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USING GIS TECHNOLOGIES TO STUDY SULFUR DIOXIDE AIR POLLUTION IN TASHKENT

ABSTRACT

This study investigates the temporal and spatial dynamics of sulfur dioxide (SO_2) concentrations in the atmosphere of Tashkent, Uzbekistan, over the period 1998–2023. Long-term observational data from the Hydrometeorological Service Agency and the National Statistics Committee were analyzed to identify the key emission sources, assess the driving factors, and evaluate the effectiveness of environmental management policies. The spatial distribution of SO_2 was modeled using the Inverse Distance Weighting (IDW) interpolation method in ArcGIS Pro. Results revealed that between 1998 and 2003, SO_2 concentrations increased markedly, particularly during winter, reaching 30–40 μg/m³ in central districts and exceeding 50 μg/m³ in the northern parts of the city. After 2008, concentrations began to decline steadily, reaching 2–4 μg/m³ by 2023 in nearly all areas. Seasonal variation analysis indicated the highest SO_2 levels in winter and the lowest in summer, mainly due to variations in heating-related fuel combustion. The spatial gradient demonstrated a clear north–south decrease, influenced by topography and prevailing wind patterns. The overall reduction in SO_2 emissions is primarily attributed to the decreased use of fuel oil at the Tashkent Thermal Power Plant, industrial modernization, urban greening initiatives, and the implementation of national environmental reforms. The study concludes that sustained environmental policies and the transition toward renewable energy are critical for improving urban air quality and achieving sustainable development in Tashkent.

KEYWORDS: urbanization, air pollution, chemicals, sulfur dioxide, GIS

INTRODUCTION

Currently, air pollution is becoming an increasingly global problem all over the world. In this regard, an analysis of the literature ([*Paolo*, 1990; *Richard* et al., 1994; *Alberti*, 2008; *Barn* et al., 2011; *Beatley*, 2012; *Richard*, 2016; *Diao* et al., 2020; *Bhat* et al., 2021; *Ramdan*, 2021; *Zhao* et al., 2021; *Alkabbani* et al., 2022; *Kan*, 2022]) shows that anthropogenic activities, in particular the transition from wood burning to coal burning as the main source of energy in the 14th century, caused a "disturbance" in the environmental balance of the Earth. Later, the increasing popularity of petroleum products also led to a new industrial revolution. For the first time, in 1945, a new type of "smog" appeared as a result of the burning of fuel products. In recent decades, it has been noted that atmospheric air is becoming increasingly polluted as a result of transport, and this has a global impact. The development of industry, the sharp increase in the number of personal vehicles, the burning of fuel resources, etc. are having a dramatic impact on atmospheric

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air pollution, and this impact is increasing. This issue is especially relevant in urban areas, where more than 4 billion people live. According to scientists, large and medium-sized cities account for more than 50 %, and in some cases up to 2/3, of global energy consumption and up to 80 % of global greenhouse gas emissions. According to the United Nations, the 21st century will be the century of urbanization, with 60 % of the world's population expected to live in cities by the end of 2030. Over the past 200 years, the world's population has grown from 1 billion in 1800 to 8.1 billion, and this figure is projected to reach 9.6 billion in 2050, with 68 % of the world's population living in urban areas [UN, 2007].

These days, one of the biggest factors affecting human well-being, sustainable development, health and many other areas is the ecological situation. Urbanized areas are the largest sources of environmental problems or have an indirect negative impact on nature and human health. The growing population in cities affects all sectors. For example, as a result, production, transport and household services, energy consumption increase. As a result, the anthropogenic load on nature in the relationship between man and nature exceeds the norm. In this case, the wrong attitude of society towards nature has a serious negative impact on the state of the environment. This makes the nature of cities and its protection an urgent issue. Therefore, it is important to know what the ecological situation is in cities.

Air pollution is becoming an increasingly urgent environmental problem not only in our country, but also in Tashkent, the largest urbanized center in our region. Tashkent is the capital of Uzbekistan, the political and cultural center of our country. The city is located on the piedmont plain of the Western Tien Shan. The highest point of the city above sea level is 515 m, and the lowest point is 381 m. The area of the city of Tashkent is 410 km² and is divided into 12 administrative districts. Today, the permanent population of Tashkent as of January 1, 2025 is 3 112.8 thous. people. This was 2 234.3 thous. people as of January 1, 2010. Over the past 15 years (the period from 2010 to 2025), the population of Tashkent has increased by almost 1 million people. The average population density in the city is 6 910 people/km². According to this indicator, the city is the most densely populated area in our country. The climate of the city is continental, and its formation is strongly influenced by the geographical location and relief of the city. In recent years, for almost a year, Tashkent has been at the top of the world's air pollution rankings[1]. Therefore, it is important to study the level of air pollution in Tashkent, to take measures to prevent and reduce it. Today, the most common pollutants affecting atmospheric air quality are: CO_2, CO, SO_2, NO_x , O3, $PM_{2.5}$, PM_{10} and HM [*Richard*, 2016]. This research study studied the emission of SO_2 (sulfur dioxide) in Tashkent for the period from 1998 to 2023. Because sulfur dioxide is one of the substances that has the worst impact on climate change, deterioration of human health and the state of the environment due to its increased content in the chemical composition of the atmosphere. Also, reducing the amount of this substance in the air is not only a matter of national importance, but also a practical result of the laws on reducing the amount of exhaust gases in order to prevent climate change, established by the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC is the basis for international efforts to combat climate change, the main goal of which is to reduce and stabilize the concentration of greenhouse gases below levels that pose a threat to the climate system. Uzbekistan joined this organization in 1993.

Modern studies on the ecological situation of Tashkent City trace back to the Soviet Union. In the 1970s, numerous Soviet scholars such as V. V. Medvedkov, M. N. Manevich, I. P. Gerasimova, Yu. V. Medvedkova, A. A. Mitsa, V. P. Kaznacheeva, O. P. Yanitsky, as well as Uzbek researchers including V. I. Sokovnina, Yu. Sh. Shadimetov, B. Ziyomukhammedov, T. I. Raimova, and Kh. T. Tursunov [*Tursunov*, 1994], conducted extensive research on the emergence of cities, their ecological conditions, development processes, and the nature of socio-

1 Web resource: https://aqicn.org/map/world (accessed 06.06.2025)

economic life within them. In 1989, V. I. Sokovniy in his monograph paid special attention to the issues of improving air quality in the cities of Uzbekistan [*Tursunov*, 1994]. In 1990, B. Ziyomuhammedov and Yu. Sh. Shadimetov (in 1990, 1992, 1993) studied the development trends of the ecological situation in the Central Asian region and conducted general philosophical research on the impact of socio-economic, ecological, and demographic factors on population health. Also, Sh. Sharipov and A. Khayitmurodov [*Sharipov*, *Khayitmurodov*, 2024] studied the role of green spaces in reducing the heat island effect of Tashkent City; Sh. Sharipov, M. Gudalov, O. Nematov [*Sharipov* et al., 2024] and others studied the impact of climate change on the nature of natural geographical areas; A. Ruziev [*Ruziev* et al., 2024] and others studied the creation of a geodetic grid system for Tashkent City; and S. Avezov and D. Yunusova [*Avezov* et al., 2024] studied water bodies through remote sensing. However, comprehensive work on studying the amount of main pollutants in Tashkent City has not been carried out.

The main objective of this study is to analyze the temporal variation in sulfur dioxide (SO_2) concentrations — one of the major pollutants contributing to air contamination in Tashkent City — from 1998 to 2023. The research also aims to identify the primary sources influencing SO_2 levels in the atmosphere and to develop proposals and recommendations for improving the current environmental situation.

To achieve this goal, data spanning a 25-year period were collected from the archives of the Hydrometeorological Service Agency and the National Statistics Committee of the Republic of Uzbekistan. Based on the gathered data, the Inverse Distance Weighting (IDW) interpolation method within the ArcGIS Pro software was employed to determine the spatial and temporal dynamics of SO_2 concentration in the city's air. Thematic maps illustrating the spatial distribution and quantitative changes of SO_2 were generated as a result.

Furthermore, the study investigated the factors influencing SO_2 levels based on identified emission sources, and a directly proportional relationship was found between these factors and the changes in SO_2 concentrations. In addition, the implementation of state environmental policy was evaluated as one of the most effective measures for preventing ecological problems [*Meng* et al., 2009; *Thompson* et al., 2014; *Novan*, 2017].

Study Area

Tashkent is the capital of Uzbekistan, serving as the country's political and cultural center. The city is located on the expansive piedmont plains of the western Tien Shan Mountains. Tashkent covers an area of 410 km² and is administratively divided into 12 districts. As of January 1, 2025, the city's population has reached 3 112.8 thous. people. In comparison, the population was 2 234.3 thous. on January 1, 2010 — indicating an increase of nearly 1 million residents over the past 15 years. The average population density in the city is approximately 6 910 people per km², making it the most densely populated area in the country.

Currently, the primary air pollutants affecting atmospheric air quality in Tashkent include CO_2, CO, SO_2, NO_x, O_3, $PM_{2.5}$, PM_{10}, and heavy metals (HM) [*Richard*, 2016]. This study focuses on the emission of sulfur dioxide (SO_2) during the period from 1998 to 2023. Sulfur dioxide is considered one of the most hazardous substances for the environment, human health, and climate stability due to its increasing concentration in the atmosphere.

Reducing SO_2 levels in the air is not only a national environmental priority but also aligns with international legal commitments, specifically the United Nations Framework Convention on Climate Change (UNFCCC). These efforts are aimed at mitigating the impacts of climate change by reducing emissions of greenhouse gases, including sulfur dioxide.

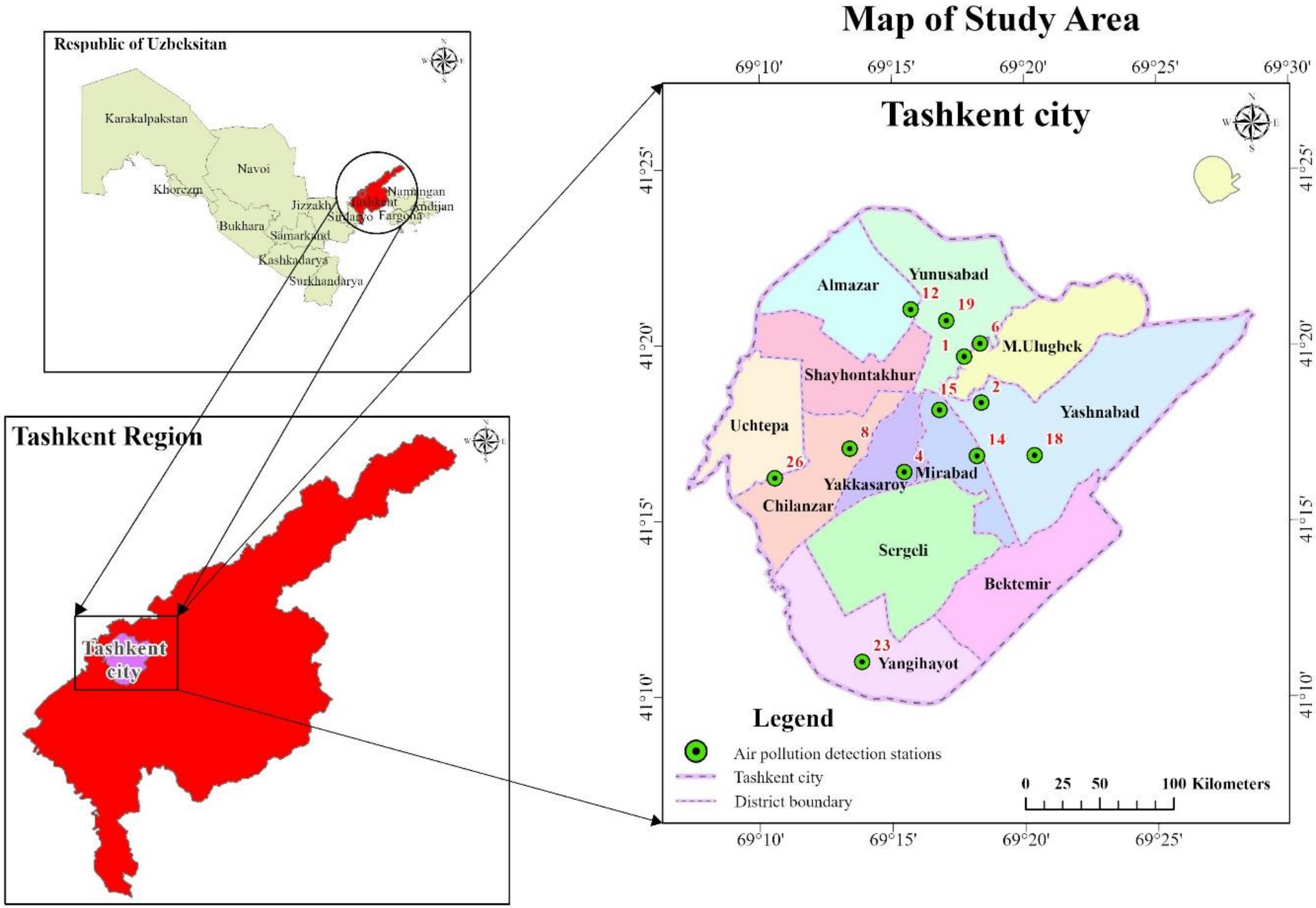

Fig. 1. Study area and air pollution monitoring stations

RESEARCH MATERIALS AND METHODS

To assess the state of air pollution in Tashkent, data on the amount of SO_2 emitted into the atmosphere for the period from 1998 to 2023 were collected from the fund of the Center for Hydrometeorological Service under the Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Uzbekistan for 12 out of 15 stations in different parts of the city (taking into account the completeness of the data and geographical location) for 12 months of the year. Using monthly data, indicators were summarized by season. Also, since the data on the amount of SO_2 obtained from the Hydrometeorological Service Center are given in mg/m³, the data provided by the International Air Quality Index (AQI) and the Individual Pollutant Index (IPI) are given in μg/m³ or ppm (parts per million) and were converted to μg/m³. The following formula (1) was used for this:

$$1\ mg/m^3 = 1\,000\ \mu g/m^3 \qquad 0.0029\ mg/m^3 = 2.9\ \mu g/m^3 \qquad (1).$$

To map the data and analyze the spatiotemporal dynamics of SO_2 concentrations, the Inverse Distance Weighting (IDW) interpolation method in ArcGIS Pro was selected. The dataset, prepared in Excel format, included the station name, date, SO_2 concentration (μg/m³), and X and Y coordinates. The IDW method was chosen due to its proven effectiveness and frequent use by researchers in recent years to study and map air pollution at various scales using ArcGIS Pro [*Yuval* et al., 2017; *Huda* et al., 2019; *Jun* et al., 2019; *Kazhal* et al., 2020]. This method allows for a clear and accurate representation of the spatial distribution and quantitative variation of pollutants. The Excel table was first imported into a geodatabase using Conversion Tools → Excel to Table, after which a point shapefile was generated via the XY Table to Point tool. In the attribute table, SO_2 units were carefully checked, and zero or erroneous values were removed to ensure data accuracy. Interpolation was then performed within the administrative boundary of Tashkent City using Spatial Analyst → IDW, and the output was saved in raster format.

The raster layer was symbolized using the Symbology → Classified menu, where it was manually divided into 10 intervals. Each interval was assigned a classification code from 1 to 10 using the Reclassify tool. The final result was composed in the Layout module in A4 format, including a legend, north arrow, scale bar, and the boundaries of Tashkent City and its administrative districts. The map utilized the WGS 84 UTM Zone 42N coordinate system and was exported as a PNG image with 300 dpi resolution. A total of six maps were created for the period from 1998 to 2023, with a five-year interval.

RESEARCH RESULTS AND DISCUSSION

The dynamics of changes in the amount of SO_2 in Tashkent for the period from 1998 to 2023 was determined. We can see that from 1998 to 2003, the amount of SO_2 increased (especially in winter), and since 2008, a decrease was observed (Fig. 2–3). In the winter of 1998, the amount of sulfur dioxide emitted into the atmosphere in the main area of the city was 10–15 μg/m³, while in 2003 this figure was 30–40 μg/m³. This figure increased even more, especially in the northern area of the city, and amounted to more than 50 μg/m³ (Fig. 2–3). In spring, we can also see that the total indicator increased from 1998 to 2003, and then decreased. In 1999, the amount of SO_2 emitted into the air in the main area of the city was 10–15 μg/m³, but by 2023 it had decreased to 2 μg/m³ in almost all areas of the city (Fig. 4–5). In summer, the amount of SO_2 emitted into the air in the main area of the city was 15–20 μg/m³ in 1998, but by 2023 it had decreased to 2–4 μg/m³ in almost all areas of the city (Fig. 6–7). In autumn, the amount of SO_2 emitted into the air in the main area of the city was 6–10 μg/m³ in 1998, but by 2023 it had decreased to 2–4 μg/m³ in almost all areas of the city (Fig. 8–9). An increase was observed in all seasons until 2003.

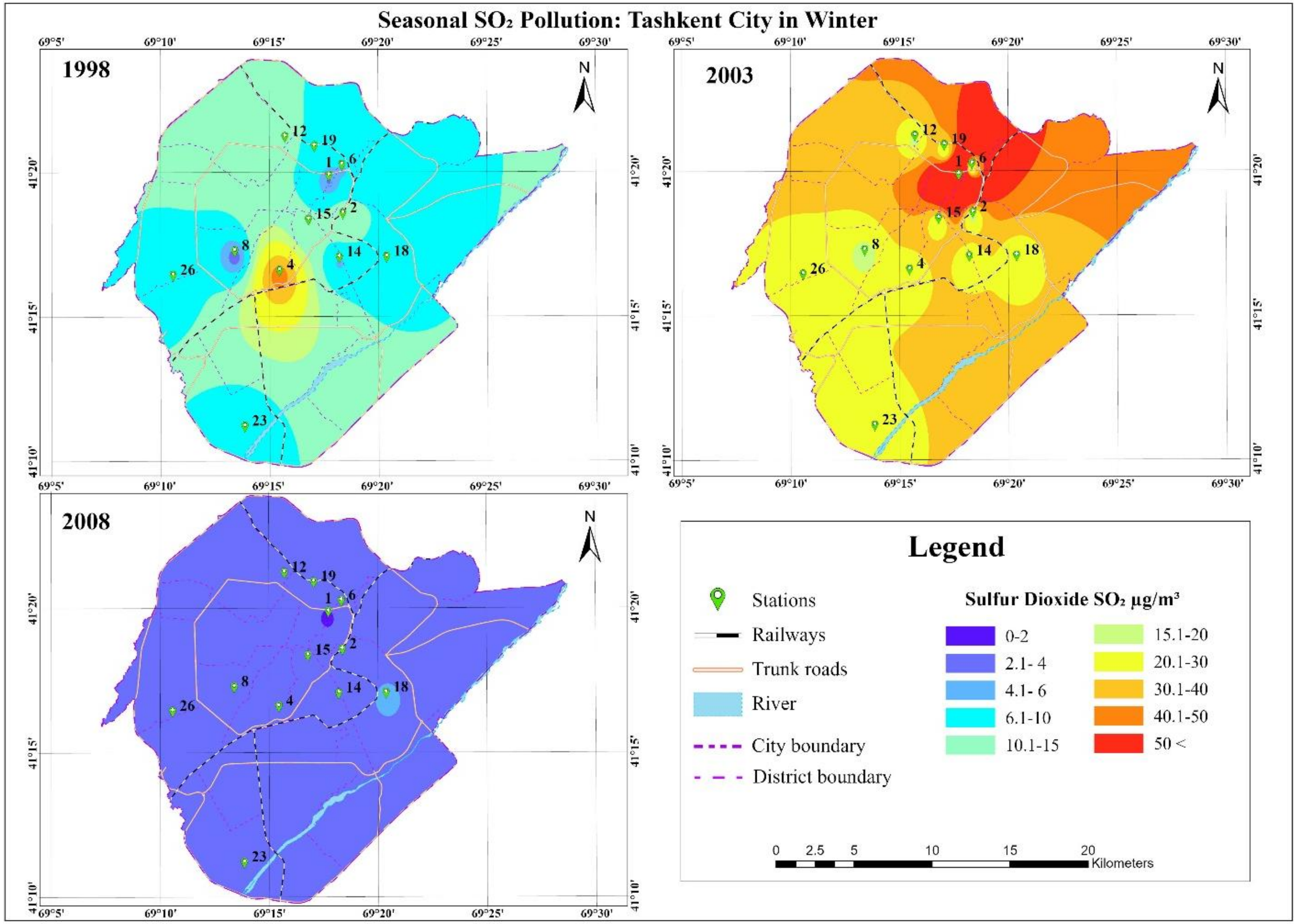

Fig. 2. Changes in SO_2 levels in the Tashkent City area during the winter season from 1998 to 2008

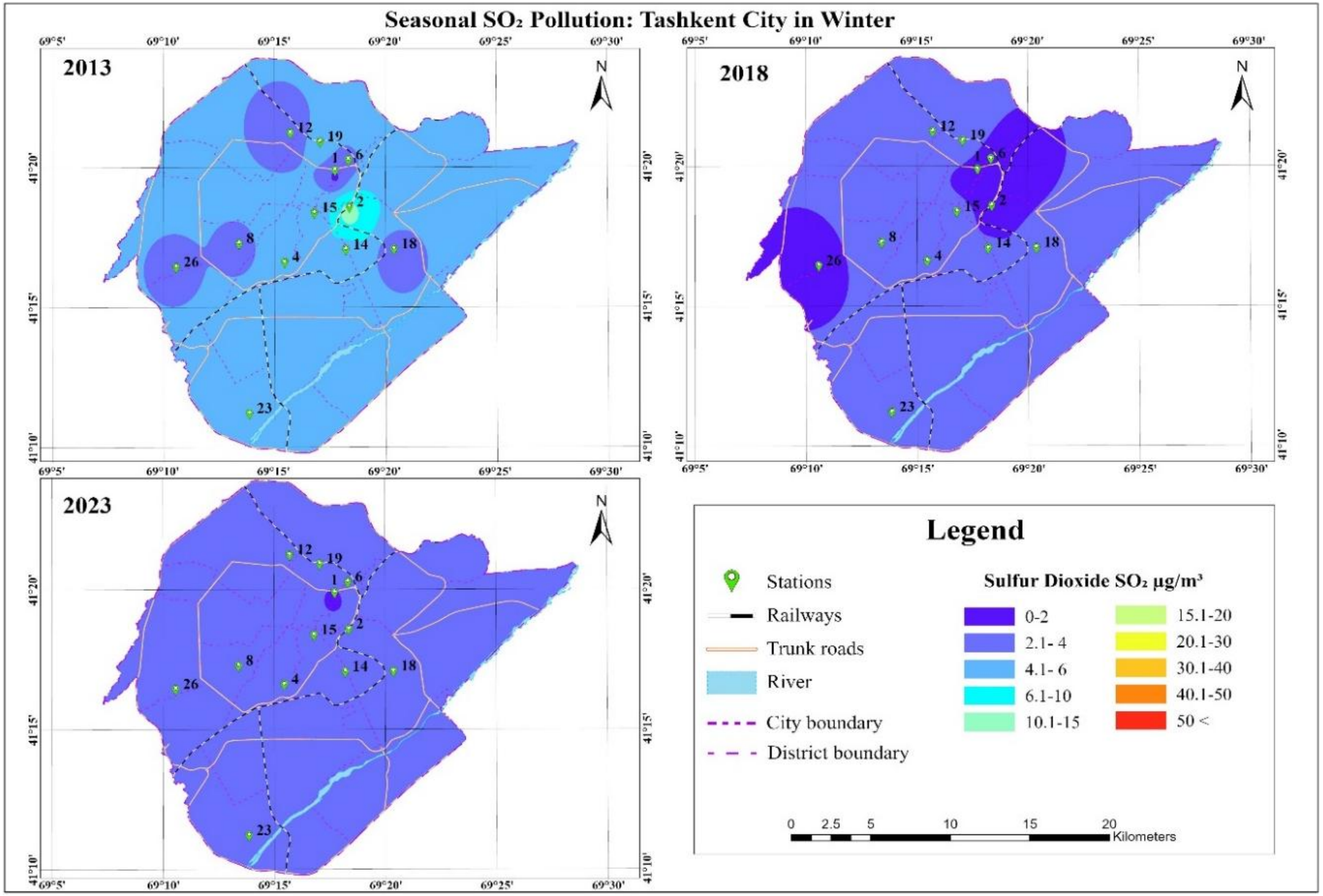

Fig. 3. Changes in SO_2 levels in the Tashkent City area during the winter season from 2013 to 2023

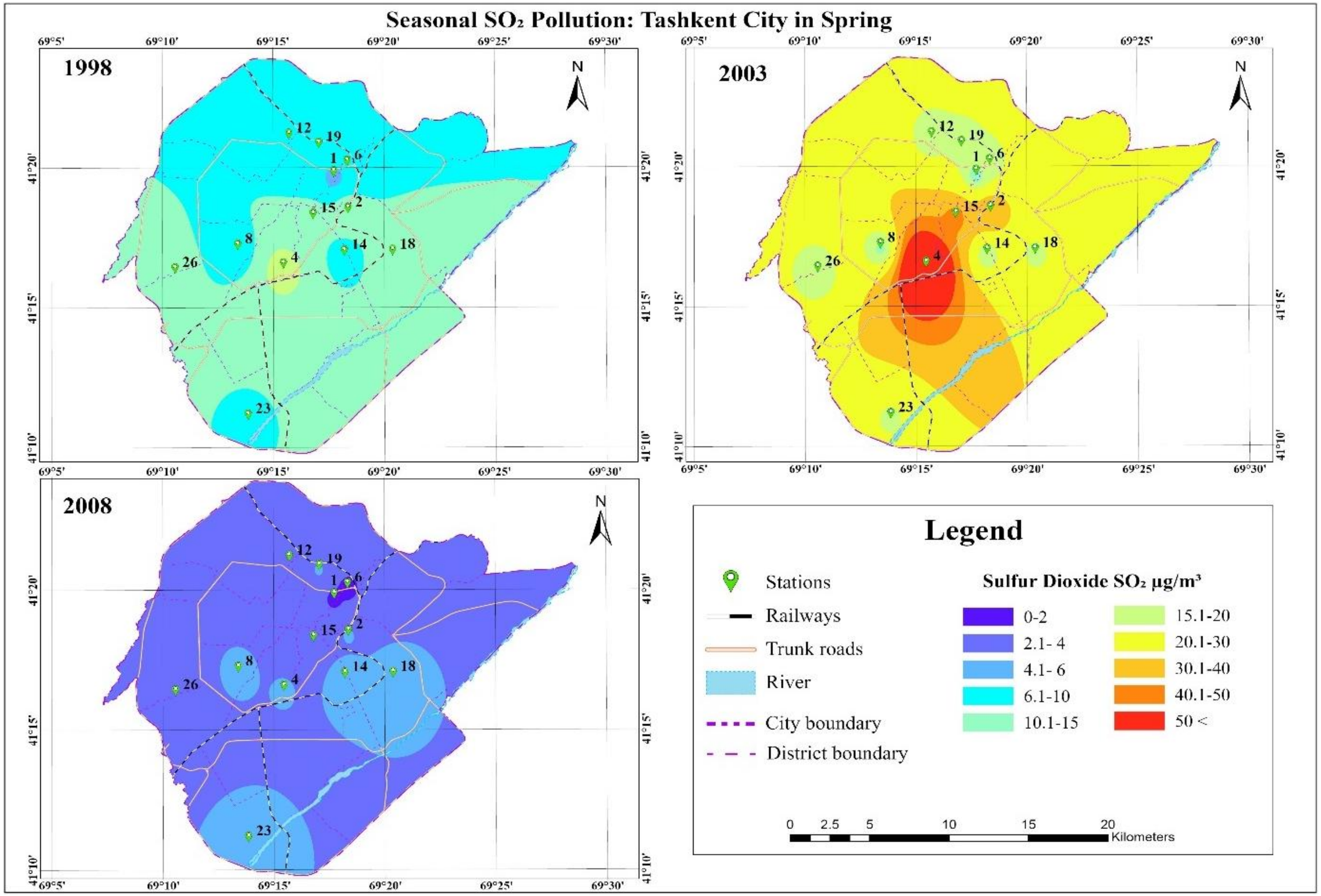

Fig. 4. Changes in SO_2 levels in the Tashkent City area during the spring season from 1998 to 2008

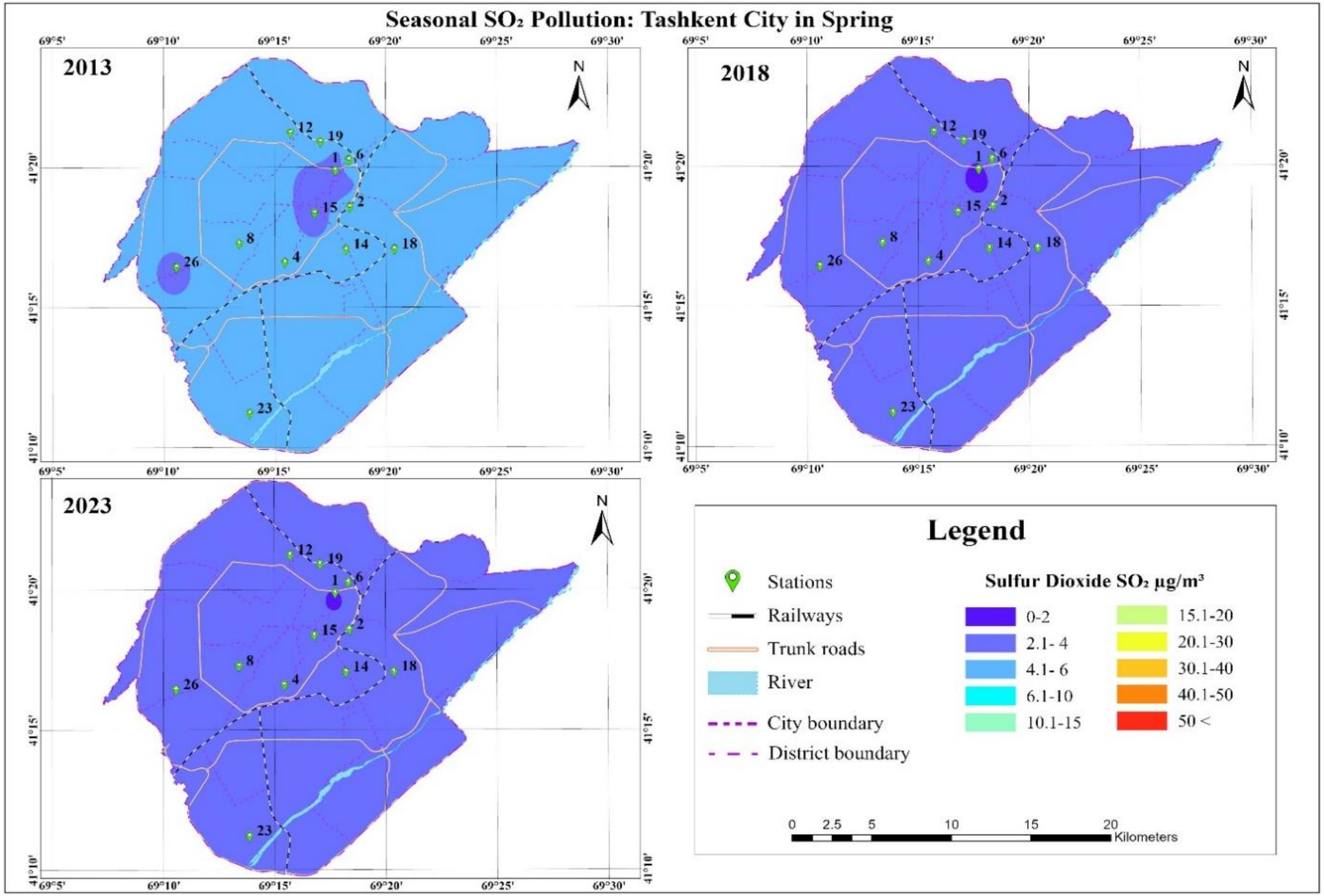

Fig. 5. Changes in SO_2 levels in the Tashkent City area during the spring season from 2013 to 2023

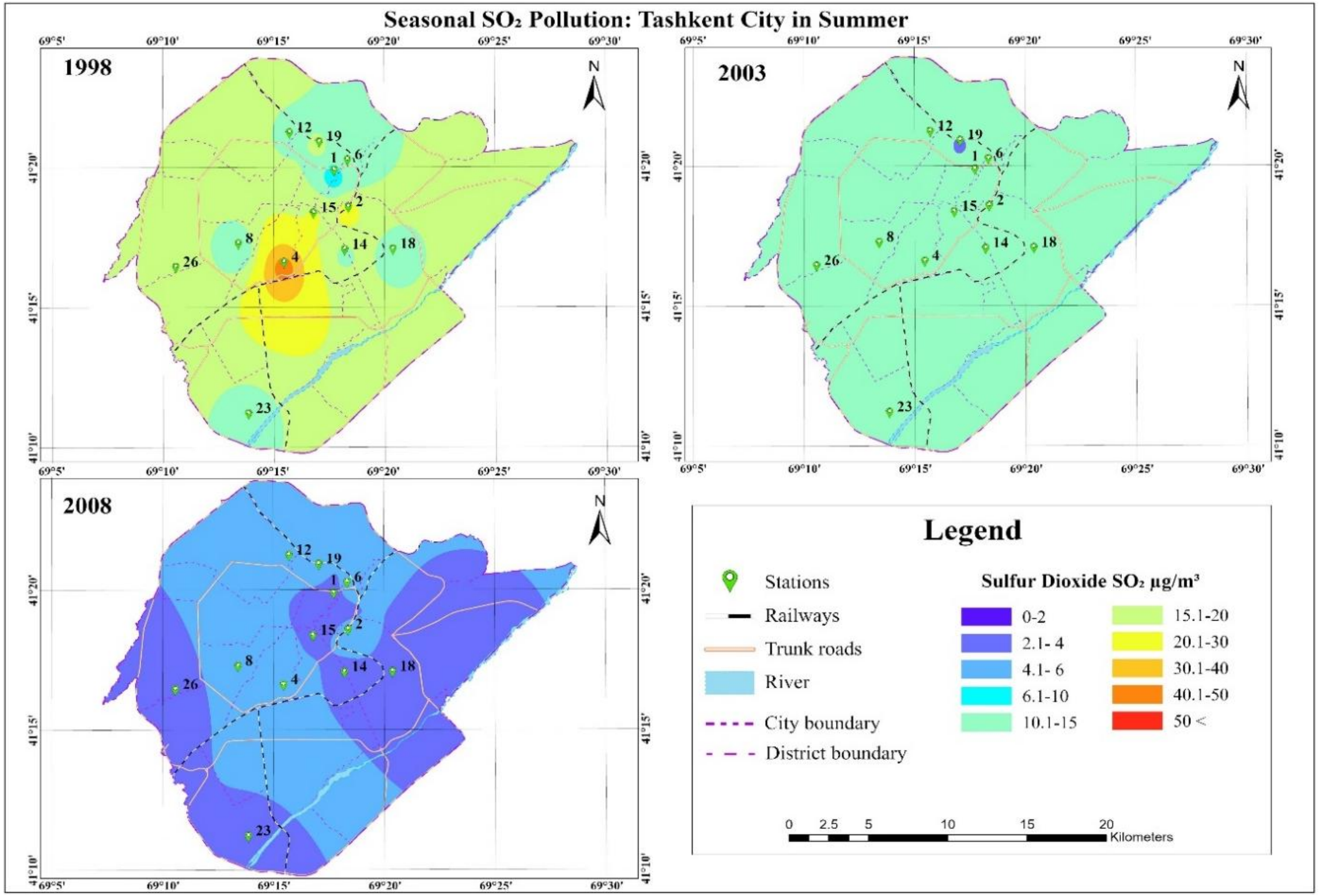

Fig. 6. Changes in SO_2 levels in the Tashkent City area during the summer season from 1998 to 2008

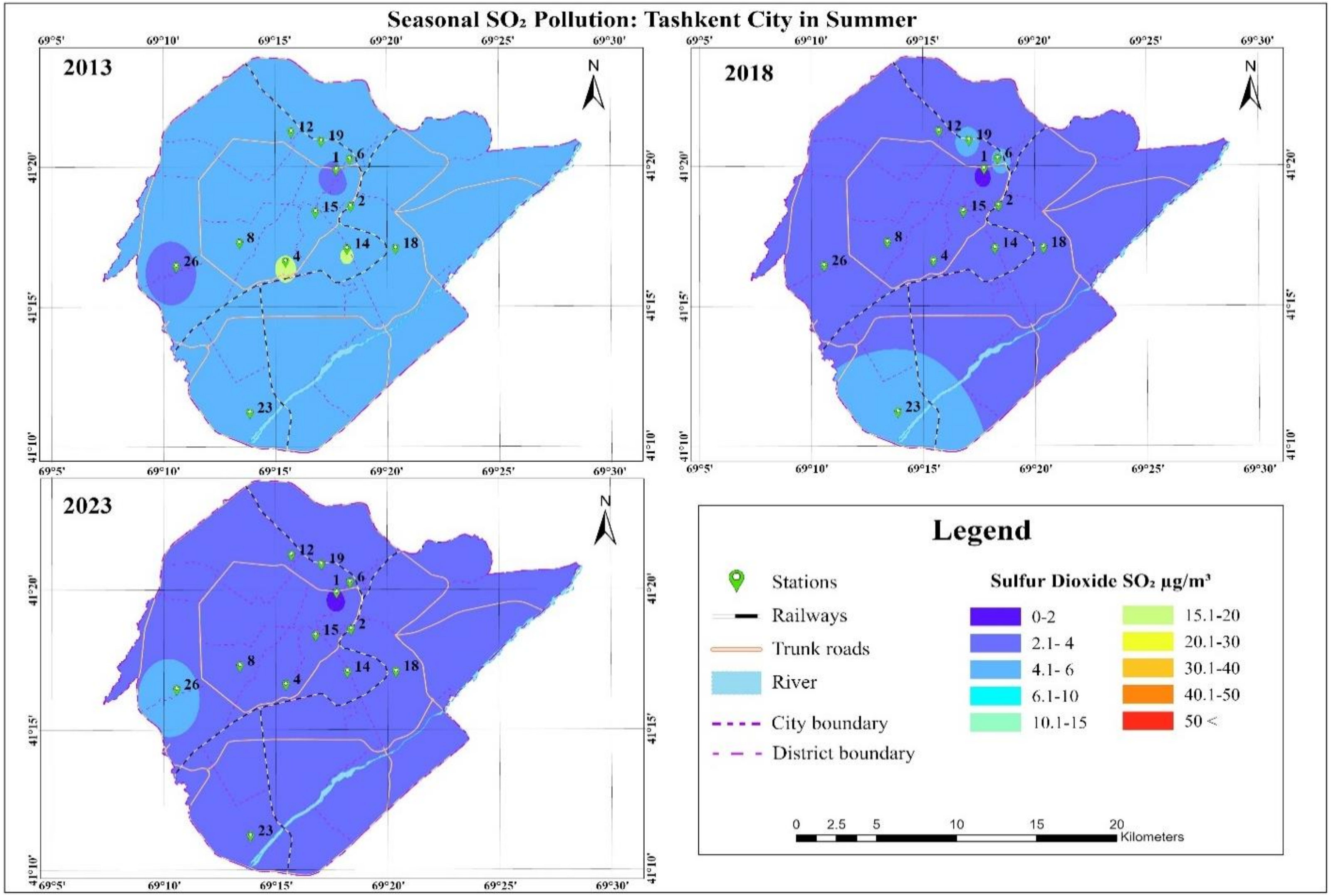

Fig. 7. Changes in SO_2 levels in the Tashkent City area during the summer season from 2013 to 2023

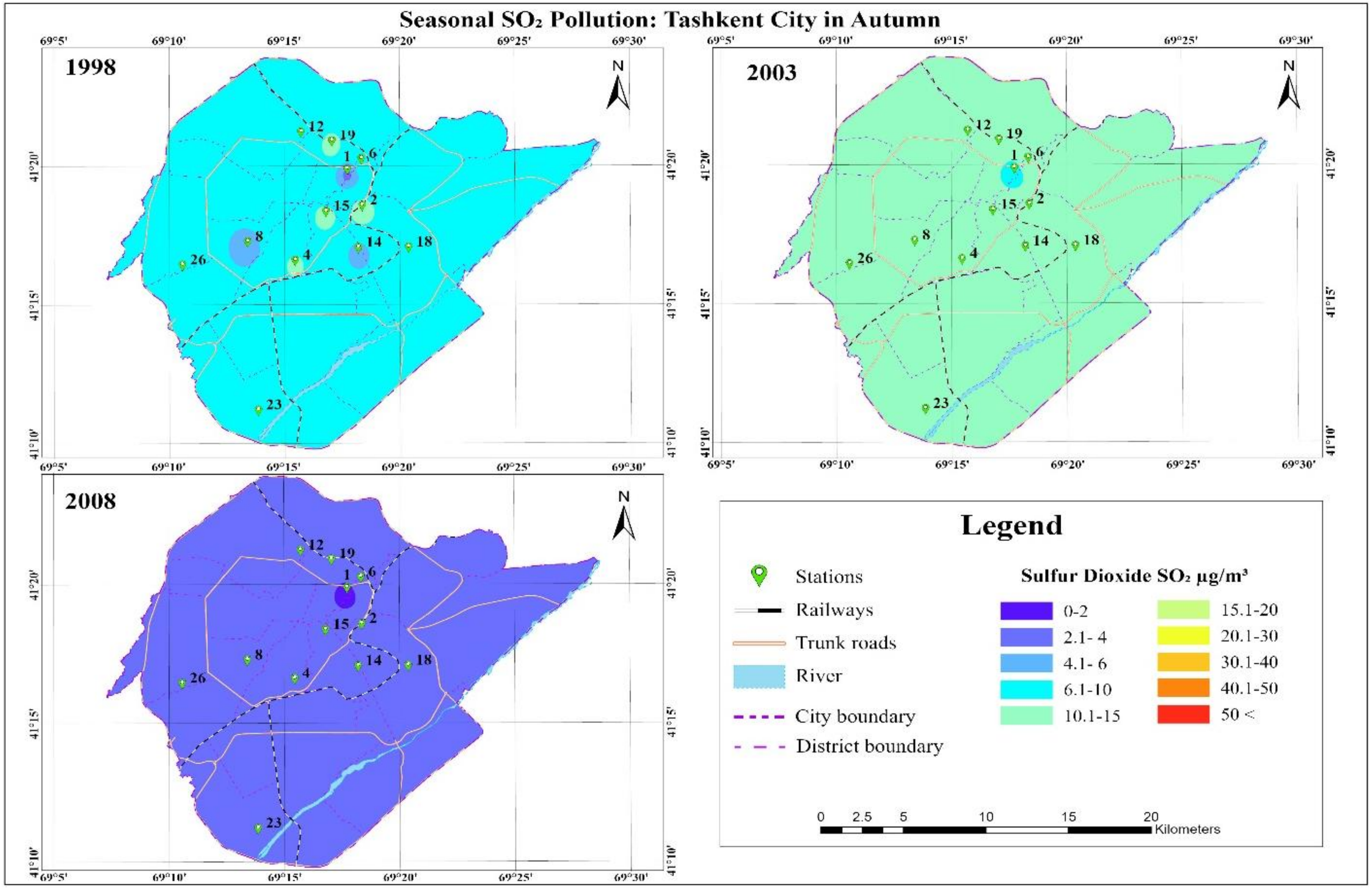

Fig. 8. Changes in SO_2 levels in the Tashkent City area during the autumn season from 1998 to 2008

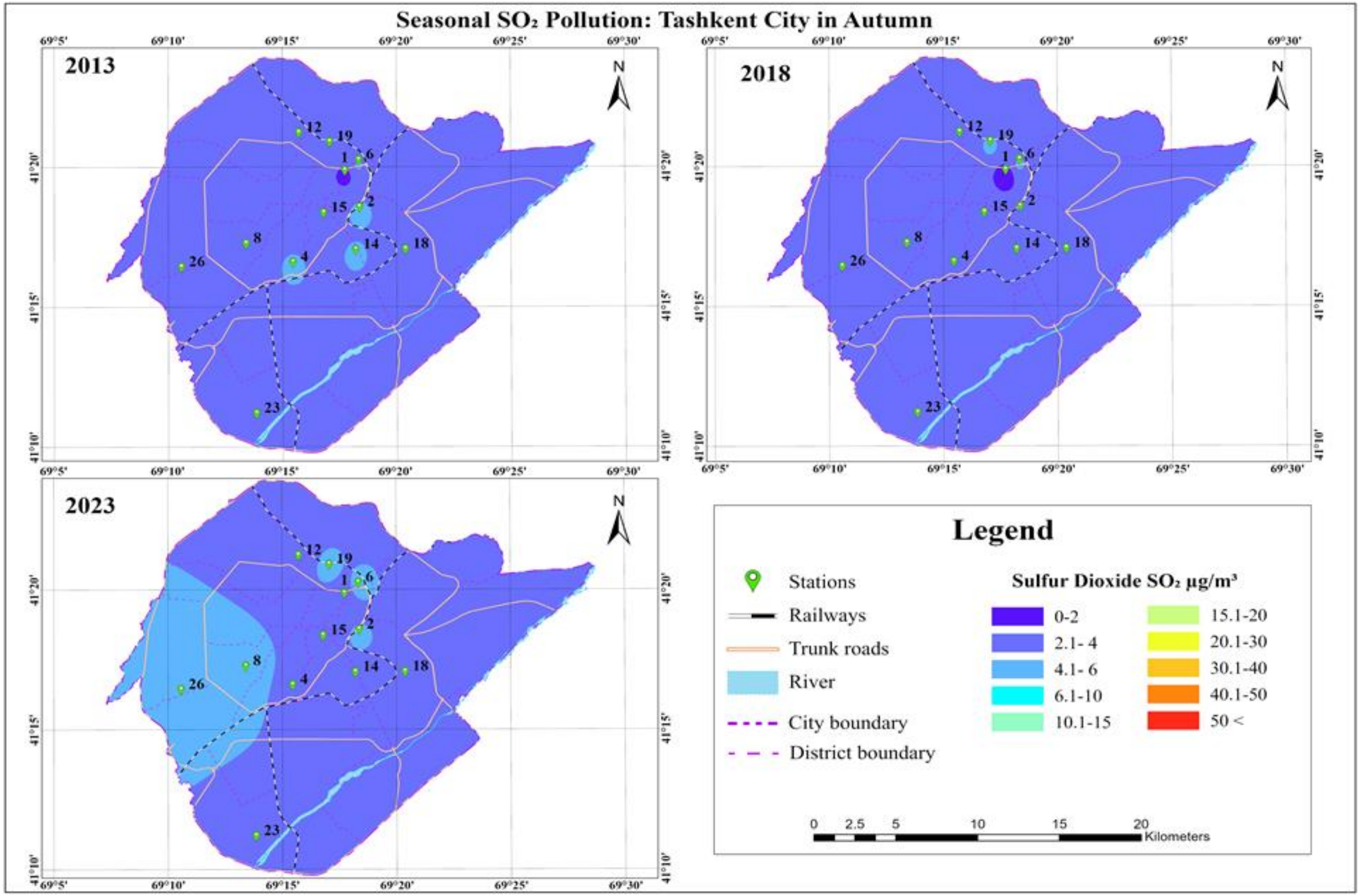

Fig. 9. Changes in SO_2 levels in the Tashkent City area during the autumn season from 2013 to 2023

Based on the main sources of sulfur dioxide [*Oke*, 2025], when studying the industrial enterprises existing in the city at that time, Tashkent TPP, and others, the following were identified.

1. Impact of Tashkent Thermal Power Plant. The technical and economic basis of the Tashkent TPP was carried out by the Central Asian Department of the Teploelektroproekt Institute (CAO TEP, 1958). Bukhara gas was adopted as the main fuel for the operation of the TPP, and fuel oil was used as an additional fuel. It was determined that the sulfur content of fuel oil for the operation of the Tashkent TPP should not exceed 0.7 %. The design work took into account the proximity of the TPP to the city of Tashkent, and attention was paid to the height of the turbines. However, due to the direction of the wind, the toxic fumes emitted from the TPP also affected the amount of sulfur dioxide in the city's atmospheric air. Initially, the land for the construction of the TPP was allocated from the territory of a peasant farm in accordance with the resolution No. 304 of the Tashkent Regional Executive Committee of People's Deputies dated September 25, 1959, but construction work began in 1961, and block 12 was commissioned on September 1, 1971. Problems with gas supply led to an increase in the share of fuel oil as a fuel for the TPP. The amount of fuel oil used gradually increased, and the largest amount of electricity was produced only in 1975, after the plant was put into operation. In subsequent years, the volume of electricity generation decreased, and the use of fuel oil increased. The use of fuel oil as a share of total fuel at the plant was 1.8 % in 1969, and 48.9 % in 1984. During the period studied in our research, the percentage of fuel oil used changed as follows: in 1998, 20.9 % of fuel oil was used, while in 1999 this figure reached 21.9 %, in 2000 it reached 22.9 %, in 2001 it reached 17 %, in 2002 it reached 24.9 %, and in 2003 it reached 25.5 %. In subsequent years, this figure gradually decreased, falling to 6.3 % in 2008 and 3.8 % in 2012 [*Soliyev*, 2014].

Table 1. Changes in fuel oil consumption and electricity generation at Tashkent TTP over the years [*Soliyev*, 2014]

Year	Fuel oil usage rate, %	Generated electricity, billion kWh
1964	0	1
1974	42.9	10.4
1984	48.9	10.7
1994	11.1	9.3
1998	20.9	8.3
2003	25.5	9.3
2008	6.3	8.4
2012	3.8	6.9

2. Reduction in the share of sectors that are sources of SO_2 (sulfur dioxide) in the industrial production of Tashkent City. A review of data from the Tashkent City Statistics Committee and literature over the past 10 years shows that in recent years, we can see a decrease in the share of sectors that are sources of SO_2 in the industrial production of the city, in particular, the production of coke and oil refining products, the production of chemical products, and the production of rubber and plastic products.

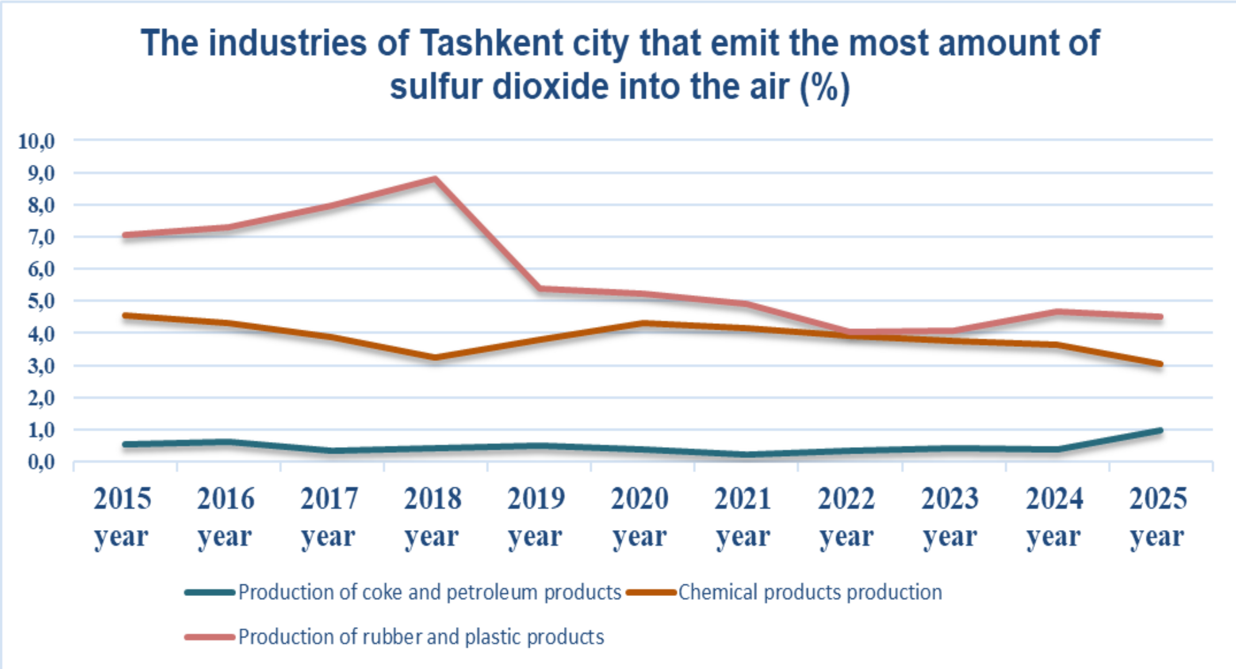

Fig. 10. Sectors with the highest SO_2 emissions in the industrial production structure of Tashkent City. Source: compiled by the author based on data from the toshstat.uz website

3. Reforms within the framework of state policy on environmental pollution. In addition, the state policy on the environment in Uzbekistan has also played a significant role in reducing the amount of harmful emissions into the air in the city, in particular sulfur dioxide. The following can be highlighted: the creation of the UNEP website www.nature.uz in 2002 and the provision of open information to the population of Uzbekistan and the world community about the work being done to improve the environmental situation in our republic [*Kasimova*, 2002], the Law on Atmospheric Air Protection in 1997, the Law on State Ecological Expertise in 2000, the Law on Waste in 2000, the establishment of the "EKOSAN" Foundation, the signing of the Paris Agreement in 2015 as an addition to the Kyoto Protocol and its ratification by Uzbekistan on November 2, 2018 [*Kasimova*, 2006], etc. Uzbekistan's main commitment under the Paris Agreement is to reduce its greenhouse gas emissions per unit of gross domestic product by 10 % by 2030 compared to 2010 levels. In addition, in accordance with Articles 4.1 and 12.1 of the UNFCCC, Parties to the Convention are required to regularly submit their National Communications on Climate Change, which is a timely report on the implementation of the UNFCCC and the Paris Agreement. In accordance with the Resolution of the President of the Republic of Uzbekistan No. PQ-4477 dated October 4, 2019, the "Strategy of the Republic of Uzbekistan for the Transition to a 'Green' Economy for 2019–2030", prepared by Uzhydromet in collaboration with relevant ministries and departments, was approved, and an Interdepartmental Council was established to promote and implement this Strategy. In accordance with the Action Plan (Roadmap) of this Strategy, each ministry and department are assigned tasks to mitigate or adapt to climate change. The adoption of the Laws of the Republic of Uzbekistan "On the Use of Renewable Energy Sources" and "On Public-Private Partnership" created a legal and regulatory framework for accelerating the introduction of renewable energy sources (construction of solar and wind power plants) in Uzbekistan[1]. In addition, the establishment of the "Climate Council" under the President of the Republic of Uzbekistan by the Decree of the President of the Republic of Uzbekistan on July 23, 2024 is also evidence of the special importance being attached to the work carried out within the framework of improving the ecological situation.

In order to protect and restore ecosystems, accelerate greening work, and expand green spaces in the republic, the implementation of the "Green Space" nationwide project was scheduled for December 30, 2021. In accordance with the Resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 681-F/9 dated October 23, 2023, it is planned to plant 85 million saplings within the framework of the "Green Space" project. In 2023, 625 thous. trees and shrubs and 20 million flower seedlings were planted in Tashkent in the spring season alone within the framework of the "Green Space" program. At a videoconference meeting chaired by the President, the task was set to increase the level of greenery in Tashkent to 28 percent by 2023. For this purpose, a new park will be established on an area of 100 ha[2].

Currently, within the framework of the national project "Green Space", scientists of the Institute of Botany of the Academy of Sciences of the Republic of Uzbekistan and the Tashkent Botanical Garden named after F. N. Rusanov are carrying out effective work in a number of remote regions of our Republic[3].

In addition, it was found that the distribution of the amount of SO_2 emitted into the atmosphere throughout the urban area corresponds to the wind direction. Also, in our opinion, the structures built around the source, their types and height, direction, and function also affect the distribution of sulfur dioxide.

CONCLUSIONS

In conclusion, it can be stated that over the past decade, the concentration of sulfur dioxide (SO_2) in the atmosphere of Tashkent City has decreased. This reduction can be attributed to several key factors:

1. Changes in the use of fuel oil at the Tashkent Thermal Power Plant (particularly in the northern parts of the city).
2. A decline in industrial activities associated with high SO_2 emissions, such as coke and petroleum refining, rubber and plastic manufacturing, and chemical production.
3. The implementation of environmental reforms under the framework of initiatives like "Green Space" and other measures aimed at improving environmental conditions.

The concentration of SO_2 is lowest during the summer months and highest in winter. This is primarily due to the increased use of fuel oil and other heating fuels during the cold season. The spatial distribution of SO_2 shows a decreasing trend from the northern part of Tashkent towards the south, which is influenced by the city's topographical features and prevailing wind directions. In order to further improve the current situation and prevent air pollution, the following recommendations are proposed:

1. Relocate industrial enterprises, power plants, and other major polluters from the city and surrounding areas to outside urban zones, and equip existing facilities with modern filtration systems.
2. Take into account the local topography, wind patterns, and other geographical characteristics when planning and constructing industrial facilities.
3. Expand and enhance continuous air quality monitoring efforts to ensure effective environmental management.

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[2] Web resource: https://www.gazeta.uz/oz/2023/03/01/green-space/ (accessed 01.03.2023)
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