Spatiotemporal analysis of CO emissions in Tashkent city using GIS technologies

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Abstract: This study investigates the changes in concentrations of key air pollutants - carbon monoxide (CO) - in Tashkent city over a 30-year period from 1994 to 2023 in winter. The aim of the research is to analyze quantitative trends in these pollutants, generate spatial distribution maps, and identify the primary sources of air contamination. Data were collected from 12 observation stations operated by the Hydrometeorological Service of the Republic of Uzbekistan. Spatial analysis was conducted using GIS technologies, particularly the Inverse Distance Weighting (IDW) interpolation method in ArcGIS Pro. Seasonal maps were created at five-year intervals. Additionally, graphical analysis and descriptive statistical methods were used to assess the trends in pollutant concentrations. Results indicate that concentration of CO peaked between 1994 and 2003, followed by a significant decline starting in 2008. This research provides a scientific foundation for air quality monitoring and environmental safety initiatives in Tashkent city.

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Key words: Tashkent city; air pollution; carbon monoxide (CO); GIS analysis; IDW interpolation; environmental monitoring; statistical analysis.

INTRODUCTION

Nowadays, air pollution in urban areas has become an increasingly urgent environmental issue. The acceleration of urbanization, the rise in the number of vehicles, the expansion of industrial enterprises, and the increase in energy consumption have resulted in the excessive emission of pollutants such as CO_2, CO, SO_2, NO_x, O_3, $PM_{2.5}$, and PM_{10} into the atmosphere (Han et al., 2011; Bollen & Brick, 2014; Cheng et al., 2016). The release of these substances into the air not only contributes to climate change and acid rain formation (Wang & Wang, 1995; Wang et al., 2001; Christoph et al., 2015; Zhou et al., 2022) but also affects photochemical reactions in the atmosphere through the emission of primary and secondary pollutants (Kuttler & Strassburger, 1999; Derwent et al., 2003; Masiol et al., 2014). Furthermore, the emission of these pollutants has significant adverse effects on human health (Salam et al., 2005; Bell, 2006; Pepe et al., 2011; Li et al., Nili et al., 2016, 2017; Puts et al., 2020; Gao et al., 2021; Bhat et al., 2021; Parrella et al., 2023; Xu et al., 2023; Fajar, 2025). Reducing the concentration of these pollutants in the air (Nam et al., 2013; Yang & Teng, 2018; Li & Xu, 2020; Street, 2000) is not only a matter of

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national importance but is also recognized as a critical environmental issue on an international level by the United Nations Framework Convention on Climate Change (UNFCCC). Air pollution has become a major environmental problem worldwide, with its impacts on human health and the environment causing significant concern globally (Novan, 2017; Diao et al., 2020; Mohammad, 2025).

Tashkent, the political, economic, and cultural capital of the Republic of Uzbekistan and the city with the highest degree of urbanization, has experienced notable demographic and economic growth in recent years. As a result, the expansion of the energy, transportation, and industrial sectors has contributed to the emission of various harmful gases into the atmosphere, including CO, NO_2, SO_2, CO_2, particulate matter (PM), and aerosols. Furthermore, Tashkent's geographic location—situated on a foothill plain—and its climatic conditions, characterized by a sharply continental climate, low precipitation, and prevailing winds, lead to prolonged atmospheric residence of pollutants instead of their natural filtration. Consequently, the horizontal and vertical diffusion of pollutants is reduced, photochemical reactions and temperature inversion phenomena are intensified, resulting in increasing air pollution. Therefore, continuous monitoring of air quality in Tashkent, analyzing the dynamics of pollutant concentrations, and studying their spatial distribution are of significant scientific and practical importance.

In recent years, numerous scientific studies have been conducted internationally to investigate the levels of major air pollutants such as SO_2, NO_x, CO, CO_2, $PM_{2.5}$, and PM, and to analyze their spatial distribution using GIS technologies. Monitoring air pollution and improving air quality remain critical environmental challenges worldwide (Chen et al., 2015). For instance, in China, Li et al. studied and mapped major air pollutants during 2015–2016, taking meteorological factors into account (Li et al., 2018). Sun et al. (2018) examined the long-term dynamics of harmful gas emissions in Chinese cities over 64 years and found that concentrations of SO_2 and NO_x decreased while VOC levels increased (Sun et al., 2018). Similarly, Yoo et al. (2015) investigated the long-term trends of major air pollutants in South Korea based on different land use types. Luis et al. (2015) assessed the dispersion of harmful gases in Mexico City using GIS and the Inverse Distance Weighting (IDW) method (Luis et al., 2015; Jung, 2019). Additionally, Jumaah et al. (2019) analyzed air quality in Kuala Lumpur using IDW and OLS models, emphasizing the effectiveness of these methods in studying pollution dynamics. In Iran, Masroor et al. (2020) employed Kriging and IDW techniques to assess $PM_{2.5}$ concentrations in Tehran. In the United Kingdom, Duggan (2024) found that not only the type of fuel but also the age of vehicles significantly affects CO emissions from transportation. Furthermore, the importance of GIS technologies in studying pollutant distribution has been demonstrated through various studies. For example, Somvanshi et al. (2019), Han et al. (2011), Alkabbani et al. (2022), and others have highlighted that GIS, combined with statistical approaches, can accurately and comprehensively reflect ecological processes, spatial distribution, and temporal dynamics of atmospheric pollutants.

Studies on atmospheric air pollution in Uzbekistan, particularly in Tashkent, date back to the 1970s. In 1989, Kh.Tursunov focused primarily on improving ecologic situation of Tashkent city in his monograph (Tursunov, 1994). In 1990, B. Ziyomuhammedov and Y. Shadimetov examined the development trends of the ecological situation in Central Asia, conducting broad philosophical research on the socio-economic, ecological, and demographic factors affecting public health. Additionally, Sharipov and Khayitmurodov (Sharipov, Khayitmurodov, 2024; Sharipov et al., 2024) investigated the role of green spaces in mitigating the urban heat island effect in Tashkent and the impact of climate change on the natural geographical landscapes. Ruziev et al. (2024) worked on creating geodetic grid systems in Tashkent and studying water bodies via remote sensing, while Azizov and Beketov (Azizov and Beketov, 2024) analyzed traffic flow on major roads in Tashkent and its effect on $PM_{2.5}$ and NO_2 emissions. However, comprehensive long-term studies focusing specifically on the concentrations of major pollutants in Tashkent remain insufficient. Therefore, within the scope of this research, the spatial analysis of CO and SO_2 concentrations in Tashkent's atmosphere was conducted using GIS technologies and the Inverse Distance Weighting (IDW) method.

The primary objective of this research is to determine the dynamic changes in the concentrations of the gases most influencing air pollution in Tashkent city - carbon monoxide (CO) - over the period from 1994 to 2023. Based on the obtained results, seasonal distribution maps will be created, and the sources affecting the concentration of CO in the air will be identified.

Accordingly, relevant data for the 30-year study period were collected from the archives of the Hydrometeorological Service Agency under the Ministry of Ecology, Environmental Protection, and Climate Change of the Republic of Uzbekistan, the State Committee of the Republic of Uzbekistan on Statistics, and additional literature sources.

To analyze the dynamics of changes in CO concentration in the urban atmosphere, the Inverse Distance Weighting (IDW) method was employed in the ArcGIS Pro software. Thematic maps illustrating the spatial distribution and quantitative variation of CO was produced. The main sources of carbon monoxide (CO) in urban environments include oxygen-limited (incomplete) combustion occurring in motor vehicles, industrial processes, domestic heating, coal, oil and gas-fired power plants, industrial boilers, and waste incinerators (Oke, 2025). Based on these emission sources, factors influencing the concentrations of CO was further studied.

Study area

Tashkent city is the capital of Uzbekistan and serves as the political and cultural center of the country. The city is situated on a wide piedmont plain of the Western Tien Shan mountains. Tashkent covers an area of 410 square kilometers and is divided into 12 administrative districts. As of January 1, 2025, the permanent population of Tashkent was approximately 3,112,800 people. This figure has increased significantly from 2,234,300 people on January 1, 2010. Over a 15-year period, the population of Tashkent has grown by nearly 1 million. The average population density of the city is 6,910 people per square kilometer, making it the most densely populated area in the country.

The climate of Tashkent is characterized by hot and dry summers and relatively mild and unstable winters. The hottest month is July, with an average temperature ranging from +24°C to +27°C and maximum temperatures reaching +43°C to +44°C. The coldest month is January, with an average temperature of 0,6°C. The annual average precipitation is approximately 400 mm. The average annual relative humidity is around 58%, with January humidity levels between 60 % and 70 %, and dropping below 30 % in July.

This study focuses on the emissions of carbon monoxide (CO) in Tashkent from 1994 to 2023. This gas, when increased in atmospheric concentration, significantly contribute to climate change, deterioration of human health, and adverse environmental impacts (Oke, 2025).

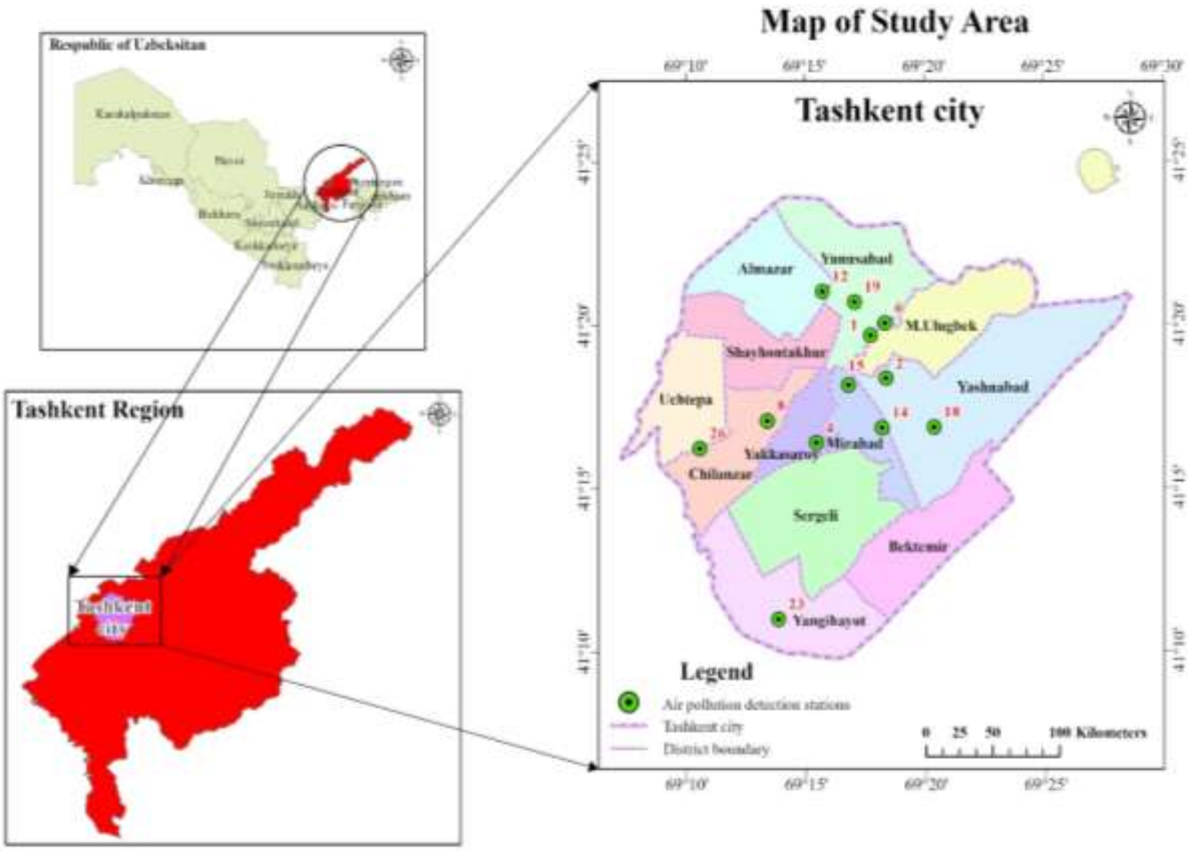

Fig.1. Study area and air pollution monitoring stations
Source: own study.

MATERIALS AND METHODS

This study investigates the spatial and temporal variations of carbon monoxide (CO) emission in the atmosphere of Tashkent city over a 30-year period from 1994 to 2023. The research methodology comprises several stages: data collection, preliminary data processing, spatial analysis using Geographic Information Systems (GIS), map creation through the application of the Inverse Distance Weighting (IDW) interpolation method, and statistical data processing. In addition, the statistical data required for the study were obtained from the National Statistical Committee of Uzbekistan (State Committee of the Republic of Uzbekistan on Statistics, 2025).

Data collection and description of air pollutant emissions

To assess the air pollution status in Tashkent city, data on the amounts of carbon monoxide (CO) emitted into the atmosphere from 1994 to 2023 were obtained from the archives of the Hydrometeorological Service Agency under the Ministry of Ecology, Environmental Protection, and Climate Change of the Republic of Uzbekistan. These data were collected from 12 monitoring stations located in various parts of the city for each month of every year within the study period. Using the monthly data, seasonal averages were calculated. For example, to determine the average value for the winter season, the mean concentration for December, January, and February was computed for each monitoring station.

Processing and integrating collected data using ArcGIS Pro software

GIS provides a practical and effective environment for integrating, analyzing, and visualizing data alongside new spatial data sources (Dobesch et al., 2013). A Geographic Information System (GIS) is a computer-based information system designed to study geographical phenomena, effects, and events occurring on the Earth's surface (Khan, 2019; Jung, 2019).

Therefore, the collected data were organized in Microsoft Excel (including station name, date, CO concentrations in µg/m³, and X and Y coordinates), and then imported into ArcGIS 10.x for geospatial analysis preparation. The Excel table was imported into the geodatabase using the Conversion Tools → Excel to Table function, followed by the creation of a point shapefile using the XY Table to Point tool. The attribute table was then reviewed to verify the units of CO and SO_2, and any null or incorrect values were removed.

Spatial analysis using the IDW Interpolation method

To visualize the spatial distribution of CO across the city, the Inverse Distance Weighting (IDW) interpolation method was applied. IDW is a deterministic technique widely used in environmental research to estimate values at locations where measurements are not available, based on the values recorded at surrounding points. The interpolation algorithm objective is to use measurements $z(s_i)$, $i= 1,2,...., n$, set in points locations, to create an probability of the point value of the experimented property in the location s0 when the observations are not existing. The weights given to elements are a function of the distance of the element from the estimate location. The weights are typically acquired through the inverse squared distance (signified by the exponent -2), and the estimate function of interpolation can be set as:

$$\hat{z}(s_0) = \frac{\sum_{i=1}^{n} z(s_i) d_{i0}^{-2}}{\sum_{i=1}^{n} d_{i0}^{-2}} \quad (1)$$

where d_{i0} is the distance by which the s_0 and the s_i are detached (Lloyd, 2010). Many studies have been carried out on air quality assessment using interpolation methods, the results of more than 70 methods showed that in most cases, the geostatistical processes is best than the deterministic techniques (Eslami and Ghasemi, 2018). According to this method, the influence of a data point decreases as the distance from the location of interest increases. Therefore, IDW is considered suitable for analyzing urban pollution patterns. In this study, interpolation was performed within the administrative boundaries of Tashkent city using the Spatial Analyst → IDW interpolation tool. The resulting surface was saved in raster format.

In the Raster Symbology → Classified menu, the interpolated values were manually divided into 10 distinct classes. Each class was then assigned a code ranging from 1 to 10 using the Reclassify tool. The final output was formatted in the Layout module using A4 page size, including a legend, a north arrow, a scale bar, and the administrative boundaries of Tashkent city and its districts.

The coordinate system used for the map was WGS 84 UTM Zone 42N. The resulting map was exported in PNG format at 300 dpi resolution. A total of seven maps were generated to represent the temporal distribution of pollutant concentrations at five-year intervals covering the period from 1994 to 2023.

Statistical data processing

As part of the methodological framework, the temporal variation of each gaseous pollutant (CO) was examined alongside spatial mapping. Graphical analyses and descriptive statistical techniques were employed to assess changes in pollutant concentrations over time. This approach facilitated the identification of long-term trends, peak concentration periods, and potential correlations with factors such as urban expansion, increased vehicle numbers, and the implementation of environmental regulatory measures.

RESULTS AND DISCUSSION

Seasonal variations of carbon monoxide (CO) in urban air from 1994 to 2023

As illustrated in Figure 3, the amount of carbon monoxide (CO) emitted into the urban atmosphere has generally decreased across winter season between 1994 and 2023. The highest seasonal CO concentrations for the entire study period were recorded in 1994. During that year, the average CO level in winter exceeded 3000 µg/m³. By 2003, the wintertime CO concentration had declined to approximately 1800–1900 µg/m³, and further decreased to around 1500 µg/m³ by 2008. However, during the subsequent five-year period, CO levels again rose above 2000 µg/m³. A declining trend resumed after 2013. In the most recent five-year period (post-2018), CO concentrations began to rise once more. By 2023, the average CO level in most parts of the city ranged from 1600 to 2000 µg/m³, with eastern areas reaching up to 2600 µg/m³.

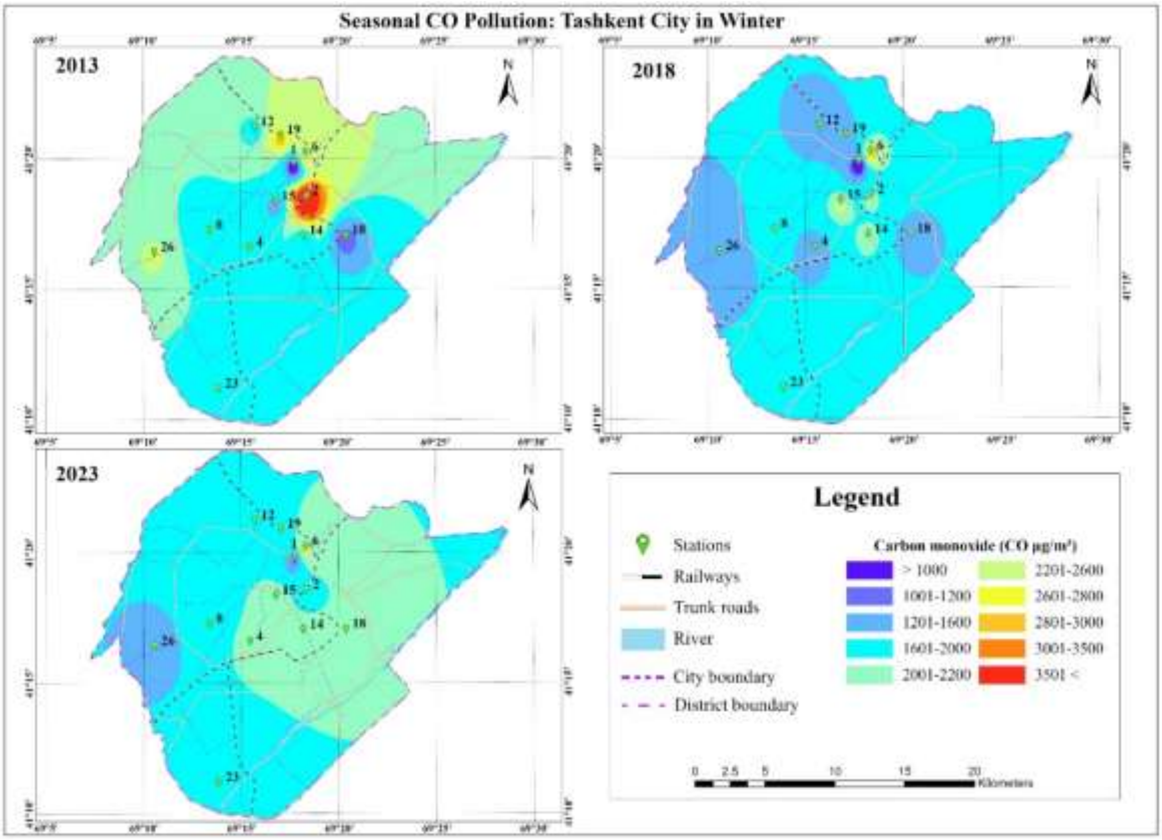

Fig.2. Seasonal variation in CO emissions into the air in Tashkent city during winter between 1994 and 2008
Source: own study.

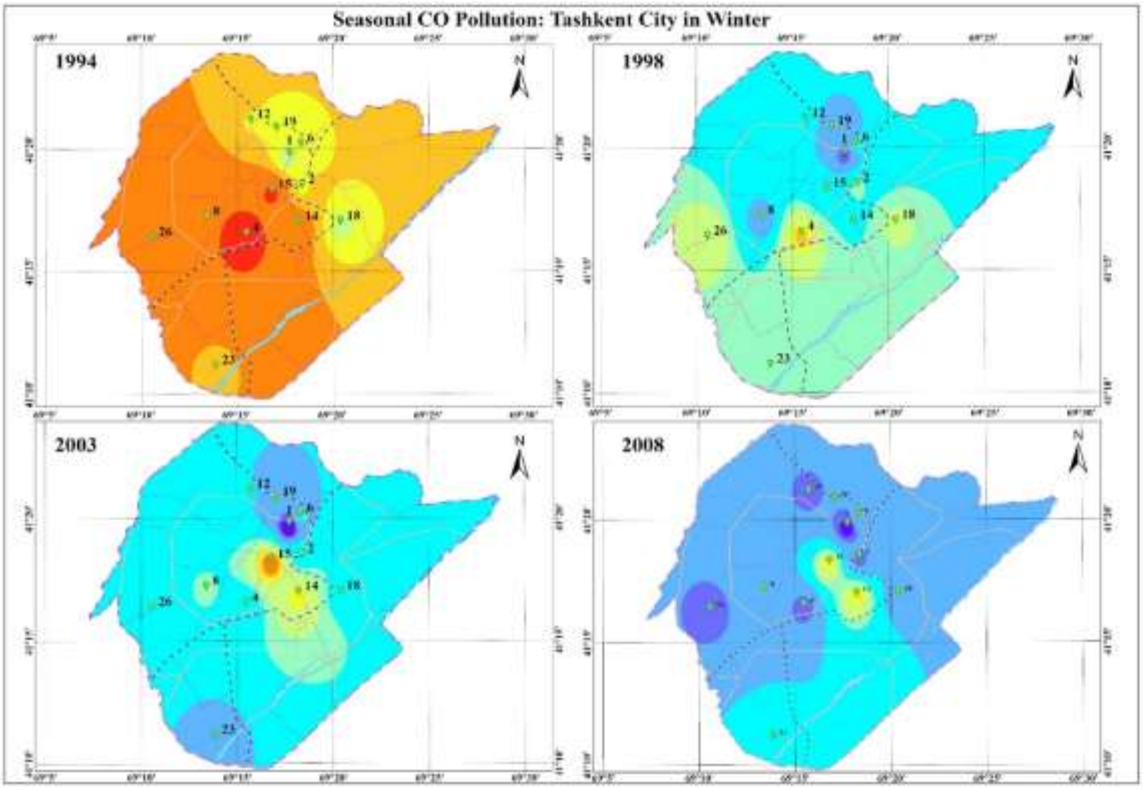

Fig.3. Seasonal variation in CO emissions into the air in Tashkent city during winter between 2013 and 2023
Source: own study.

Based on the analysis of maps and diagrams, it can be concluded that the concentrations of emitted pollutant sharply increased during the period from 1994 to 2003. Over the studied period, the level of CO generally showed a decreasing trend. Air pollutants originate from both natural and anthropogenic sources. Natural sources of air pollution include volcanic activity, wildfires, dust storms, oceans, and others. Anthropogenic sources comprise industry, municipal services, transportation, and others (Richard, 1994; Richard, 2016; Zhao, 2021). Urban air pollution is predominantly influenced by anthropogenic factors, and Tashkent city is no exception. As the largest metropolis in our region, Tashkent has experienced in recent years industrial growth, an increase in the number of vehicles, and intensified construction activities, all of which negatively impact the ecological situation, particularly air quality.

Considering the sources of CO emissions (Oke, 2025), the industrial, construction, and transportation sectors of Tashkent city were analyzed in this study.

The impact of industry on air pollution in Tashkent city

Tashkent's favorable geographic location—situated at the crossroads of major international and local railway and highway networks—has contributed to the city becoming a key industrial hub. Additionally, its status as the capital, abundance of water and energy resources, proximity to raw materials for processing industries, availability of skilled labor, and the presence of a large consumer market have all significantly influenced industrial development.

As of July 1, 2024, there were approximately 11,000 active industrial enterprises operating in Tashkent city. Between January and July 2024 alone, 873 new industrial enterprises were established [toshstat.uz]. Out of the 68,000 industrial enterprises across the country, more than 11,000, or nearly 20%, are located in Tashkent.

Table 1. Changes in the Share of Industrial Production by Districts of Tashkent City

Districts	In 2010 (%)	In 2015 (%)	In 2020 (%)	In 2025 (january-march, %)
Uchtepa	3,9	6,1	7,5	4,0
Bektemir	5,1	7,0	6,8	11,4
Yunusabod	5,0	7,2	6,4	4,0
Mirzo Ulugbek	12,2	10,9	7,6	7,7
Mirobod	8,4	8,2	9,2	6,3
Shaykhontohur	21,2	11,4	6,1	6,6
Olmazor	5,8	11,6	6,8	6,7
Sergeli	7,4	7,3	9,1	12,1
Yakkasaroy	5,3	5,4	6,0	5,0
Yashnobod	10,8	15,1	28,2	20,4
Chilonzor	14,9	9,8	6,3	9,2
Yangihayot	-	-	-	6,7

Source: Own compilation based on statistical materials from toshstat.uz.

Analysis of the table shows that until the 2010s, the largest share of industrial production by city districts belonged to Shaykhontohur, Chilanzar, and Mirzo Ulugbek districts. By 2025, Yashnobod, Sergeli, and Bektemir districts became the largest industrial centers, contributing a total of 43,4% of industrial output.

From this, it can be concluded that after the 2010s, major industrial enterprises producing significant environmental pollutants were relocated from the city center to the outskirts and were modernized with contemporary equipment. Environmentally, the most polluting industries such as metal processing, rubber and plastic manufacturing, automobile production, and oil refining were moved to suburban or peripheral areas. In contrast, industries that emit fewer pollutants and require highly skilled labor and innovative technologies were maintained within the city.

Impact of transportation on air pollution in Tashkent city

The rapid urbanization process, population growth, and expansion of industrial and other sectors in Tashkent city have also led to an increase in the number of vehicles. Consequently, numerous ecological issues related to transportation have emerged, among which air pollution has become particularly pressing. Incomplete combustion of fuel in automobile engines results in the emission of (1) nitrogen oxides (NO_x); (2) sulfur dioxide (SO_2); (3) carbon dioxide (CO_2); (4) fine particulate matter ($PM_{2.5}$ and PM_{10}); and (5) unburned hydrocarbons (CH). These emissions contribute to deteriorating human health, acid rain, smog formation, and global warming, among other problems.

As of January 1, 2023, the number of privately owned passenger cars in Tashkent amounted to approximately 638,800. On average, around 1,1 million vehicles operate daily in the city, including 850,000 registered in Tashkent and 250,000 entering from surrounding regions. The increase in the number of private vehicles contributes to the worsening of environmental conditions, an increase in road traffic accidents, and a reduction in traffic speed to 9-11 km/h during peak congestion hours (Ziyayev, Vohidov, 2022).

Analysis of maps illustrating the seasonal dynamics of CO emissions reveals that during the period from 1994 to 2008—particularly in the summer—the levels of CO released into the atmosphere were significantly higher compared to recent years. This indicates a decline in CO emissions over the study period when compared to the early 1990s. However, in recent years, there has been a relative increase in CO levels during the winter season.

CONCLUSION

This study analyzed the seasonal dynamics of carbon monoxide (CO) emissions in the air of Tashkent city over the period from 1994 to 2023. The results indicate that although the amounts of these gases released into the atmosphere have decreased compared to 1994, a recent upward trend has been observed. During the study period, the highest emission levels for all three pollutants were recorded in 2003. Seasonal analysis revealed that CO concentrations peaked during the summer. This pattern is primarily attributed to the increased use of fuel oil and other heating fuels during the cold season. The analysis demonstrated that industrial activity, construction, and the transport sector in Tashkent play significant roles in the emission of air pollutants. In recent years, the most polluting industrial enterprises in the city center have been relocated to the outskirts. Additionally, the proportion of industries related to coke and petroleum refining, rubber and plastic products, chemical manufacturing, and fabricated metal products has decreased, whereas the share of metallurgical production has increased. Furthermore, there has been a sharp increase in construction activities in the city, accompanied by a reduction in green spaces. The number of vehicles and the types of fuel they use have also significantly influenced the amount of pollutant gases emitted into the air.

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