



ORIGINAL ARTICLE

Air Quality Assessment in the Republic of Tajikistan and Improving the Monitoring System

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ABSTRACT

The article presents studies of the current state of the system of environmental monitoring and assessment of atmospheric air quality in the conditions of Tajikistan. Some shortcomings have been identified in the organization of monitoring of atmospheric air quality, the level of equipment with modern automatic systems, the coverage of the country by atmospheric observation networks, the efficiency of emissions of pollutants into the atmosphere and methods for determining the quality of atmospheric air, taking into account various restrictions. Based on the research conducted, taking into account international experience, measures to improve the environmental monitoring system using modern methods and computer models are recommended.

Keywords: environmental monitoring; atmospheric air quality; industrialization; “green city”; air pollution; pollutants; regulation; maximum permissible concentration; Internet of Things (IoT); blockchain.

1 | INTRODUCTION

The deterioration of atmospheric air quality caused by emissions from the energy sector, industry, and transport has a negative impact on both public health and the environment as a whole. Therefore, air pollution is recognized by the WHO as one of the most serious environmental threats in the world (*World Health Organization, n.d.*), which has a number of negative effects on human health, leading to the formation and progression of various pathologies of the cardiovascular, respiratory, and endocrine systems, allergic reactions, oncopathology, etc. (*Dominski et al., 2021*). In Tajikistan, air pollution can cause significant damage not only to human health, but also economic losses due to reduced crop yields and accelerated glacier melting. In this regard, constant monitoring of atmospheric air quality is a critical task at both the national and global levels.

To regulate atmospheric air pollutants based on their hazard class, there are “WHO Global Air Quality Guidelines” for Ozone (O₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), carbon monoxide (CO) and particulate matter (PM_{2.5} and PM₁₀), which each country uses to independently establish its maximum permissible concentrations (MPC) for harmful substances by determining the maximum hourly, daily average, and annual average concentrations of pollutants (*World Health Organization, 2021*).

Based on this, many countries have established MPCs for various pollutants at the legislative level and are implementing a set of measures aimed at strengthening control over air quality and reducing pollution levels. The greatest success in the field of air quality control has been achieved in Europe, the USA, and China, where residents can obtain up-to-date information on air quality in real time (*Pozdnyakov et al., 2023*). However, developed and developing countries have different capabilities for monitoring atmospheric air quality and covering their territories with a network of atmospheric observation stations.

For example, air quality monitoring in Central Asian countries is carried out in each country, and the number of monitoring stations, cities covered by monitoring, controlled pollutants, air pollution indicators, and public information vary (*Analysis of Air Quality Monitoring in Central Asia, 2021*).

The Republic of Tajikistan has a unified state system of environmental monitoring at the legislative level. Monitoring of atmospheric air quality is carried out in accordance with the laws of the Republic of Tajikistan “On Hydrometeorological Activities” dated July 23, 2016, No. 1345 and “On Atmospheric Air Protection” dated December 28, 2012, No. 915, by the Hydrometeorological Agency of the Environmental Protection Committee under the Government of the Republic of Tajikistan, and the results of atmospheric air pollution levels in five cities are published daily in electronic form on the agency's website (*Hydrometeorological Agency of the Committee for Environmental Protection under the Government of the Republic of Tajikistan, n.d.*). In addition, there is one independent automatic monitoring station on the territory of the US Embassy in Dushanbe (*US Embassy in Dushanbe, n.d.*).

However, according to the World Bank, the republic lacks a comprehensive air quality monitoring system, i.e., stations are unevenly distributed throughout Dushanbe and other areas to cover various sources (background, traffic, industry, etc.), and data availability is insufficient to obtain the necessary information on atmospheric air quality (*World Bank, 2023*).

In connection with the accelerated industrialization of the country (*Accelerated Industrialization Program of the Republic of Tajikistan for 2020–2025, 2020*), the implementation of the “Green City” concept in Dushanbe, which provides for improving the ecological situation in the city, increasing the quality and reliability of environmental assessments, and improving public information through the use of digital technologies (*Green City Action Plan, 2022*), and forecasting the situation with sand and dust storms, which in recent years have been covering almost the entire territory of the country more frequently (*National Action Plan of the Republic of Tajikistan for the Prevention and Mitigation of Sand and Dust Storms for 2022–2030, 2021*), there is a growing need to improve air quality monitoring.

Consequently, researching atmospheric air quality with the aim of reducing the impact of air pollution on human health and the economy requires a comprehensive approach involving all stakeholders (*Haqdođ et al., 2023*) and the use of modern automated systems based on models and computer technologies (*Statistical Yearbook of the Republic of Tajikistan, 2022; Liu et al., 2020*).

Therefore, analyzing the state of atmospheric air quality monitoring in order to improve its effectiveness using modern methods and technologies is a pressing task.

2 | SUBJECT AND METHODS OF RESEARCH

Air quality monitoring is an activity that includes observation, collection, storage, recording, systematization, generalization, processing, and analysis of data.

Air quality is assessed both on the basis of instrumental measurements using stationary, route, and mobile observation posts, and on the basis of calculated data using modern computer models (*Pozdnyakov et al., 2023*).

Currently, the organization and implementation of monitoring of atmospheric pollution levels based on physical and chemical indicators in the Republic of Tajikistan is carried out using five stationary observation points in the cities of Dushanbe, Bokhtar, Tursunzade, Khujand, and Guliston (Fig. 1). The monitored pollutants are PM_{2.5}, PM₁ and PM₁₀ suspended particles (dust), CO, SO₂, NO_x, NO₂, HF, etc. Information is collected, processed, and stored both manually and automatically, and annual reviews of atmospheric air quality are compiled. The degree of atmospheric air pollution is assessed by comparing the concentration of impurities mg/m³ with the maximum permissible concentration (MPC).

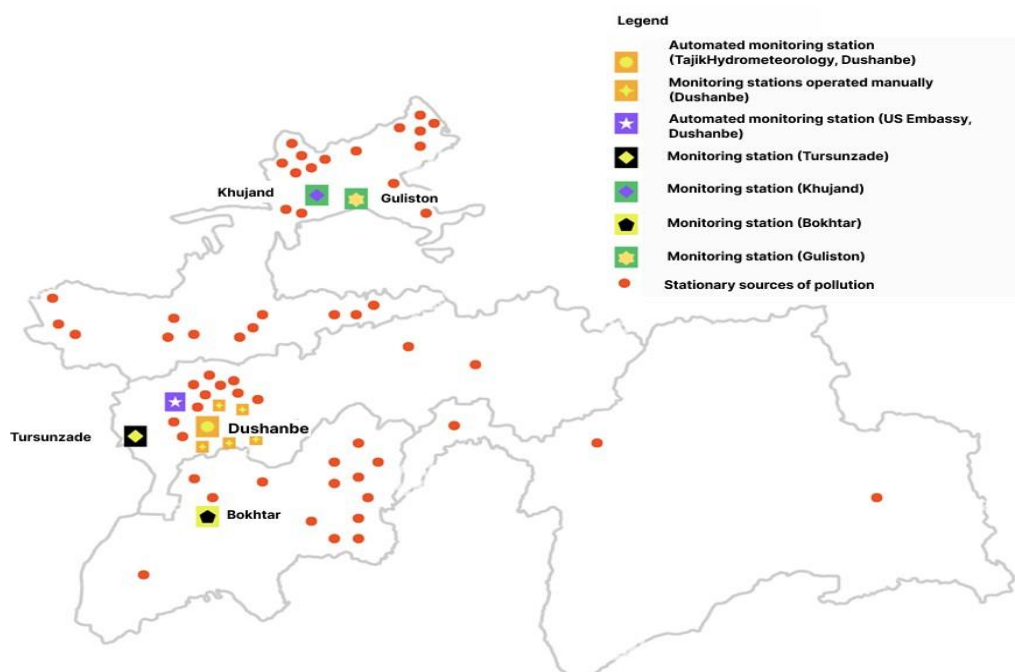


Fig. 1. Location of monitoring stations and stationary sources of pollution in the Republic of Tajikistan

The existing air quality control system in Tajikistan relies on a limited number of stationary observation posts, which makes it impossible to obtain objective information about pollution on a city-wide scale. In these conditions, there is a growing need for digital technologies capable of ensuring continuous and distributed collection of environmental data. Some of the most promising areas are the Internet of Things (IoT) and blockchain, which together can create a transparent and reliable air quality monitoring system.

2.1 | Analysis of research results

Data from monitoring stations located in Dushanbe and global models based on satellite measurements and model estimates were used to analyze the current state of air quality. Data on the distribution of pollution sources and the formation of the average annual concentration of PM_{2.5} in Dushanbe (*World Bank, 2023*) (Fig. 2) often exceeds the recommended values of the World Health Organization (*World Health Organization, 2021*), which indicates a high burden on the healthcare system and requires the introduction of new technological solutions in the field of atmospheric air monitoring.

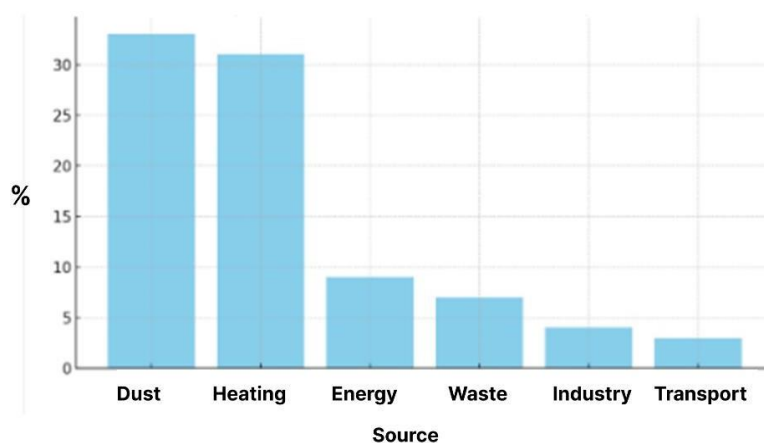


Fig. 2. Distribution of PM_{2.5} sources in Dushanbe

An analysis of seasonal changes in pollutant concentrations (Fig. 3) shows that PM_{2.5} and PM₁₀ concentrations peak in the winter months (November–February) and decrease in the spring and summer months, which is associated with increased use of heating and coal combustion during the cold months. Concentrations of NO₂ and SO₂ are also higher in the winter months due to emissions from heating and transport (in summer, concentrations of these pollutants decrease). The higher concentration of CO in winter is directly related to the use of coal and other fuels for heating, while the concentration of ozone O₃ peaks in summer (July–August) due to photochemical reactions under the influence of sunlight (ozone concentrations decrease in the winter months).

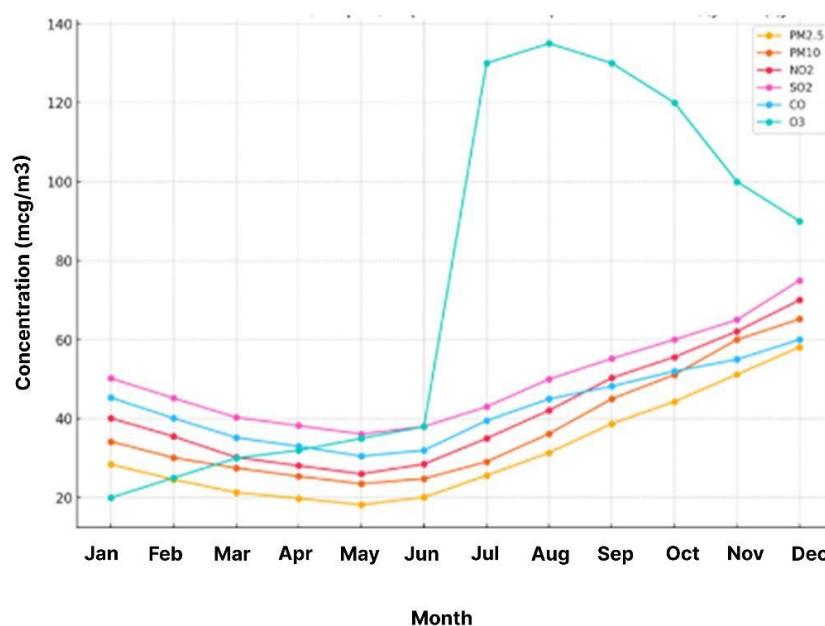


Fig. 3. Seasonal changes in the concentrations of various air pollutants in Dushanbe

The statistical yearbook of the Republic of Tajikistan (*Statistical Yearbook of the Republic of Tajikistan, 2022*) provides data on atmospheric air pollution from stationary sources of pollution in total volume, by ingredients, by region, and the amount of harmful substances captured from stationary sources of atmospheric air pollution.

The dynamics of changes in total emissions of solid, gaseous, and liquid substances into the atmosphere, shown in Figures 4 and 5, indicate that the highest level of emissions of solid, gaseous, and liquid substances into the atmosphere occurred in 1991. This is due to the fact that until 1991, the industrial enterprises of the republic used equipment and technology from the 1950s and 1960s, which relied on liquid and solid fuels as energy sources, resulting in high emissions of pollutants into the atmosphere.

During the period of independence, fundamental changes took place in the structure of industry, with the reorientation of production and the use of new technologies and equipment powered by electricity with lower emissions into the atmosphere. As a result, between 1995 and 2015, there was a decline in pollutant emissions into

the atmosphere, but with the increase in production volumes and the development of the industrial sector, there has been a rise in emissions into the atmosphere.

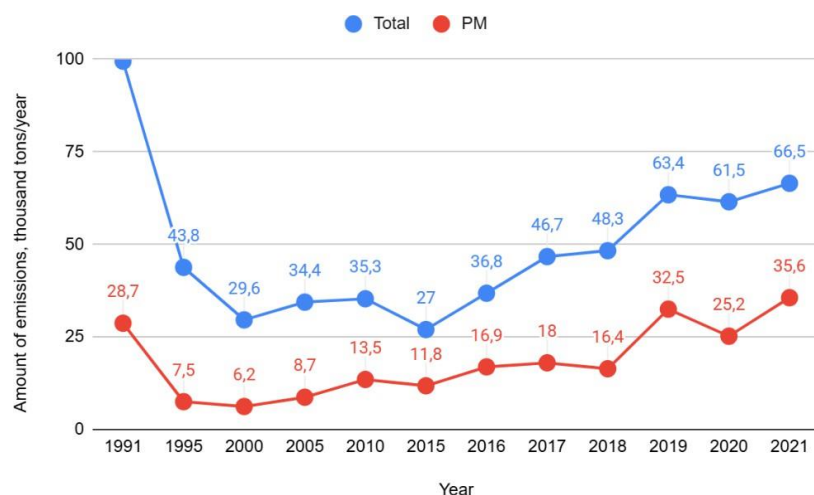


Fig. 4. Dynamics of total emissions of solid substances into the atmosphere

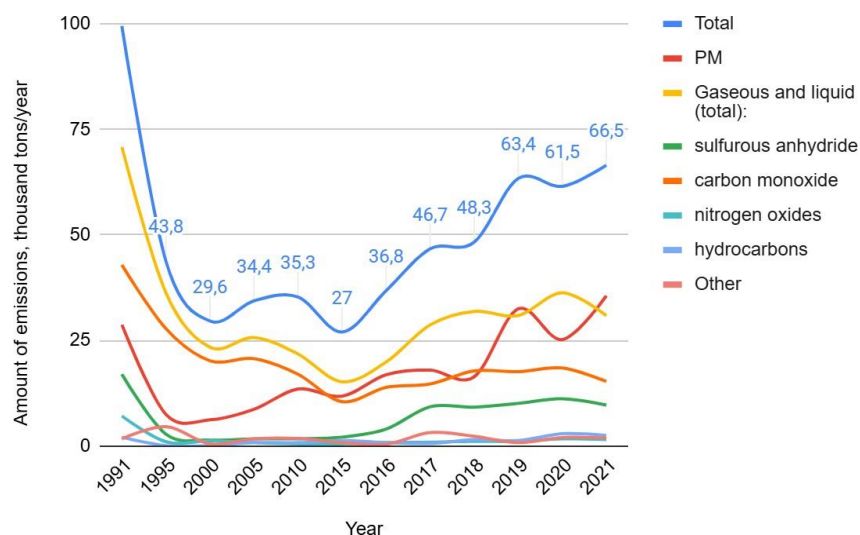


Fig. 5. Dynamics of total pollutant emissions into the atmosphere by ingredient

Figure 6 shows the dynamics of total pollutant emissions by region in the Republic of Tajikistan, where the Sughd region, Dushanbe, and Tursunzade account for the largest share of total harmful emissions.

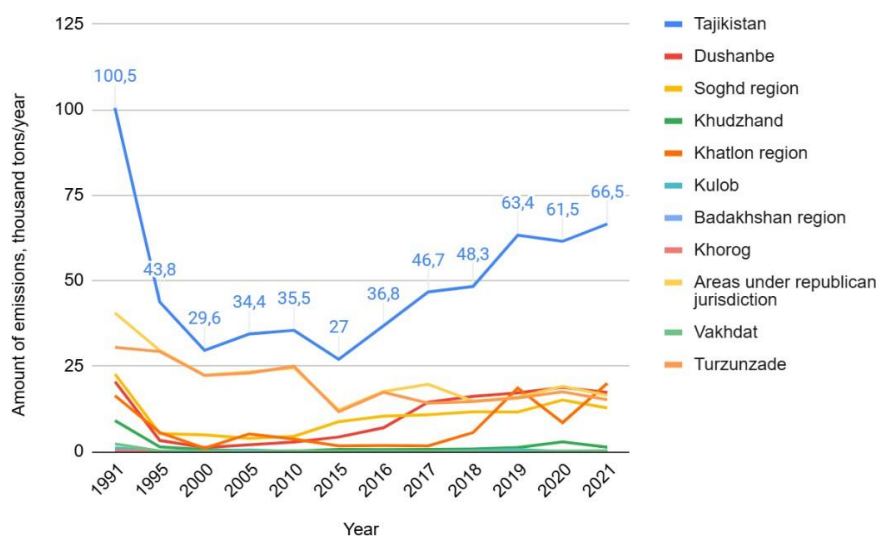


Fig. 6. Dynamics of total emissions of pollutants into the atmosphere by region

It should be noted that the statistical data presented does not reflect the full picture of atmospheric air quality, since the degree of atmospheric pollution depends on many factors: the amount of pollutant emissions, their chemical composition, the height at which emissions occur, and the geographical and climatic conditions that determine the transport, dispersion, and transformation of substances in the atmosphere.

Statistical data on atmospheric air contains information only on stationary sources of pollution, which may lead to an insufficient understanding of air quality in a particular region. Here are some problems that may arise in this regard:

- lack of data on different types of pollution: different sources can emit different types of pollutants;
- lack of information on mobile sources: motor vehicles, industrial processes, and other mobile sources also contribute significantly to air pollution;
- time variability: air pollution can vary depending on the time of day, season, and other factors;
- inability to identify sources of short-term impacts: some events, such as accidents or sudden emissions, can have a short-term but significant impact on air quality;
- assessment of health impacts: to determine risks to human health, it is necessary to consider not only pollution levels, but also the characteristics of specific pollutants.

All factors can be taken into account when modern automated systems are used in the atmospheric air monitoring system, where various approaches and models are used to predict atmospheric air quality.

2.2 | Improving the atmospheric air quality monitoring system

Various approaches and models are used to forecast atmospheric air quality. There are three main types of models for forecasting air pollution: statistical, intelligent, and hybrid (*Liu et al., 2020*). Statistical models mainly take into account the statistical relationship between air pollutant concentrations and historical data on various influencing factors and are established using mathematical and statistical methods. Intelligent models take into account the sources of pollutants (e.g., industrial enterprises, transport, man-made accidents, natural sources such as forest fires, etc.). It should be noted that data on the state of atmospheric air obtained through predictive modeling are very similar to data obtained from field measurements, so using a wide network of measuring stations allows us to get the most accurate data on the concentration of atmospheric pollutants at a given time (*Pozdnyakov et al., 2023*).

Internationally, projects based on the use of IoT networks for air monitoring are being actively implemented (*Zanella et al., 2014*). Among them are the Airly initiative in Poland, Smart Citizen in Spain, and the global OpenAQ platform, which accumulates data from thousands of sensor nodes. These projects have proven that distributed sensors can complement traditional methods and provide a more accurate picture of air pollution.

However, despite their effectiveness, there is a problem of data reliability. In some cases, information may be subject to adjustments or loss during transmission. In addition, centralized data storage reduces transparency and limits access to information. In this context, blockchain (*Khan & Salah, 2018*) is seen as a technology capable of eliminating these shortcomings.

The Internet of Things is an infrastructure that combines sensors, communication devices, and data processing platforms. In the case of air monitoring, these can be compact sensors that measure concentrations of harmful substances (PM_{2.5}, PM₁₀, CO, NO₂, SO₂, O₃), humidity, and temperature.

A key advantage of the IoT is the ability to deploy large networks of inexpensive devices, which allows for detailed distribution of pollutants within urban areas. The use of wireless communication technologies such as LoRaWAN or NB-IoT enables real-time data transmission. The collected information is used to generate analytical reports, forecasts, and models to support decision-making in the field of ecology and urban management.

Blockchain was originally developed as a distributed ledger for financial transactions, but its potential turned out to be much broader. For environmental monitoring, blockchain makes it possible to guarantee the immutability of information, eliminate the possibility of its falsification, and ensure equal access for all interested parties.

Smart contract technology opens up new opportunities for automating management processes. For example, if permissible concentrations of pollutants are exceeded, the system can automatically record the event in the ledger and initiate notification of authorities or scientific institutions. This makes blockchain technology an important link in the formation of a trusted monitoring ecosystem. The proposed model combines IoT networks and blockchain technologies into a single environmental monitoring platform. A conceptual model of the proposed system is shown in Fig. 7.

The first level consists of sensor nodes that collect data on air quality in different areas of the city. The second level consists of data transfer gateways that connect the sensors to cloud or edge computing systems. The third level is a blockchain registry that records all the data received, ensuring its transparency and immutability.

The final level consists of user interfaces — web portals and mobile applications that allow residents, scientists, and government agencies to access information in real time. Such a system not only provides control, but also involves the public in solving environmental problems.

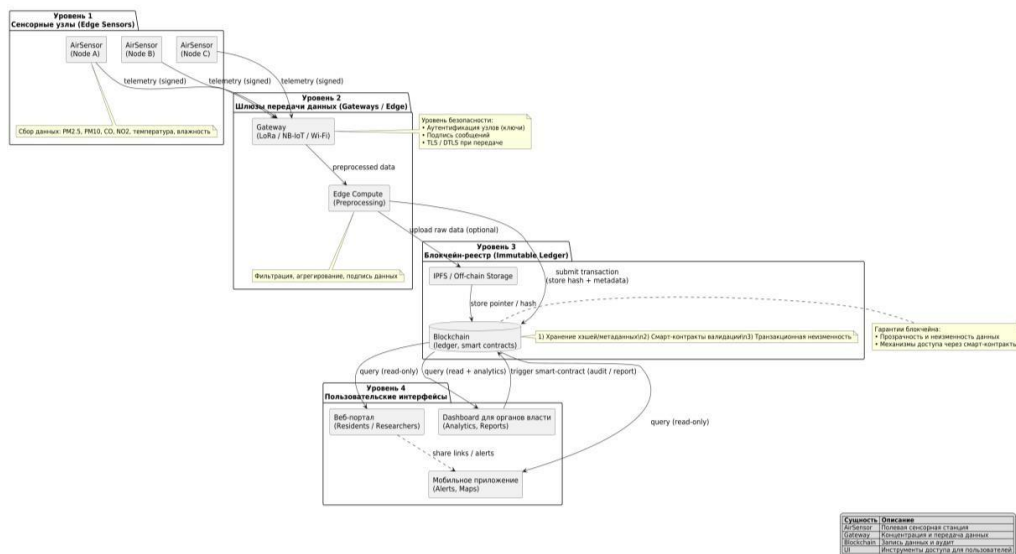


Fig. 7. Conceptual model of the proposed system

The specific features of the environmental situation in Dushanbe, including the limited number of stationary monitoring stations and high levels of air pollution, make the implementation of an integrated system based on IoT and blockchain particularly relevant. The scalability and low cost of sensor networks allow for the gradual expansion of the geographical coverage of observations, while decentralized data storage guarantees their reliability and transparency.

3 | CONCLUSIONS

Air pollution affects not only the quality of life, but also has economic consequences. To reduce the risk of air quality deterioration, countries are implementing a set of measures aimed at strengthening air quality control and reducing pollution levels, based on their economic capabilities.

In the Republic of Tajikistan, along with other countries in Central Asia, environmental monitoring has been organized at the legislative level. On this basis, atmospheric pollution levels are monitored in five regions of the country using stationary observation points in the cities of Dushanbe, Bokhtar, Tursunzade, Khujand, and Guliston. Based on the results of measurements of controlled pollutants, information on atmospheric air quality is compiled after processing. At the same time, the existing air quality monitoring system is not comprehensive enough to cover various territories and sources of pollution, including mobile ones, not only in the city of Dushanbe, but also in other regions of the country, as well as to improve the availability of necessary information on atmospheric air quality to the public.

Therefore, improving the atmospheric air quality monitoring system using modern models and technologies provides more accurate data and comprehensive accounting of all environmental factors. The integration of these technologies could form the basis for the digital transformation of environmental monitoring in Dushanbe. The implementation of such a project could contribute to improving environmental safety, enhancing the quality of life of the population, and creating a scientific basis for the development of sustainable development strategies, which would ultimately increase confidence in environmental data and facilitate informed management decisions.

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AUTHOR CONTRIBUTION

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DATA AVAILABILITY

[Authors to state data availability, e.g., “The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.”]

CONFLICTS OF INTEREST

[Authors to state any conflicts of interest, or “The authors declare no conflict of interest.”]

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