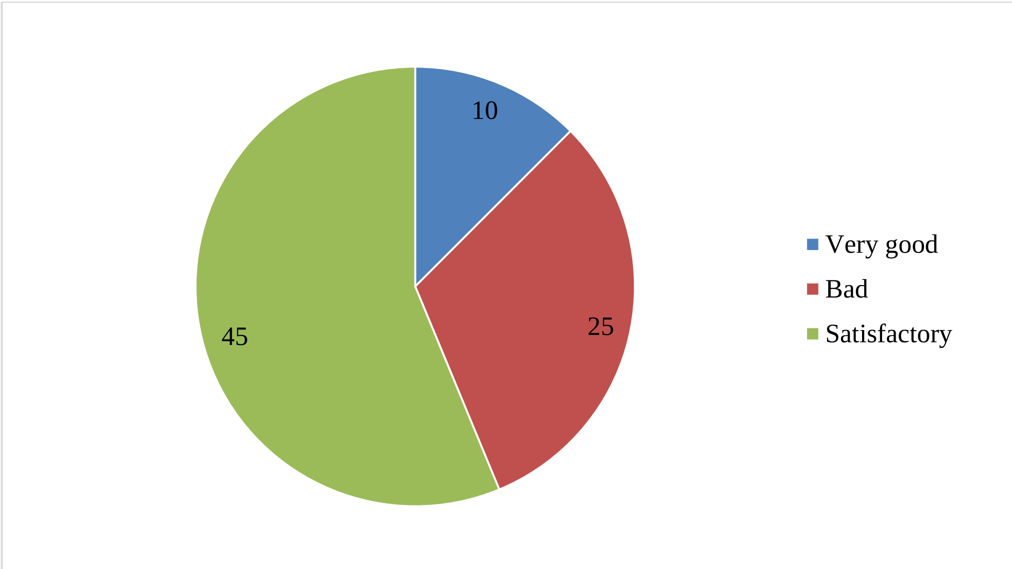

Figure 4: Assessment of air pollution levels

The willingness of residents to participate in local environmental initiatives is a key indicator of community activity and awareness of environmental issues. The high percentage of respondents (50%) who expressed a desire to participate in such initiatives indicates that the population is not only aware of environmental challenges, but is also ready to act to address them (Figure 5). This result is extremely important, since active public involvement can significantly affect the success of environmental projects and become the basis for sustainable development and improved living conditions. In the context of global environmental problems, including climate change and pollution, local initiatives can become a catalyst for positive change.

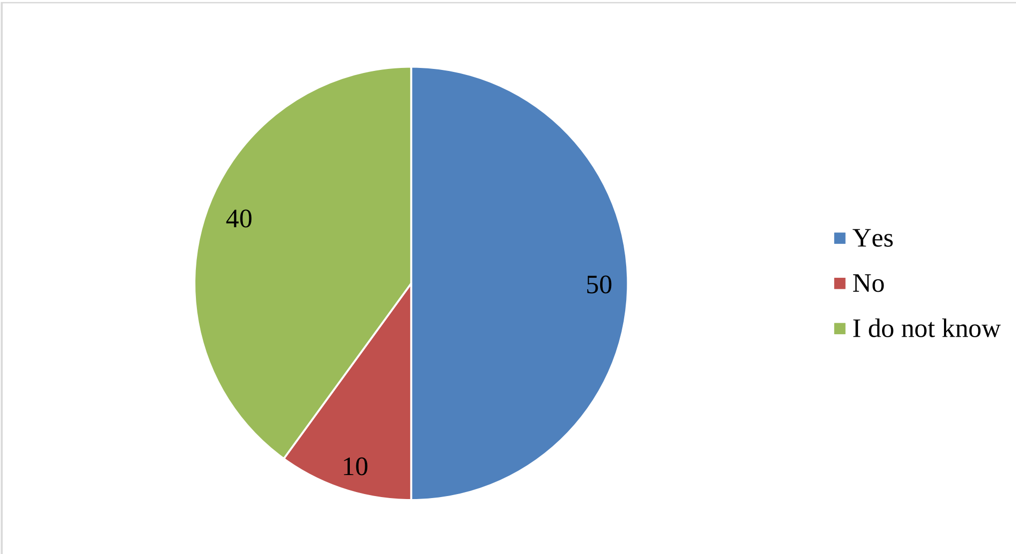

Figure 5: Willingness to participate in environmental initiatives

To make effective use of the willingness expressed by 50% of respondents to participate in environmental initiatives, policymakers should consider institutionalising participatory environmental governance mechanisms. This can be realised by including mechanisms for public involvement in municipal and regional environmental strategies. For example, the establishment of “green councils” or local environmental committees composed of residents, civil society representatives and local officials can facilitate the joint development of activities aimed at addressing the environmental problems of a particular neighbourhood.

In addition, policy instruments such as environmental volunteering programs, public monitoring platforms (e.g., mobile apps for pollution reporting), and “citizen science” projects can formalise and support citizen participation. Legal and financial incentives - for example, tax reductions on green household practices or grants for grassroots initiatives - can further enhance participation. Incorporating environmental education and awareness campaigns into local school curricula and public information systems also promotes long-term behaviour change. Thus, the institutional design of environmental policy should recognise citizen willingness as a resource that needs to be mobilised through structured, inclusive and scalable mechanisms, ensuring that environmental governance is not only top-down but also community-driven.

The revealed readiness of the population to participate in environmental initiatives not only emphasizes their desire to improve the environmental situation, but also leads to the possibility of implementing joint projects that can lead to significant changes in the environment. It also indicates the possibility of forming active communities that can effectively counteract environmental problems at the local level.

Thus, although in the 21st century there is a rapidly increasing negative impact of the urbanization process on the environment due to increased pollution, loss of biodiversity, changes in natural ecosystems and resource consumption, which contributes to a significant increase in waste, changes in temperature conditions and disruption of the natural balance, the population of Samarkand city and subordinate settlements are ready to make efforts to change the prevailing conditions and improve the ecological state.

In their study, Se et al. (2024) emphasised that urbanisation, particularly in China, has caused significant pressure on natural resources and the infrastructure of cities. Although infrastructure provision in the city of Samarkand is at a sufficient level, the impact of environmental conditions on the health of the population is highlighted, indicating the specificity of the local context. Urbanisation strongly affects the well-being and standard of living of the population. The same conclusion was reached in the work by Gong et al. (2012), and the authors noted the negative impact of urbanisation on the environmental condition of urban space, and the study of Tripathi and Maiti (2023) highlighted the impact of urbanisation on the health status of the population.

Soil pollution in urbanisation is a serious environmental problem caused by increased levels of heavy metals, chemicals, and industrial wastes in urban soils. Urbanisation contributes to this process through heavy transport, construction, pesticide use and the growth of industrial areas (Kunakh *et al.,* 2021). Heavy metals such as mercury, cadmium, and lead accumulate in soils, altering their structure and reducing the biodiversity of microbial communities that are important for fertility. Soil pollution negatively affects the general health of the population and the stability of ecosystems, so the process of soil pollution requires certain solutions in urban management to protect natural resources and improve the overall health indicators of city residents. The same conclusion was reached by Hu *et al.* (2024) in their study. The authors noted that the process of urbanisation contributes to the increase of heavy metal levels in the soil, which negatively affects the overall health of ecosystems and their biodiversity.

Ecology is closely related to the environment and mental health, as living conditions directly affect the psycho-emotional state of people. Air pollution, noise, loss of green space and climate change can cause stress, anxiety, and depression. Positive environmental conditions, such as access to natural areas and quality habitat, promote better mental health. Similar findings were reported by Gugsa *et al*. (2023), who emphasised the need for global cooperation in the field of ecology and mental health, as environmental challenges such as climate change, biodiversity loss and pollution directly affect people’s psycho-emotional well-being.

This study's results highlight a definitive and statistically validated correlation between environmental deterioration, specifically air pollution, and negative health outcomes in Samarkand, marked by significant rises in respiratory and cardiovascular disease incidence. The poll results indicate a populace cognisant of environmental hazards and inclined to participate in local projects, underscoring the possibility for participatory environmental governance. These findings indicate an immediate necessity for cohesive policy measures aimed at reducing emissions, reforming urban design, and enhancing public health preparedness. Future studies should broaden the spatial and temporal dimensions of analysis to corroborate these findings in other parts of Uzbekistan and integrate longitudinal health data to enhance causal inference.

Conclusions

This study confirmed that rapid urbanisation in Samarkand has resulted in significant ecological degradation, including increased emissions of hazardous substances, poor air quality, and insufficient waste and water management—all of which directly correlate with rising morbidity and mortality rates. The findings demonstrated particularly strong associations between air pollution and the incidence of respiratory, cardiovascular, and endocrine system diseases, supported by both statistical analysis (e.g., correlation coefficient of 0.845) and sociological survey results. These trends indicate that environmental conditions are a critical determinant of public health in urban Uzbekistan.

The empirical evidence provides a solid foundation for formulating targeted policy recommendations. First, the modernisation of outdated industrial infrastructure in Samarkand is essential. Policy implementation should prioritise emission-reduction technologies in key polluting sectors, such as transport and light industry, where concentrations of pollutants are highest. Second, green infrastructure initiatives—such as expanding the "Yashil Makon" (Green Space) programme—should be geographically concentrated in the most polluted districts (e.g., Kimyogarlar), which the survey identified as environmentally and demographically vulnerable.

The study also highlights the necessity of localised environmental governance mechanisms. Policy makers should institutionalise community engagement in environmental decision-making, for example, by establishing district-level “green councils” that align public participation with municipal planning. Additionally, integrating environmental education into the public health system and school curricula would contribute to long-term behavioural change and improve ecological awareness.

Finally, the use of predictive models (e.g., exponential smoothing) revealed a projected continuation of harmful emission trends through 2027. This predictive insight underscores the urgency for region-specific interventions, including stricter emissions monitoring and a strategic realignment of health services to address pollution-related diseases. In this way, the findings not only advance academic understanding but also inform actionable, location-sensitive policy solutions for environmental and public health sustainability in Samarkand.

The limitation of the study lies in the insufficient amount of relevant statistical data on environmental pollution, mortality rate and health status of the population. The limited period of the study may not reflect long-term trends in environmental change, as environmental problems may be seasonal and highly variable due to technological developments and political situations. Also, while the study draws significantly on empirical data and illustrative examples from Samarkand, it is important to recognise that regional disparities across Uzbekistan, particularly in terms of industrialisation levels, climatic conditions, and healthcare infrastructure, may limit the generalizability of the findings. Samarkand's relatively advanced development and infrastructural base may not reflect the conditions in other provinces such as Karakalpakstan or Khorezm. Consequently, any conclusions derived from this region should be interpreted with caution when applied to the national context. Future research should aim to conduct comparative analyses across multiple regions to better capture the heterogeneity of spatial, technological, and socioeconomic factors influencing architectural design and AI integration throughout Uzbekistan.

Prospects for further research on the environmental situation in the Republic of Uzbekistan may include long-term studies to monitor changes in environmental conditions and their impact on the health of the population.

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Appendix 1

The questionnaire survey included the following questions:

1. How do you rate the air quality in your neighbourhood? (Possible answers: very good, satisfactory, unsatisfactory, poor).
2. Do you feel the impact of pollution on your health? (Possible answers: yes, no, don't know).
3. What exactly is the effect of the polluted environment on your health? (Open-ended question).
4. How often do you get information about the environmental situation in your neighbourhood? (Possible answers: very often, often, not often, do not receive).
5. Are you ready to participate in local environmental initiatives? (Possible answers: yes, no, don't know).

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*	*Author 5*
Conceived and designed the research or analysis	Yes	Yes	No	No	No
Collected the data	Yes	Yes	No	No	Yes
Contributed to data analysis & interpretation	No	Yes	Yes	Yes	No
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes
Critical revision of the article/paper	Yes	No	Yes	Yes	No
Editing of the article/paper	No	No	No	Yes	Yes
Supervision	No	No	Yes	No	No
Project Administration	No	Yes	No	No	No
Funding Acquisition	No	No	No	No	No
Overall Contribution Proportion (%)	20	25	20	20	15

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Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

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The author(s) solemnly declare(s) that this research has not involved the plants for experiment and field studies. Some contexts of plants are also indirectly covered through literature review. Thus, during this research the author(s) obeyed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

Research Involving Local Community Participants (Non-Indigenous) or Children
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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