THE INFLUENCE OF CIRCULATION PROCESSES ON THE ECOLOGICAL CONDITION OF TBILISI CITY IN THE BACKGROUND OF CLIMATE CHANGE

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Abstract

Since the second half of the twentieth century, the atmosphere, as the main component of the environment, has undergone significant changes due to the impact of anthropogenic factors, which have resulted in global climate change and its impact on humans and ecosystems. The consequences of climate change are often complex in nature, which makes it particularly difficult to determine the cause-and-effect relationship between them. The paper presents the results of the monitoring of atmospheric polluting components for Tbilisi City territory (period of March 2023), when there was observed smog, accompanied by a sharp worsening of visibility and the synoptic situation, causing the mentioned condition was determined. The main aim of the study is detection of atmospheric pollution level in Tbilisi, and assessment of anthropogenic sources. Studies have revealed, that the main synoptic situation for Tbilisi, during which the total pollution increases, is a "high-pressure trough", which is mainly associated with the stationary anticyclone of Kazakhstan, Western Siberia, or Eastern Siberia. During the mentioned situation, the concentration of polluting substances in the atmosphere (for Tbilisi city) increases. In almost every related case: Wind speed at the surface of the earth is less than 5 m/s; The influence of the front and stream currents is not observed, and the wind speed is also reduced at the height; Turbulent mixing is weak at 1-3 m/s; Cases of inversion and isotherms are common. Under these conditions, the level of pollution in the ground layer increases as a result. In the paper, the dynamics of quantitative change of individual pollutant sources, and aerosols in the atmosphere is revealed. Research has established, that the ecological condition of the atmosphere depends on the specificity and intensity of the pollution source, on physical-geographical and meteorological conditions (inversion, isothermy), and synoptic situations, typical for Tbilisi.

Keywords: Climate change, smog, synoptic situation, Tbilisi, pollution

I. Introduction

Starting with the second part of the 20th century, atmosphere, as a main component of the environment underwent substantial changes due to impact of anthropogenic factors that as a consequence caused global climate changes and its influence on human and ecosystem [1].

Polluting agents emitted in the troposphere not only impact on human and ecosystem, but also generate harmful substances. There are two factors of atmosphere pollution, namely natural and anthropogenic-technogenic factors.

One of biggest problems of the modern world is a global environmental pollution that causes climate changes [2]. Following civilization development, a human modifies environment and ecosystem, in general. All this is resulted in deterioration of social environment, human health status that is already of global nature and covers the entire planet [3, 4, 5].

Elemental processes become more frequent and intense along with climate changes. Intensification of some of these events is related to the change of global climate system.

During the past century, in parallel with upcoming of so-called "era of industrialization", the problem of atmosphere pollution became relevant in the entire world, including Georgia. Alongside with technological progress, the number of harmful emissions has continuously increased that caused surpass of maximum permissible concentrations of separate components entering the atmospheric air [6, 7].

The last decade clearly showed that under conditions of demographic explosion and intense development of manpower the tomorrow of the Earth and its future in general, mostly depends on the fact how we can protect the natural environment from anthropogenic impact. That is why the environmental protection problem got an extremely actual role among the most acute problems facing the mankind today [8].

Climate change results are frequently of integrated nature that especially complicates establishment of cause-and-effect relationship between them [9]. The scientific literature has repeatedly studied the issues of atmospheric circulation and dispersion of air pollution [10], effects of atmospheric processes on smog formation [11], impact of meteorological parameters of atmospheric pollution [12], etc.

The article represents the research results of monitoring of Tbilisi atmosphere polluting ingredients (2022-2023, March), when a smog accompanied by rapid deterioration in visibility was recorded at the territory of city. Synoptic situation causing the mentioned state was established.

The research **goal** is a qualitative and quantitative assessment of anthropogenic sources of Tbilisi city atmosphere pollution; establishment of quality conditions of atmospheric air; quantitative assessment of main atmosphere polluting ingredients: solid suspended particles (PM10 and PM2.5), sulfur dioxide (SO_2) and carbon oxide (CO) with the use of monitoring data, identification of atmosphere pollution level and its impact on human health under Tbilisi conditions.

It was established by studies that so-called high-pressure baric field, which is mainly related with stationary anticyclone of Kazakhstan, western Siberia or eastern Siberia is the most characteristic synoptic situation for Tbilisi, during which the total pollution increase occurs. During the mentioned situation, atmospheric concentrations of polluting substances (Tbilisi city) increase almost in all cases. Wind velocity near the Earth surface is less than 5 m/sec; front and stream flow effect is not observed, wind velocity is decreased at a height, as well; turbulent mixing is weak and equals to 1-3 m/sec; there are frequent cases of inversion and isothermy. Under the mentioned conditions, pollution level in the surface layer increases.

Dynamics of quantitative changes of aerosols emitted in the atmosphere from separate polluting sources is revealed in the work.

It is established by the study that ecological state of the atmosphere depends on peculiarity and intensity of pollution source, physical-geographic and meteorological conditions (inversion, isothermy), and synoptic situations under complex microclimate and physical-geographic conditions of Tbilisi city. The mentioned state results in increase of surface layer pollution level.

Meteorological conditions of atmosphere pollution

Tbilisi is located in the eastern Georgia, in the Tbilisi hollow, and is spread on both embankments of Mtkvari (Kura) River, at 380-600 meters height from the sea level.

Complex terrain of Tbilisi territory predetermines peculiarities of its natural environment. It is generally represented in the form of hollow. Terrace system of Mtkvari River, the nature of its horizontal and vertical dissection puts the city-planning measures within narrow bounds, complex topographic conditions established thereof hinders proportional territorial growth of the city. City expansion put its relief form under influence of anthropogenic factors, and as a consequence drastically changed its morphometrical characteristics. Terrace forms of city building modified original form of water-dividing ridges and slopes [13, 14].

Aerosols are non-uniformly distributed in Tbilisi that depends not only on distribution of the pollution focuses, but also on meteorological conditions (inversion, isothermy). The main among meteorological processes is an atmosphere circulation, when aerosols are spread in both, vertical

and horizontal directions. Aerosols transfer intensity depends on relief, meteorological conditions and wind regime.

Dissipation or diffusion of aerosols generated by the different sources occurs very intensely by means of turbulent mixing peculiar for surface air. In this case aerosols are dissipated and their concentration is getting smaller, that depends on atmosphere stratification [4, 5].

It is obvious that duration and repetition of meteorological conditions cause severe pollution of Tbilisi air compared to those cities, which are characterized by relatively less duration and repetition of elemental meteorological events [13].

Complex terrain and meteorological conditions of Tbilisi substantially change characteristics of general circulation of atmosphere that causes peculiar character of aerosols distribution, for which sustainable condition of atmosphere is especially important. Duration of aerosols availability in the atmosphere is considerably influenced by character of the vertical profile of meteorological elements (temperature, wind, humidity).

Wind velocity is reduced by 20-30% in the city, compared to suburban areas, that is caused by air flow inhibition between buildings. Above buildings the wind velocity rapidly increases (approximately according to logarithmic law). In the cases, when temperature inversion is not recorded in Tbilisi, wind velocity at heights may increase up to the value, which exceeds velocity peculiar for open places and jet flow may originate at heights. Wind direction and velocity are changeable enough, especially during strong winds.

Convection development, which in the surface layers is accompanied by air mass shift towards city center, may be associated with a "heat island". The observations show that in case of light wind, there are originated air flows routed to the city center with 2-3 m/sec velocity, and ascending vertical flows headed to the central part. These factors promote water steam condensation and precipitation enhancement in the city [14, 15].

Water steam content in the city center is reduced in comparison to its suburban areas that become especially noticeable in summer, since evaporation from asphalt and stone surface is low. Relative humidity is 10-15% less in summer in the central parts than in outskirts. Decrease of wind, increased cases of inversion, shift to the center of an air bringing admixtures from suburban areas, promotes admixture concentrations growth in the central part of the city. Extremely hazardous cases of air pollution in the city are observed during formation of fog and its variety – smog.

II. Methods

In order to evaluate atmospheric pollution in Tbilisi city, there have been used the materials of atmospheric air pollution monitoring of the National Environmental Agency, who carries out observation on air background pollution and measurements of aerosol and harmful substance concentrations in automatic mode. The work also makes use of indicatory measurement results for Tbilisi city.

The following polluting agent concentrations are measured citywide, namely: solid suspended particles PM10 and PM2,5, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO2) and ozone (O_3).

Standard statistical, climatological and graphical analysis research methods are used for study. Data processing is based on the methods of multifactorial statistical analysis [16].

III. Results and Discussion

The research makes use of research results of the following polluting ingredients monitoring data (2022-2023, March) conducted at the atmospheric air observation automatic station located at Tsereteli Avenue, namely: solid suspended particles PM10 and PM2,5, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2).

Tbilisi city environmental pollution degree was assessed based on atmospheric air

observation and results of automatic station monitoring materials study. We made comparison and graphical analysis of materials of polluting ingredients ($PM_{2.5}$, PM_{10}, SO_2, O_3, NO_2 and CO) monitoring carried out in 2022-2023, March (Fig. 1, 2, 3, 4, 5); qualitative and quantitative comparison of anthropogenic sources of atmosphere pollution and identification of atmospheric air quality state.

We have established synoptical and meteorological conditions which caused smog registered in March 2023.

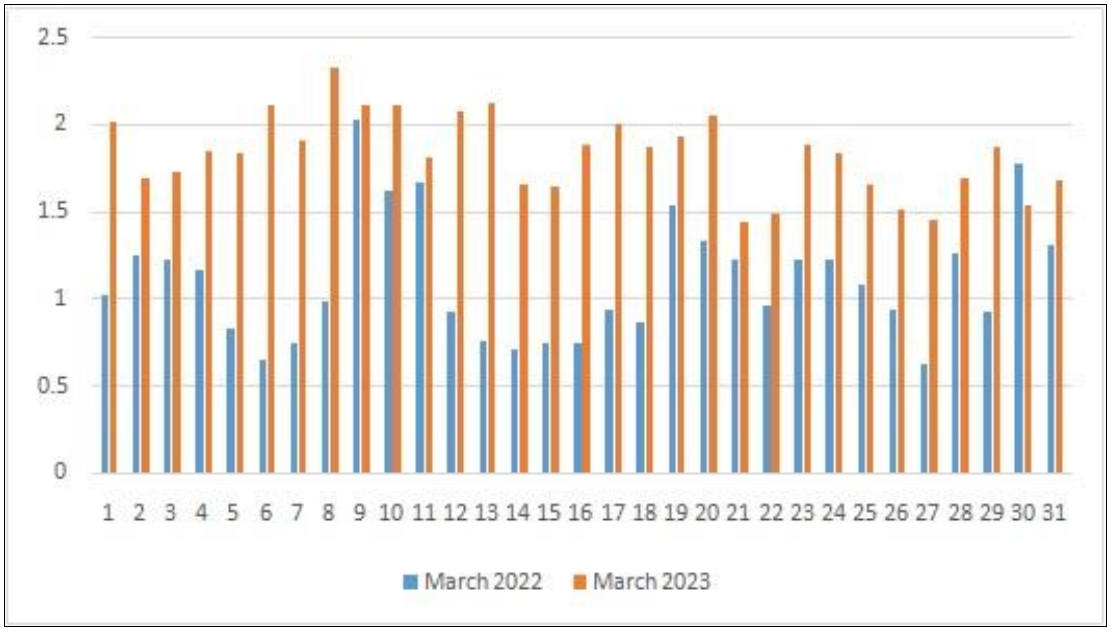

Figure 1: *Carbon Monoxide (CO) dynamics (March 2022 and March 2023)*

As is seen from the diagram, according to March 2023 data, carbon monoxide (CO) concentration over the course of a month surpassed the data of March 2022, though exceedance of the maximum permissible concentration was never recorded in any case. Main sources of CO entering into atmosphere are exactly vehicle emissions and natural gas consumption. Such concentration of carbon monoxide is presumably caused by city motor park upgrading and control over vehicles carried out by technical inspection. CO has a substantial impact on human health, in particular causes cardiovascular diseases, fetal development delay, while in case of inhalation in large amount a lethal outcome may come (Fig. 1).

Solid particles (PM10) dynamics is not stable. There are days, when March 2022 data prevail over March 2023 data and vice versa (Fig. 2). In both cases the situation is complicated enough. Taking into account that PM10 maximum permissible concentration is 40 mkg/m^3, it is clearly seen that in March 2022 concentration of solid particles (PM10) exceeded a limit. However, much more complicated situation was in March 2023, since concentration of solid particles was sharply increased and far exceeded the previous year level, in particular during 17 days. Especially should be noted the period from 8^{th} to 21^{st} of March, when solid particles concentration exceeded maximum permissible norms that was caused by frequent penetration of air masses from Kara-Kum desert to Georgia during the eastern process and as a consequence a smog was recorded in the period from $10^{th}$to 17^{th} of March. This is an emergency situation, since such a high content causes severe diseases in humans like eye irritation, asthma, bronchitis, tumors, intoxication etc.

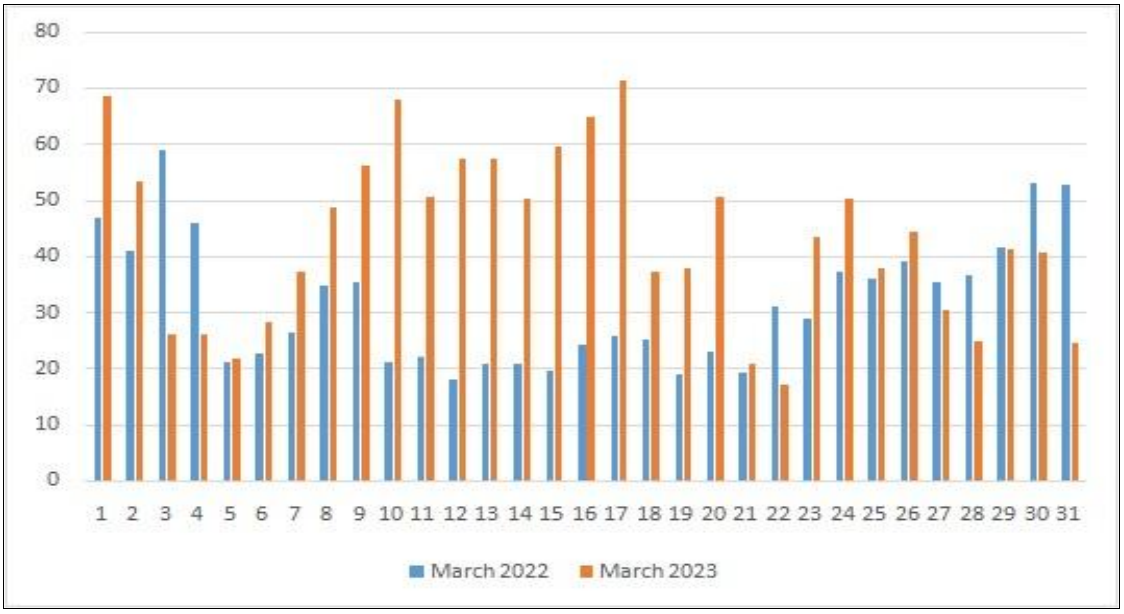

Figure 2: *Solid particles (PM10) dynamics (March 2022 and March 2023)*

Similar to PM10 particles, PM2.5 concentration exceeded MPC (Fig. 3). In both cases (2022-2023 March) the cases of exceedance of maximum permissible concentration were recorded. Maximum permissible concentration for PM2.5 is 25 mkg/m^3. In March 2022, PM2.5 concentration during 7 days surpassed the maximum permissible concentration (basically in the beginning of the month), while in 2023 – in the course of 22 days, mainly in the middle of month, from 10th to 20th March (that was caused by air mass entrance from Kara-Kum desert during the eastern process).

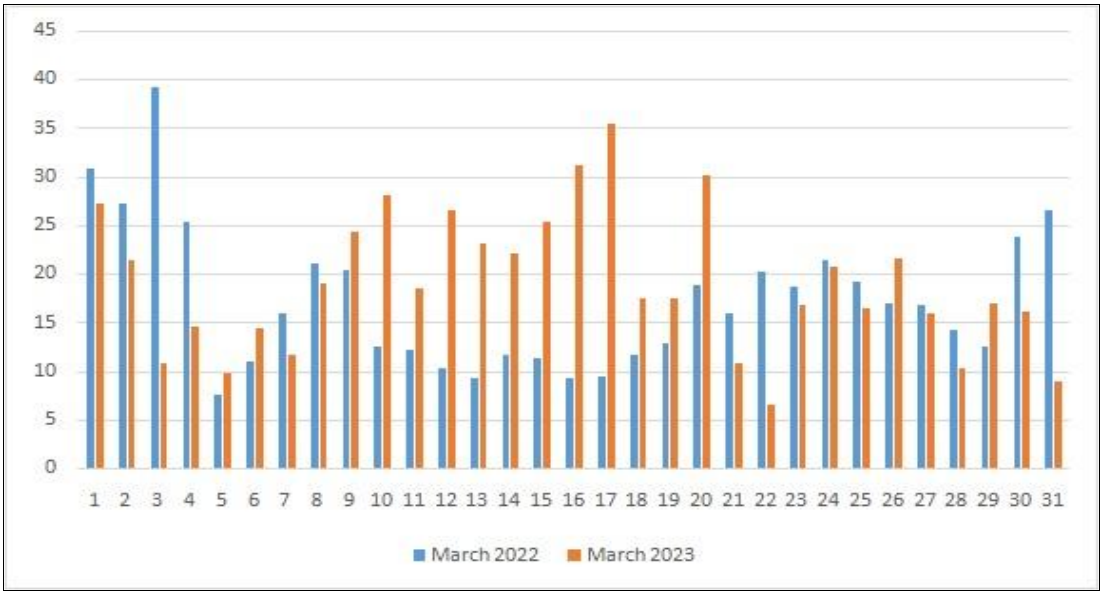

Figure 3: *Solid particles (PM2.5) dynamics (March 2022 and March 2023)*

Here one has to take into account the circumstance that PM2.5 particles are of very small size and respectively they are very light. As a consequence, they present in suspended state in the atmospheric air (due to very low sedimentation rate, since PM2.5 particle deposition rate is 10-time lower compared to PM10 particles). Small dispersive PM2.5 particles available in the air due to their small mass and size easily penetrate human lungs through respiratory passages; these particles are discovered even in the blood composition. Proceeding from this fact they can likely cause different types of diseases and, therefore, pose a threat to human health.

96% of urban population live in the environment of high concentrations of solid dust particles (PM2.5), which excesses WHO recommendations (5 mkg/m^3), while less than 1% - in the medium of such concentrations of PM2.5 particles, which surpass annual permissible level of 20 mkg/m^3 established by European Union.

The sulfur dioxide (SO_2) concentration decrease trend, not counting several days, is clearly seen from the diagram (Fig. 4). Maximum value 58.68 mkg/m^3 was recorded on 21st of March, 2022, while in 2023 the maximum was registered on 6th of March and was equal to 53.06 mkg/m^3. This state may be considered as satisfactory, since maximum concentration of sulfur dioxide according to these data approximately approaches (not exceeds) the maximum values. The mentioned circumstance is caused by the strict control over motor transport and by fuel quality check performed in recent years.

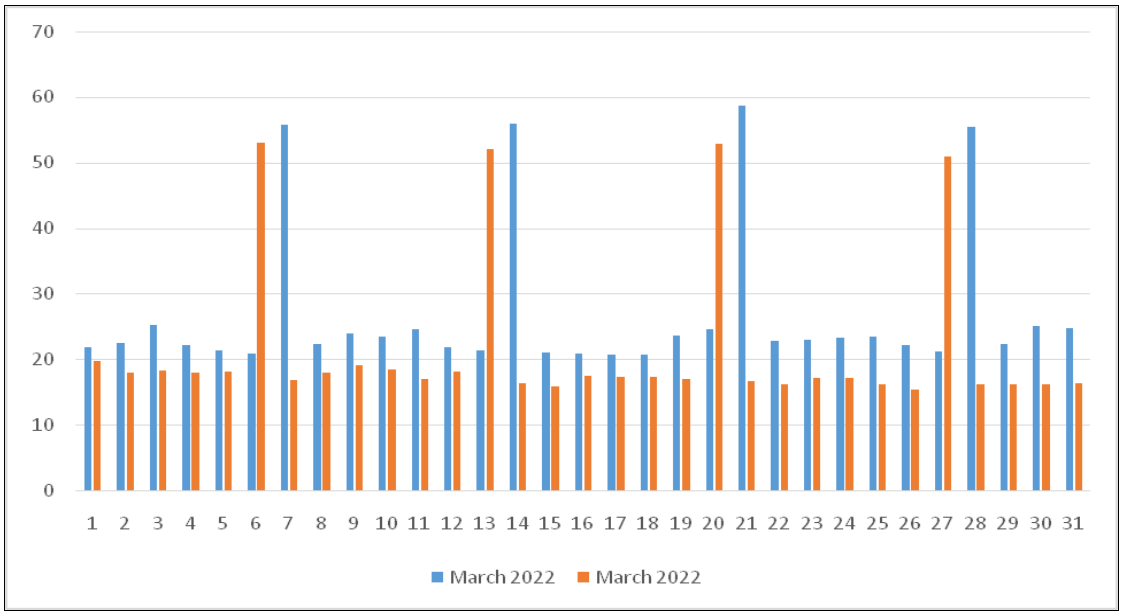

Figure 4: *The sulfur dioxide (SO_2) dynamics (March 2022 and March 2023)*

Nitrogen dioxide (NO_2) MPC equals to 40 mkg/m^3. It is well seen from the diagram (Fig. 5) that according to March data nitrogen dioxide concentration in both cases is more than 40 mkg/m^3 in the majority of days and approximately varies between 40 and 100 mkg/m^3, that 1.5-times exceeds maximum permissible concentration. The mentioned circumstance may be caused, as it was already mentioned, by features of circulation processes peculiar for the region and by frequent cases of inversion and isothermy. Pollution level in the surface layer increases under mentioned conditions. It is also important that aerosol concentrations growth under these conditions leads to ozone concentration increase and formation of photochemical smog, as a result.

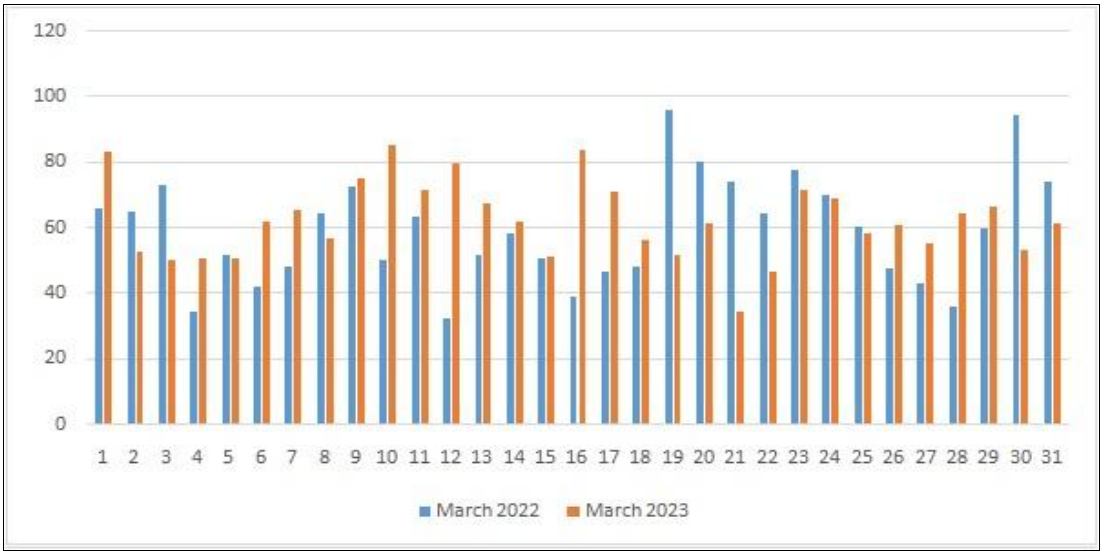

Figure 5: *Nitrogen dioxide (NO_2) dynamics (March 2022 and March 2023)*

IV. Conclusions

- Ecological state of the atmosphere depends on pollution source specificity and power, as well as on microclimatic, physical-geographical, and meteorological conditions peculiar for this place, and the most important, on the level of economic development and environmental awareness of the country.
- Maximum concentration (78%) of atmosphere polluting substances under Tbilisi conditions is caused by high intensity of motor transport use, and by physical-geographical, microclimatic and meteorological conditions.
- Solid particle concentrations were rapidly increased in March 2023 that was stipulated by the frequent penetration of air masses from Kara-Kum desert to Georgia, as a consequence of which a smog was recorded for several days.
- According to National Environmental Agency data, due to air masses (desert dust) invasion, a daily rate of PM10 particles at the Tsereteli Avenue was exceeded 47-times in 2022, and 78-times – in 2023.
- According to National Environmental Agency data, in some cases nitrogen dioxide (SO2) content at the Tsereteli Avenueis 10-times higher compared to other territories.
- Under conditions of Georgia, there is established a negative impact of atmosphere pollution on human health, and meteotropic diseases, malignant tumors, mutation etc are revealed.
- It was established by the studies that a synoptic situation the most peculiar for Tbilisi, during which a total pollution increases, is a high-pressure baric field (anticyclone), which is mainly associated with stationary cyclone of Kazakhstan, Western Siberia or Eastern Siberia. During the mentioned situations, concentrations of polluting agents in the atmosphere of Tbilisi increase almost in all cases. Wind velocity near the Earth surface is less than 5 m/sec; front and stream flow effect is not observed, and wind velocity is decreased at a height, as well; turbulent mixing is weak and equals to 1-3 m/sec; there are frequent cases of inversion and isothermy. Under the mentioned conditions, pollution level in the surface layer increases.
- Air quality deterioration in March, 2023 in Tbilisi was caused by increase in solid particles content. The World Health Organization considers that the smallest dust particles present in the air, concentration of which at this moment in Tbilisi exceeds maximum permissible level, more than other pollutants do damage to human health. Their inhalation heightens the risk of cardio-vascular and respiratory diseases, as well as lung cancer.

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