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Statistical Characteristics of Monthly Mean and Annual Concentrations of Particulate Matter PM2.5 and PM10 in Three Points of Tbilisi in 2017-2022

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ABSTRACT

Results of the detailed statistical analysis of the average monthly and annual concentrations of particulate matter PM2.5 and PM10 at three locations in Tbilisi (Kazbegi av., Tsereteli av. and Varketili) in 2017-2022 are presented. An analysis of the correlations between the indicated characteristics of air pollution has been carried out. The variability of the average annual values of PM2.5 and PM10 in the study period of observations was studied. In particular, it was found that in 2020-2021 there was a significant decrease in the average annual concentration of aerosols due to restrictions on the movement of vehicles associated with the covid-19 pandemic. It is noted that for the entire observation period, the average annual concentration of PM2.5 and PM10 was above the permissible norm.

Key words: *Atmospheric aerosols, particulate matter, PM2.5, PM10.*

Introduction

Over the past four decades at the M. Nodia Institute of Geophysics, TSU, as well as with his participation, carried out theoretical and experimental studies of the physical characteristics and variations of mineral and secondary aerosols (size distribution, weight and number concentrations, coagulation, condensation and ice-forming properties, optical characteristics, the effect of ionizing radiation on the formation secondary aerosols, influence on solar radiation, connection with thunderstorm and hail processes, as well as atmospheric precipitation, environmental aspects of air pollution, numerical modeling of the distribution of particulate matter in various regions of Georgia, etc.) [1-4].

Thus, a theoretical study of the influence of the periodicity of the source of particles on the process of their coagulation was carried out; modeling of processes that control the change in dispersion and the state of various coagulating systems [5].

The spatial and temporal changes in the concentration of solid impurities in the area with a large source of emissions in the city of Zestaponi and the conditions for the formation of aerosols and their accumulation in cities were studied [6].

The analysis of data on the distribution of aerosols with a radius of more than 0.35 μm over the territory of Georgia was carried out. In particular, it was found that within the lower five-kilometer layer of the atmosphere, the size distribution of aerosols is quite stable and changes little with height and under the influence of cloudiness. However, on days with cumulus clouds, compared to cloudless days, the mass of aerosols in a five-kilometer atmospheric layer increases by about 1.4 times, and on days with clouds of various types, including cumulus, by 2.5 times [7–11].

The results of studies of the long-term dynamics of surface air pollution in Tbilisi (weight concentration of aerosols, nitrogen oxides, sulfur dioxide, ozone) are presented in [12,13].

Works have been carried out on the numerical calculation of the spectral density of the aerosol optical depth of the atmosphere according to the total intensity of direct solar radiation, modeling the transfer of solar radiation in the atmosphere with allowance for aerosol scattering, and determining the aerosol optical depth of the atmosphere for various wavelengths [14, 15].

The results of studies of long-term variations in the aerosol optical depth of the atmosphere for individual points in Georgia and for the territory of Georgia as a whole were presented in [15-21]. In particular, it was found that the increase in the total aerosol pollution of the atmosphere in Georgia from 1928 to 1990 is exponential.

Anthropogenic, random and background values of the aerosol optical depth of the atmosphere (AOD) have been established for various regions of Georgia in the period from 1928 to 1990. Between the stations (Tbilisi, Telavi, Tsalka, Anaseuli, Senaki, Sukhumi) there is a high linear correlation both in the observed AOD values and in the values of their random components.

It was found that the level of atmospheric pollution by aerosols of the optically active size range over Kakheti differs little from this level over Tbilisi. In Western Georgia (Anaseuli, Senaki, Sukhumi), the level of air pollution is much lower than in Kakheti and in the areas adjacent to Tbilisi.

A model of the spatial and temporal distribution of AOD in Georgia has been created and maps have been constructed that show the dynamics of changes in AOD over the specified territory for five-year periods from 1956 to 1990. The contribution of local sources of aerosol pollution of the atmosphere to the AOD value is estimated, which, in particular, in the period from 1981 to 1990 in Tbilisi and Telavi is 33% each, Anaseuli, Senaki, Sukhumi - 10%. It is shown that on weekdays AOD values in Tbilisi and Kakheti are higher than on weekends.

Results of aircraft studies of aerosol pollution of the lower five-kilometer layer of the troposphere and Kakheti in 1973-1977 in particular showed the following. More than 70% of the mass of aerosols 0.2–4.0 μm in size is concentrated in the lower three-kilometer layer of the atmosphere. On cloudless days over Kakheti, the mass of aerosols in a vertical air column 5 km high is 66 mg/m², on days with cumulus clouds it is 90 mg/m², and on days with varying cloudiness it is 165 mg/m². In Tbilisi, the proportion of AOD for mineral aerosols of its total value is about 23%, for sulfates - 26%, and for industrial dust, nitrates, etc. - 50%. It is shown that the aerosol is more hygroscopic in urban areas than in rural areas. In Kakheti, a significant excess of aerosol content on weekdays compared to weekends is observed at an altitude of 1.0 km for particles with sizes $d>0.7$ μm, $2.0\leq d<4.0$ and $d\geq4.0$ μm. Variations in AOD in Kakheti are approximately 49% due to the content of radon in the lower three-kilometer layer of the atmosphere and only 10% due to solid aerosols larger than 0.7 μm.

In clouds, as well as in the free atmosphere, there is a direct relationship between the level of air ionization (radon and cosmic radiation) and the content of condensation nuclei. Changing the ionization intensity from 5.75 ion pairs $cm^{-3}sec^{-1}$ to 8.0 ion pairs $cm^{-3}sec^{-1}$ increases the content of condensation nuclei by a factor of 1.56. In this case, the proportion of ionization intensity due to radon and short-lived products of its decay is small and does not exceed 10%.

A direct correlation was found between AOD and ozone content in the troposphere over Tbilisi, indicating the important role of ozone in the formation of secondary aerosols. It has been shown that AOD is a fairly representative characteristic of surface air pollution with small aerosols (at least up to a diameter of 0.8 μm) [15–20].

Studies [22-24] showed that the dynamics of total aerosol pollution in Georgia and the North Caucasus (Kislovodsk) is similar.

The work [25] presents some results of modeling the distribution of the aerosol optical depth of the atmosphere (AOD) over the territory of Georgia in accordance with the previously proposed methodology for the combined analysis of satellite and ground-based AOD measurements in Tbilisi [26, 27]. In particular, it was found that elevated AOD values are observed in places with high cloudiness. Despite the fact that in Tbilisi there is a strong aerosol pollution of the atmosphere, the value of the AOD on days with clouds here differs slightly from the AOD over other cities (Kutaisi, Batumi) and even less than in places with high cloudiness. On cloudless days, AOD values decrease with increasing distance from the main source of air pollution in the city of Tbilisi [25]. This quite satisfactorily agrees with the previously obtained results on the distribution of AOD over the territory of Georgia in cloudless weather [16, 19–21].

The issue of monitoring aerosol pollution of the atmosphere in Georgia was discussed as part of the global air pollution monitoring network [28,29]. The issues of prospects for active impacts on atmospheric aerosols in order to clean the air from them were discussed [30, 31].

A theoretical model of heterogeneous nucleation on modified aerosol particles has been developed. In this case, a generalized heterogeneous nucleation equation was used, which takes into account the dependence of the interfacial specific surface energy on water vapor supersaturation. The issues of the formation of secondary ice crystals and the influence of particle sizes on the ice-forming activity of aerosol are considered [32, 33].

A refined concept of the interaction of aerosols with convective clouds has been developed, taking into account electrical, ionization, and other processes occurring in the atmosphere and clouds. Based on the concept, it is concluded that this interaction should be characterized by regional features due to both the physical conditions of cloud formation processes and the physicochemical properties of aerosol-gas air pollution. It has been shown that powerful convective and thunderclouds can make a significant contribution to direct and indirect radiation effects [9, 19, 21, 34].

Particular attention was paid to studying the effect of ionizing radiation (radon, gamma radiation, cosmic rays) on the formation of secondary aerosols in the atmosphere according to the gas → particle scheme. It has been found that all of these types of ionizing radiation are catalysts for the formation of submicron aerosols from gases [19, 21, 35–38].

The analysis of monitoring data in 2009-2012 was carried out. smog-forming and accompanying atmospheric parameters in Tbilisi, both in the mode of continuous measurements at two stationary observation bases (territories of the atmospheric physics department and the cosmic ray laboratory of the Institute of Geophysics), and in the mode of episodic route measurements at 20 points in various parts of the city (the content of ozone in the air, submicron aerosols, radon, light ions; intensity of solar radiation, visibility range, cloud cover, temperature, humidity, wind, pressure; soil gamma radiation; intensity of galactic cosmic rays). A physical-statistical model of the relationship between the processes of formation of photochemical smog and ozone with various atmospheric parameters is presented, on the basis of which the conditions for the formation of smog ozone in different seasons of the year are established. Maps of the spatial distribution of ozone, aerosols, light ions, radon and soil gamma radiation are presented. It is shown that according to the data of a stationary measurement point (territory of the atmospheric physics department), it is possible to estimate the level of air pollution in the city Tbilisi as a whole.

The features of the effect of radionuclide radiation in the formation of secondary aerosols in the conditions of the city of Tbilisi (Tbilisi type of smog) are revealed. The intensification by ionization of aerosol pollution of the atmosphere in Tbilisi is so strong that it also leads to a deterioration in air quality in terms of its ionic composition. In general, the Tbilisi type of smog is characterized by an impossible in natural conditions feedback of the content of radon, gamma radiation and cosmic radiation with the concentration of light ions in the air, caused by the formation of secondary aerosols in an amount that, together with primary particles, is able to attach more ions to itself than their formed during ionization. It is assumed that the Tbilisi type of smog can also occur in other cities with a heavily polluted atmosphere [38-42].

In [43], the results of a study of variations in the concentration of submicron aerosols with a diameter of ≥0.1 μm and their relationship with the content of radon (Rn) in the surface air layer of the city of Tbilisi are presented.

Particular attention was paid to the study of the influence of various components of photochemical smog on human health [38]. Thus, in particular, it was found that at an average daily concentration of submicron aerosols of more than 1000 cm^{-3} in Tbilisi, an increase in the number of emergency medical calls by 11% was noted [44].

Considerable attention was paid to studies of the relationship between aerosol pollution of the atmosphere, including radioactive pollution, and thunderstorm and hail processes, as well as the precipitation regime [21, 45–53].

In recent years, work has been actively carried out on numerical modeling of dust distribution in various regions of Georgia, taking into account external conditions (wind, etc.) [54-61]. A comparative analysis of aerosol air pollution in Tbilisi and Kutaisi was carried out [62]. The possibility of using the METEOR 735CDP10 meteorological radar for monitoring the movement of dust formations in the atmosphere was considered [63].

Several studies have examined the effects of traffic restrictions in Tbilisi due to the COVID-19 pandemic on airborne air pollution levels [64-66] compared to the pre-pandemic period [67]. In general, it was found that the level of aerosol air pollution in the absence of vehicular traffic decreased significantly. In particular, in [64], ground-based measurements of solid aerosol particles PM2.5 and PM10 were compared with satellite measurements of the aerosol optical depth of the atmosphere. It was found that there is a direct relationship between these parameters. We note that qualitatively similar results were obtained by us earlier [68] when comparing data on the AOD of the atmosphere, measured using actinometric observations, with the countable concentration of aerosols in the surface layer of the Tbilisi atmosphere.

This work is a continuation of previous studies [34-67]. Below are the results of the statistical analysis of the average monthly and annual concentrations of particulate matter PM2.5 and PM10 at three locations in Tbilisi (Kazbegi av., Tsereteli av. and Varketili) in 2017-2022.

Study Area, Materials and Methods

Study area – three locations of Tbilisi (A. Kazbegi av. - KZBG, A. Tsereteli av. - TSRT, Varketili - VRKT). Coordinates of these locations of air pollution measurements points in [67] is presented.

The data of Georgian National Environmental Agency about the daily mean values of dust concentration (atmospheric particulate matter - PM2.5 and PM10) [http://air.gov.ge/reports_page] that averaged on three indicated stations are used. Period of observation: January 2017 - December 2022.

In the proposed work the analysis of data is carried out with the use of the standard statistical analysis methods [69]. Missed data of time-series of observations were restored in the correspondence with the standard methods [70].

The following designations will be used below: Min – minimal values; Max - maximal values; St Dev - standard deviation; Cv = 100·St Dev/Average, coefficient of variation (%); R coefficient of linear correlation. KZBG(PM2.5), KZBG(PM10) …etc. - concentrations of particulate matter PM2.5 and PM10 on the Kazbegi av. measurement point, etc.; Av_Tb or Av(PM2.5) and Av(PM10) - averaged over all three stations PM2.5 and PM10; Δ(2018-2017) … etc. - difference between mean annual values of PM2.5 and PM10 for different year. The difference between the mean values of PM with the use of Student's criterion was determined (level of significance α is not worse than 0.15).

In the correspondence with the standards of the World Health Organization maximum permissible concentration (MPC) composes: annual mean for PM2.5 - 10 μg/m³ and for PM10 - 20 μg/m³ [71]. In the text below, the dimension of aerosol concentration (μg/m³) is mostly omitted.

Results and Discussions

Results in Fig. 1-4 and Tables 1-4 are presented.

In Fig. 1 and 2 for clarity for clarity time-series of mean monthly and annual values of PM2.5 and PM10 at three points in Tbilisi and their averaged values for all measurement points in 2017-2022 are presented.

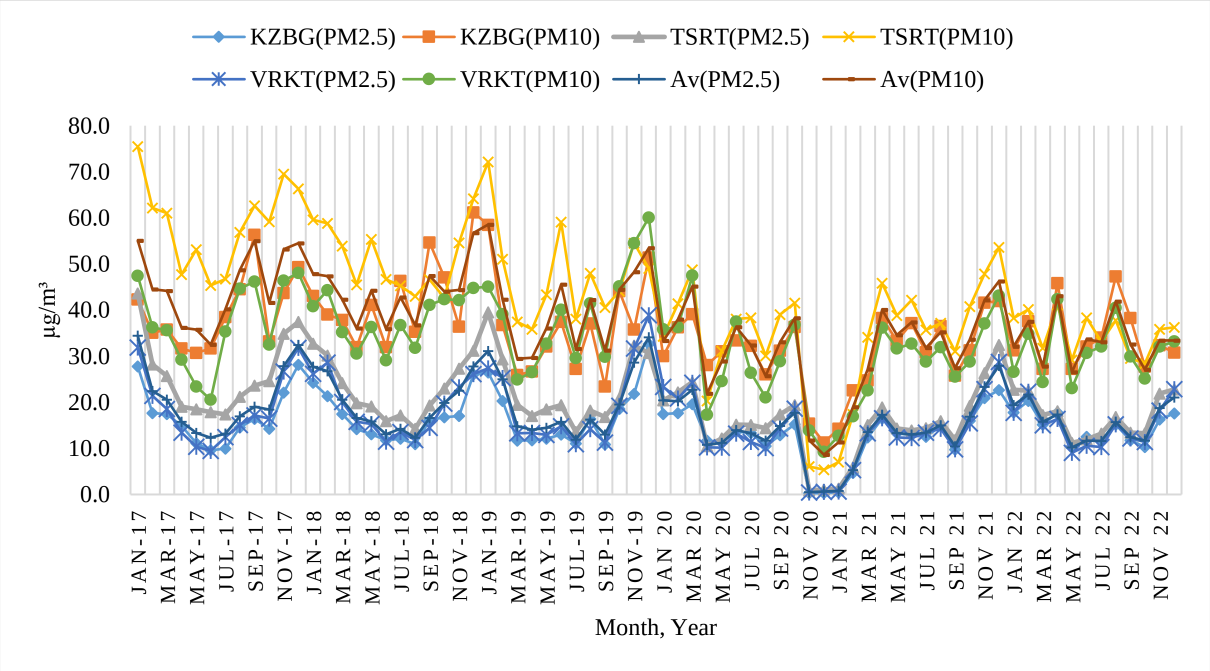


Fig. 1. Time-series of mean monthly values of PM2.5 and PM10 at three points in Tbilisi and their averaged values for all measurement points in 2017-2022.

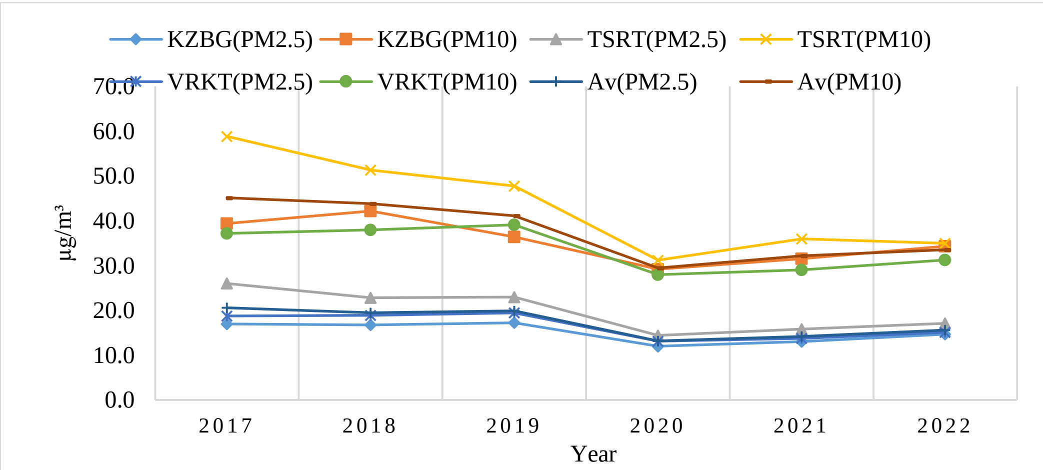


Fig. 2. Time series of mean annual values of PM2.5 and PM10 at three points in Tbilisi and their averaged values for all measurement points in 2017-2022.

In Table 1 statistical characteristics of mean monthly values of PM2.5 and PM10 at three points in Tbilisi and their averaged values for all measurement points in 2017-2022 are presented. In Table 2 the ratio between PM10 and PM2.5 at three points in Tbilisi and their averaged values for all measurement points are presented.

Analysis of the data presented in Fig. 1-2 and in Table 1-2 shows the following.

Table 1. Statistical characteristics of mean monthly values of PM2.5 and PM10 at three points in Tbilisi and their averaged values for all measurement points in 2017-2022 (μg/m³).

Variable	KZBG (PM2.5)	KZBG (PM10)	TSRT (PM2.5)	TSRT (PM10)	VRKT (PM2.5)	VRKT (PM10)	Av (PM2.5)	Av (PM10)
Year	2017							
Max	28.2	56.3	43.6	75.5	31.9	48.0	34.4	55.1
Min	9.6	30.7	17.3	45.3	9.5	20.6	12.3	32.5
Average	17.0	39.4	26.0	58.8	18.7	37.2	20.6	45.1
St Dev	6.2	8.0	8.5	9.4	7.7	9.5	7.4	8.1
Cv, %	36.7	20.3	32.9	15.9	41.3	25.7	36.2	18.0
Year	2018							
Max	26.1	61.2	32.7	64.2	28.7	44.8	27.8	56.7
Min	11.0	32.0	14.3	42.6	11.5	29.1	12.3	35.9
Average	16.8	42.2	22.9	51.3	18.9	37.9	19.5	43.8
St Dev	4.9	8.9	6.3	7.3	6.0	5.4	5.6	5.9
Cv, %	29.2	21.2	27.4	14.2	31.9	14.3	28.9	13.5
Year	2019							
Max	32.7	58.5	39.5	72.1	38.9	60.1	34.1	58.6
Min	10.8	23.4	13.6	35.8	10.9	24.9	11.9	29.4
Average	17.2	36.4	23.0	47.8	19.4	39.1	19.9	41.1
St Dev	7.0	10.7	7.9	10.5	9.2	11.0	7.8	9.6
Cv, %	40.7	29.3	34.6	21.9	47.4	28.1	39.0	23.5
Year	2020							
Max	19.6	39.1	24.4	48.8	24.3	47.5	22.7	45.1
Min	0.3	11.3	0.8	5.4	0.5	9.3	0.5	8.6
Average	12.0	29.2	14.4	31.2	13.1	28.0	13.2	29.4
St Dev	6.1	8.3	7.5	13.8	7.8	11.3	7.1	10.9
Cv, %	51.0	28.5	51.8	44.3	59.3	40.4	53.6	36.9
Year	2021							
Max	22.6	41.9	32.4	53.6	28.8	43.2	27.9	46.2
Min	0.4	14.3	1.3	7.0	0.7	12.7	0.8	11.3
Average	13.1	31.5	15.8	35.9	13.7	29.0	14.2	32.2
St Dev	6.2	8.4	8.2	12.9	7.3	8.6	7.2	9.8
Cv, %	47.2	26.6	52.0	35.9	52.9	29.6	50.5	30.5
Year	2022							
Max	20.3	47.3	22.8	41.1	22.9	42.4	21.7	43.1
Min	10.3	27.2	11.2	28.4	9.1	23.1	10.2	26.5
Average	14.7	34.3	17.1	35.0	15.1	31.3	15.6	33.5
St Dev	3.3	6.8	4.5	4.4	4.6	6.1	4.1	5.2
Cv, %	22.8	19.7	26.2	12.7	30.4	19.4	26.0	15.6
Year	2017-2022							
Max	32.7	61.2	43.6	75.5	38.9	60.1	34.4	58.6
Min	0.3	11.3	0.8	5.4	0.5	9.3	0.5	8.6
Average	15.1	35.5	19.8	43.3	16.5	33.7	17.2	37.5
St Dev	5.9	9.4	8.2	14.1	7.5	9.7	7.1	10.2
Cv, %	39.1	26.5	41.5	32.5	45.2	28.8	41.1	27.3

Year 2017:

Monthly average PM2.5 concentrations range from 9.5 (VRKT) to 43.6 (TSRT) and PM10 from 20.6 (VRKT) to 75.5 (TSRT). The range of change in the average annual concentration of PM2.5 is 17.0 (KZBG) ÷ 26.0 (TSRT), and PM10 - 37.2 (VRKT) ÷ 58.8 (TSRT). The ratio between average annual concentration of PM10 and PM2.5 change from 1.98 (VRKT) to 2.32 (KZBG).

A significant difference between the average annual concentrations of PM2.5 is noted for the following pairs of points and the city average concentrations (Av_Tb): KZBG-TSRT, TSRT-VRKT, Av_Tb-TSRT, and for PM10: KZBG-TSRT, TSRT-VRKT, Av_Tb-KZBG, Av_Tb-TSRT, Av_Tb-VRKT.

Year 2018:

Monthly average PM2.5 concentrations range from 11.0 (KZBG) to 32.7 (TSRT) and PM10 from 29.1 (VRKT) to 64.2 (TSRT). The range of change in the average annual concentration of PM2.5 is 16.8 (KZBG) ÷ 22.9 (TSRT), and PM10 - 37.9 (VRKT) ÷ 51.3 (TSRT). The ratio between average annual concentration of PM10 and PM2.5 change from 2.01 (VRKT) to 2.52 (KZBG).

A significant difference between the average annual concentrations of PM2.5 is noted for the following pairs of points and the city average concentrations (Av_Tb): KZBG-TSRT and TSRT-VRKT, and for PM10: KZBG-TSRT, TSRT-VRKT, Av_Tb-TSRT, Av_Tb- VRKT.

Year 2019:

Monthly average PM2.5 concentrations range from 10.8 (KZBG) to 39.5 (TSRT) and PM10 from 23.4 (KZBG) to 72.1 (TSRT). The range of change in the average annual concentration of PM2.5 is 17.2 (KZBG) ÷ 23.0 (TSRT), and PM10 - 36.4 (KZBG) ÷ 47.8 (TSRT). The ratio between average annual concentration of PM10 and PM2.5 change from 2.01 (VRKT) to 2.11 (KZBG).

A significant difference between the average annual concentrations of PM2.5 is noted for the following pairs of points and the city average concentrations (Av_Tb): KZBG-TSRT, and for PM10: KZBG-TSRT, TSRT-VRKT, Av_Tb-TSRT.

Table 2. The ratio between PM10 and PM2.5 at three points in Tbilisi and their averaged values for all measurement points.

Year	KZBG (PM10/PM2.5)	TSRT (PM10/PM2.5)	VRKT (PM10/PM2.5)	Av (PM10/PM2.5)
2017	2.32	2.27	1.98	2.19
2018	2.52	2.25	2.01	2.25
2019	2.11	2.08	2.01	2.07
2020	2.43	2.17	2.13	2.24
2021	2.41	2.28	2.11	2.26
2022	2.33	2.05	2.07	2.14
2017-2022	2.35	2.18	2.04	2.19

Year 2020: Period with COVID-19 restrictions on the movement of vehicles.

Monthly average PM2.5 concentrations range from 0.30 (KZBG) to 24.4 (TSRT) and PM10 from 5.4 (TSRT) to 48.8 (TSRT). The range of change in the average annual concentration of PM2.5 is 12.0 (KZBG) ÷ 14.4 (TSRT), and PM10 - 28.0 (VRKT) ÷ 31.2 (TSRT). The ratio between average annual concentration of PM10 and PM2.5 change from 2.13 (VRKT) to 2.43 (KZBG).

A significant difference between the average annual concentrations of PM2.5 is noted for the following pairs of points and the city average concentrations (Av_Tb): no significant difference, and for PM10: no significant difference.

Year 2021: Period with COVID-19 restrictions on the movement of vehicles.

Monthly average PM2.5 concentrations range from 0.40 (KZBG) to 32.4 (TSRT) and PM10 from 7.0 (TSRT) to 53.6 (TSRT). The range of change in the average annual concentration of PM2.5 is 13.1 (KZBG) ÷ 15.8 (TSRT), and PM10 - 29.0 (VRKT) ÷ 35.9 (TSRT). The ratio between average annual concentration of PM10 and PM2.5 change from 2.11 (VRKT) to 2.41 (KZBG).

A significant difference between the average annual concentrations of PM2.5 is noted for the following pairs of points and the city average concentrations (Av_Tb): no significant difference, and for PM10: TSRT-VRKT.

Year 2022: Post-COVID-19 period.

Monthly average PM2.5 concentrations range from 9.1 (VRKT) to 22.9 (VRKT) and PM10 from 23.1 (VRKT) to 47.3 (KZBG). The range of change in the average annual concentration of PM2.5 is 14.7 (KZBG) ÷ 17.1 (TSRT), and PM10 - 31.3 (VRKT) ÷ 35.0 (TSRT). The ratio between average annual concentration of PM10 and PM2.5 change from 2.07 (VRKT) to 2.33 (KZBG).

A significant difference between the average annual concentrations of PM2.5 is noted for the following pairs of points and the city average concentrations (Av_Tb no significant difference, and for PM10: TSRT-VRKT.

In Table 3 data on the Min, Max and Average values of linear correlation coefficient between concentrations of particulate matter for all point and Av(PM) are presented.

Table 3. Min, Max and Average values of linear correlation coefficient between concentrations of particulate matter for all point and Av(PM).

Year	Parameter	Min	Max	Average
2017	R	0.44	1.0	0.81
	Pair of point	TSRT(PM2.5)-KZBG(PM10)	Av(PM2.5)-VRKT(PM2.5)	
2018	R	0.28	1.0	0.74
	Pair of point	VRKT(PM2.5)-KZBG(PM10)	Av(PM2.5)-TSRT(PM2.5)	
2019	R	0.54	0.98	0.82
	Pair of point	VRKT(PM2.5)-TSRT(PM10)	Av(PM2.5)-VRKT(PM2.5)	
2020	R	0.87	0.99	0.94
	Pair of point	VRKT(PM2.5)-KZBG(PM10)	Av(PM2.5)-KZBG(PM2.5), TSRT(PM2.5),VRKT(PM2.5)	
2021	R	0.86	1.0	0.95
	Pair of point	TSRT(PM2.5)-KZBG(PM10)	Av(PM2.5)-TSRT(PM2.5), VRKT(PM2.5)	
2022	R	0.13	0.98	0.63
	Pair of point	TSRT(PM2.5)-KZBG(PM10)	Av(PM2.5)-TSRT(PM2.5), VRKT(PM2.5)	
2017-2022	R	0.66	0.98	0.84
	Pair of point	VRKT(PM2.5)-KZBG(PM10)	Av(PM2.5)-KZBG(PM2.5), TSRT(PM2.5), VRKT(PM2.5)	

As follows from Table 3 values of R between study parameters change from 0.13 (pair TSRT(PM2.5)-KZBG(PM10), 2022, "negligible correlation") to 1.0 (pairs Av(PM2.5)-VRKT(PM2.5), 2017; Av(PM2.5)-TSRT(PM2.5), 2018; Av(PM2.5)-TSRT(PM2.5), Av(PM2.5)-VRKT(PM2.5), 2021 "very high correlation"). Average value of R change from 0.63 (2022, "moderate correlation" to 0.95 (2021, "very high correlation"). It should be noted that the highest average values of R between the studied parameters of air pollution in Tbilisi were observed in 2020 and 2021 with restrictions on the movement of vehicles due to the covid-19 pandemic ("very high correlation"). The lowest average R value was observed in 2022 in the post-COVID-19 period.

In Table 4 data on the Min, Max and Mean values of linear correlation coefficient between PM2.5 and PM10 for separated point and Av(PM) are presented.

Table 4. Min, Max and Mean values of linear correlation coefficient between PM2.5 and PM10 for separated point and Av(PM).

Year	Parameter	Min	Max	Average
2017	R	0.52	0.93	0.76
	Point	KZBG	TSRT	
2018	R	0.54	0.83	0.73
	Point	KZBG	TSRT	
2019	R	0.79	0.89	0.85
	Point	TSRT	VRKT	
2020	R	0.92	0.96	0.94
	Point	VRKT	TSRT	
2021	R	0.92	0.94	0.93
	Point	TSRT,VRKT	Av(PM)	
2022	R	0.35	0.60	0.45
	Point	KZBG	TSRT	
2017-2022	R	0.76	0.88	0.84
	Point	KZBG	TSRT	

Values of R between indicated parameters change from 0.35 (KZBG, 2022, “low correlation”) to 0.96 (TSRT 2020, “very high correlation”). Average value of R change from 0.45 (2022, “low correlation” to 0.94 (2020, “very high correlation”). As in the previous case (Table 3) the highest average values of R between the studied parameters were observed in 2020 and 2021 during the COVID-19 pandemic (“very high correlation”), and lowest – in post-COVID-19 period (“low correlation”).

In Fig. 3 data on difference between mean annual values of PM2.5 and PM10 at three points in Tbilisi and their averaged values for all measurement points in 2018-2017, 2019-2018, 2020-2019, 2021-2020 and 2022-2021 are presented.

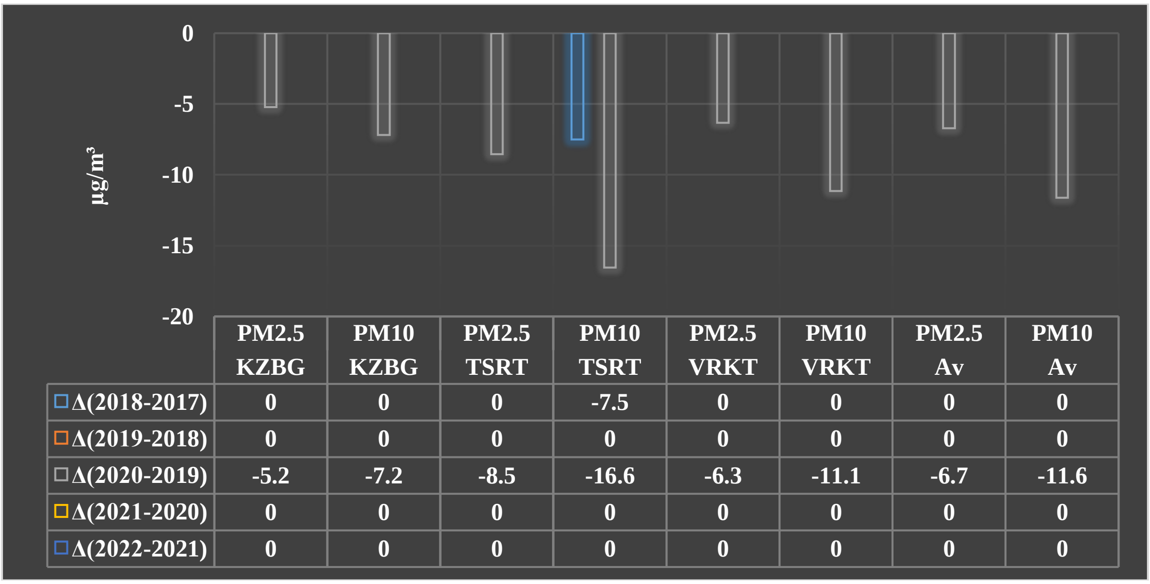
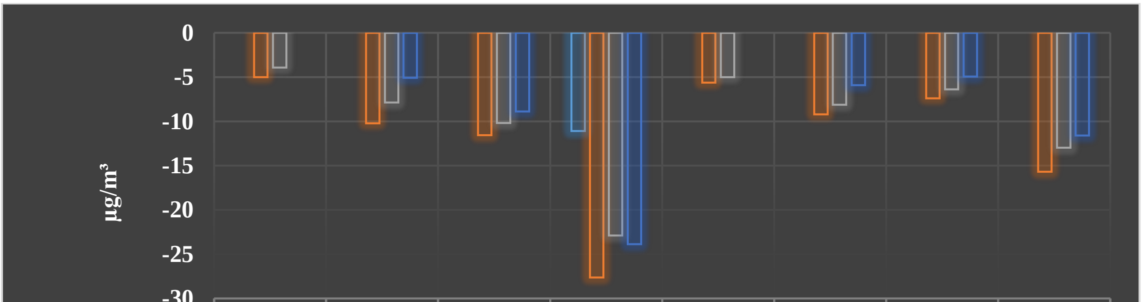


Fig. 3. Difference between mean annual values of PM2.5 and PM10 at three points in Tbilisi and their averaged values for all measurement points in 2018-2017, 2019-2018, 2020-2019, 2021-2020 and 2022-2021 (0 - not significant difference, α>0.15).

As follows from Fig. 3 a significant difference between the average annual concentrations of aerosol air pollution in Tbilisi in neighboring years is noted for PM10 for the TSRT measurement point (a decrease of 7.5 in 2018 compared to 2017), as well as for all points in 2020 (the period with the COVID-19 pandemic) compared to 2019. Δ(2020-2019) values change from –16.6 (TSRT point for PM10) to –5.2 (KZBG point for PM2.5).

In Fig. 4 data on difference between mean annual values of PM2.5 and PM10 at three points in Tbilisi and their averaged values for all measurement points in 2019-2017, 2020-2017, 2021-2017 and 2022-2017 are presented.



	PM2.5 KZBG	PM10 KZBG	PM2.5 TSRT	PM10 TSRT	PM2.5 VRKT	PM10 VRKT	PM2.5 Av	PM10 Av
Δ(2019-2017)	0	0	0	-11.1	0	0	0	0
Δ(2020-2017)	-5.0	-10.2	-11.6	-27.6	-5.6	-9.2	-7.4	-15.7
Δ(2021-2017)	-3.9	-7.9	-10.2	-22.9	-5.0	-8.1	-6.4	-13.0
Δ(2022-2017)	0	-5.1	-8.9	-23.9	0	-5.9	-4.9	-11.6

Fig. 4. Difference between mean annual values of PM2.5 and PM10 at three points in Tbilisi and their averaged values for all measurement points in 2019-2017, 2020-2017, 2021-2017 and 2022-2017 (0 - not significant difference, α>0.15).

As follows from Fig. 4 a significant value of Δ(2019-2017) only on point TSRT for PM10 is observed. A significant values of Δ(2020-2017) and Δ(2021-2017) for all measurement points are fixed. A significant values of Δ(2022-2017) for all measurement points except KZBG and VRKT for PM2.5 are observed.

Δ(2020-2017) values change from –27.6 (TSRT point for PM10) to –5.0 (KZBG point for PM2.5), Δ(2021-2017) values change from –22.9 (TSRT point for PM10) to –3.9 (KZBG point for PM2.5). Greatest value Δ(2022-2017) is -23.9 (TSRT point for PM10).

Note that in 2020-2021, the largest decrease in the average annual concentration of aerosols was observed due to restrictions on the movement of transport associated with the COVID-19 pandemic. In 2022, there was a slight increase in aerosol pollution of the atmosphere compared to the years with the COVID-19 pandemic.

However, for the entire period of observation, the average annual concentration of both PM2.5 and PM10 was higher than the permissible norm. On average in the city of Tbilisi, this increase was correspondingly. For PM2.5: 2017 (106%), 2018 (95%), 2019 (99%), 2020 (32%), 2021 (42%), 2022 (56%). For PM10: 2017 (126%), 2018 (119%), 2019 (105%), 2020 (47%), 2021 (61%), 2022 (68%).

On average, in 2017-2022, the least polluted air in terms of PM2.5 was recorded at the KZBG point (exceeding the concentration of PM2.5 compared to the permissible norm - 51%), the most polluted - at the TSRT point (exceeding - 98%). The least polluted air according to PM10 was recorded at the VRKT point (exceeding the concentration of PM10 compared to the permissible norm - 69%), the most polluted - at the TSRT point (exceeding - 117%).

Conclusion

In the near future, it is planned to continue similar studies of the variability of daily, average monthly and average annual values of PM2.5 and PM10 in both Tbilisi and other regions of Georgia.

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თბილისის სამ წერტილში 2017-2022 წლებში მყარი ნაწილაკების PM2.5 და PM10-ის საშუალო თვიური და წლიური კონცენტრაციების სტატისტიკური მახასიათებლები

დ. კირკიტაძე

რეზიუმე

წარმოდგენილია PM2.5 და PM10 ნაწილაკების საშუალო თვიური და წლიური კონცენტრაციების დეტალური სტატისტიკური ანალიზის შედეგები თბილისის სამ წერტილში (ყაზბეგის გამზ., წერეთლის გამზ. და ვარკეთილი) 2017-2022 წლებში. ჩატარდა ჰაერის დაბინძურების მითითებულ მახასიათებლებს შორის კორელაციის ანალიზი. შესწავლილი იყო PM2.5 და PM10 საშუალო წლიური მნიშვნელობების ცვალებადობა საკვლევი დაკვირვების პერიოდში. კერძოდ, დადგინდა, რომ 2020-2021 წლებში დაფიქსირდა აეროზოლების საშუალო წლიური კონცენტრაციის მნიშვნელოვანი შემცირება COVID-19-ის პანდემიასთან დაკავშირებული მანქანების გადაადგილების შეზღუდვის გამო. აღნიშნულია, რომ დაკვირვების მთელი პერიოდის განმავლობაში PM2.5 და PM10 საშუალო წლიური კონცენტრაცია დასაშვებ ნორმაზე მაღალი იყო.

საკვანძო სიტყვები: ატმოსფერული აეროზოლები, მყარი ნაწილაკები, PM2.5, PM10.

Статистические характеристики среднемесячных и годовых концентраций твердых частиц PM2.5 и PM10 в трех пунктах города Тбилиси в 2017-2022 гг.

Д.Д. Киркитадзе

Резюме

Представлены результаты детального статистического анализа среднемесячных и годовых концентраций твердых частиц PM2.5 и PM10 в трех точках Тбилиси (пр. Казбеги, пр. Церетели и Варкетели) в 2017-2022 гг. Проведен анализ корреляционных связей между указанными характеристиками загрязнения воздуха. Изучена изменчивость среднегодовых значений PM2.5 и PM10 в исследуемый период наблюдений. В частности получено, что в 2020-2021 наблюдалось значительное понижение среднегодовой концентрации аэрозолей из-за ограничений перемещений транспорта, связанного с ковид-19 пандемией. Отмечается, что за весь период наблюдений среднегодовая концентрация PM2.5 и PM10 была выше допустимой нормы.

Ключевые слова: Атмосферные аэрозоли, твердые частицы, PM2.5, PM10.