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Geophysics

Numerical and Experimental Investigation of Particulate Matters 2.5 and 10 Distribution in Tbilisi City Atmosphere

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(Presented by Academy Member Tamaz Chelidze)

The paper presents the investigation of the distribution of Particulate Matter 2.5 and Particulate Matter 10 (PM2.5 and PM10) concentrations in Tbilisi atmosphere during the pandemic period (2020-2021) through an analysis of routine observations of Georgian National Environmental Agency, special expedition measurement data obtained with mobile apparatus „Aeroqual Series 500" and „TROTEC PC220" and numerical modeling. The observation showed that hourly variation of concentration boost in winter and summer was characterized by two maximums in the intervals between 9:00-10:00 and 18:00-21:00. and by one minimum from 0:00 to 06:00. Sharp increase in concentration values was observed at some road sections that are caused by local ecological conditions. The concentrations of PM2.5 and PM10 in these sections in winter reached 1.5 and 2 maximum permissible concentrations. It was established that measures related to Lockdown cause significant reduction of microaerosols concentration in urban air. Kinematics of PM2.5 and PM10 concentration changes induced by motor transport in the territory of Tbilisi were explored using a 3D model of admixture transfer-diffusion in the atmosphere developed at M. Nodia Institute of Geophysics at Ivane Javakhishvili Tbilisi State University. A diurnal pattern of microaerosols spatial distribution was studied. Concentration values obtained via modeling are within the limits of values received through routine observations. It was established that a disposition of heavily polluted areas depends on motor transport traffic intensity, highways location, and local convective circulation systems formed by the dynamic and themal influence of the underlying surface. *© 2022 Bull. Georg. Natl. Acad. Sci.*

atmosphere, pollution, numerical modelling, concentration, motor transport

Particulate Matter 2.5 and Particulate Matter 10 (PM2.5 and PM10) are the main ingredients of environmental pollution with high-risk factors for human health. Atmospheric air pollution with PM2.5 and PM10 is especially dangerous in terms of the COVID-19 pandemic. Scientific investigations show that microaerosols as COVID-19 virus carriers with great permeability into a human organism are very hazardous to public health [1-4].

Though Tbilisi is not among the 500 most contaminated cities in the world [5], according to data from the National Environmental Agency of Georgia (NEA), PM2.5 and PM10 concentrations in Tbilisi city atmosphere reach and in some cases even exceed the values of maximum permissible concentrations. Therefore, the study of temporal variation and spatial distribution of PM2.5 and PM10 in Tbilisi atmosphere is of great importance for the elaboration of practical measures aimed at protecting the human health and environment.

Some issues of temporal and spatial variation of dust propagation in Tbilisi atmosphere are discussed in [6-9]. The current paper deals with the problems of atmospheric pollution of Tbilisi and adjacent territories with PM2.5 and PM10 during the restrictions related to the COVID-19 pandemic through the analysis of routine observations, experimental measurements data, and numerical modelling.

According to NEA of the Ministry of Environmental Protection and Agriculture (MEPA) of Georgia, concentrations of PM2.5 particles in Tbilisi atmosphere are 2-4-times less than PM10 concentrations, and their change behaviour over time is similar.

inclusive, low concentrations are registered. Concentration drop is related to measures foreseen by the Lockdown (during the second pandemic wave) introduced from November 24: motor transport traffic restriction, the closure of stores, shift to remote work for many public services, etc. On November 29, so-called "Black Friday", transport traffic was sharply increased that respectively caused the rise in microparticles concentrations.

Experimental route measurements of PM2.5 and PM10 concentrations were conducted at the main trunk roads of Tbilisi and its adjacent territories. Concentration values were determined using portable devices „Aeroqual Series 500" and „TROTEC PC220" with 10 minute averaging. Analysis of measurement data carried out in the summer period of 2020 and 2021 from 09:00 to 10:00 showed that microaerosols concentrations in daylight hours were high throughout the central part of the city and in the surroundings of trunk roads. Relatively fewer concentrations were obtained in the neighbourhood of the Tbilisi Sea.

To investigate the temporal and spatial evolution of microaerosols, PM2.5 and PM10 distribution in Tbilisi and adjacent territories were modelled using a 3D numerical model [7]. A numerical grid of high-resolution ability with 300 and 400 m horizontal steps along parallel and

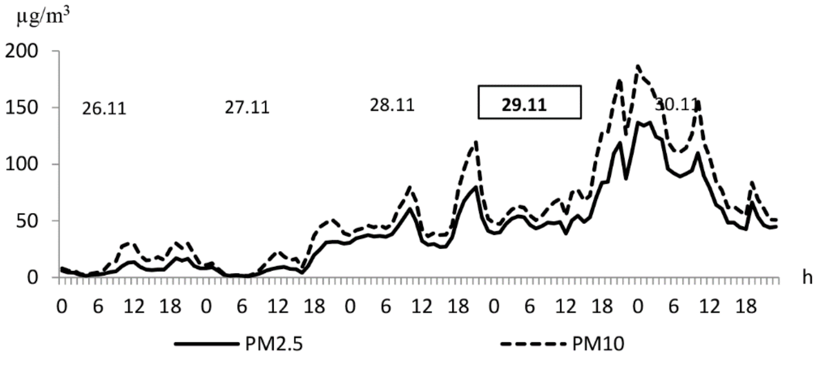

Fig. 1. Hourly variation of PM2.5 and PM10 concentrations on November 26-30, 2020 at the observation point of monitoring.

Fig. 1. shows the diagram of hourly variation for the last 5 days in November 2020. As it can be seen from Fig. 1, from November 26 to November 28

meridian was used. The vertical step varied from 0.5 to 15 m in the 100 m thick surface layer of the atmosphere, while in the atmospheric boundary layer and free atmosphere a vertical step was equal to 300 m. As far as there are no atmosphere-polluting large industrial enterprises in Tbilisi, it is assumed that the main source of atmospheric contamination is represented by microparticles generated and dispersed due to motor transport traffic. PM2.5 and PM10 concentrations change was modelled for 72 hours in cases of meteorological conditions typical to the region.

Numerical modelling showed that in summer, during background light southern air, a spatial distribution of PM2.5 in the atmosphere in 00:00 – 06:00 time interval is not uniform. Its concentration in the major part of the city is within 0.001-0.1 μg/m^3 at 2 m height from the Earth surface. In the city center, at the territories of Vake, Saburtalo districts, in the neighbourhood of Tsereteli Avenue, Kakheti Highway and trunk roads connecting Tbilisi and Rustavi, PM2.5 concentrations vary from 1 to 5 μg/m^3. Above 100 m, concentration reduces with its value at 600 m altitude not exceeding 1 μg/m^3.

Fig. 2 shows the fields of wind velocity and PM2.5 concentration obtained through numerical integration at 2 and 100 m height above ground level at t = 09:00 and 12:00. in case of background light southern air. It was established that after 06:00. PM2.5 concentration increases in the entire territory of the city with the increase of traffic intensity. The concentration growth is not uniform. It is especially high in the city center (Vake and Saburtalo districts).

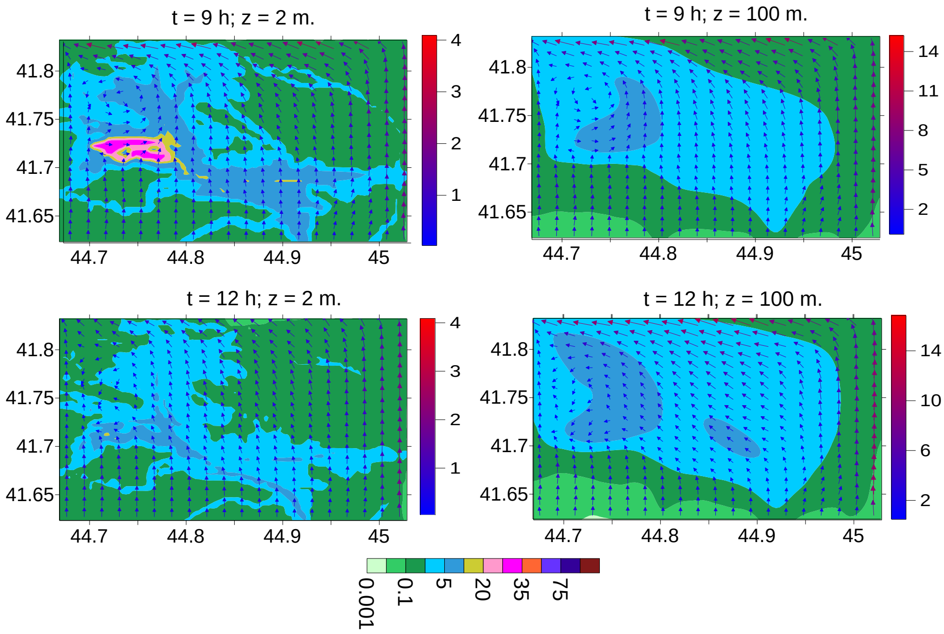

Fig. 2. Wind velocity (m/s) and PM2.5 concentration (μg/m^3) fields in summer, in the surface layer of the atmosphere, when t = 09:00 and 12:00.

In time interval from t = 15:00 to 21:00, sharp increase of PM2.5 concentration takes place what is caused by the second “rush-hour”-like situation of traffic. Concentration increase at 2 m height from the Earth surface at t =18:00 was obtained in Vake and Saburtalo districts. Concentration rise is lower in some small-size areas of Rustaveli and Gorgasali Avenues, Kakheti and Rustavi Highways, Ortachala and Ponichala. From t = 18:00 to 21:00, PM2.5 concentration decreases in more highly polluted areas.

Vertical distribution of PM2.5 concentration in the surface layer of the atmosphere, in three vertical cross-sections made along the parallel, is shown in Fig. 3 from t = 09:00 to 24:00. The modelling results show that from t = 03:00 to 06:00, PM2.5 concentration in the surface layer of the atmosphere is less than 4 μg/m^3 and is characterized by slight reduction trend. After t = 06:00, aerosol concentration in the surface layer is incrasing with the traffic intensity growth and by t = 09:00, average and high pollution zones are formed. They have quite big vertical and horizontal sizes and include almost the entire surface layer. Fig. 3 shows that from t = 09:00 to 15:00, despite a fixed amount (09:00 – 12:00) and small reduction (12:00 – 15:00) of aerosols, entering into the atmosphere, a substantial reduction of concentration and air quality improvement occur. A sharp increase of ground-level concentration is registered in t = 16:00 – 21:00 time interval. In this timespan, the maximum value of concentration near the ground reaches 50 μg/m^3 in a small area. Through the analysis of the vertical distribution of PM2.5 concentration at various time points, one can conclude that in case of background light air, the prevailing mechanism of aerosol propagation is represented by vertical and horizontal diffusion into the surface layer of the atmosphere.

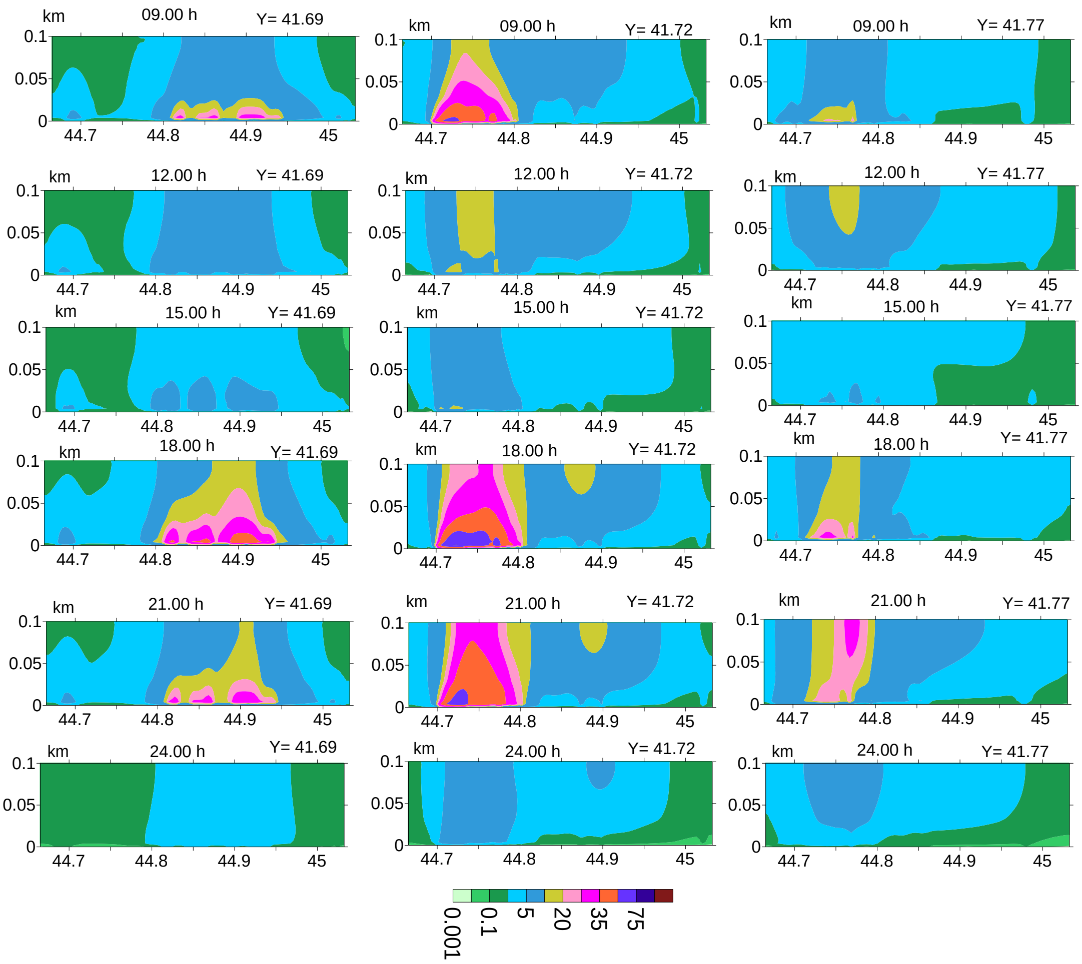

Fig. 3. PM2.5 concentration isolines in three vertical cross-sections made along the parallel in the lower 100 m thick atmospheric layer.

Turbulent flows take aerosols away from the surface layer to the boundary layer, where an advective transfer causes pollution to disperse in large areas and air self-purification. In a high pollution zone, in the second half of a day, an important role is played by convective transfer, during which a heated air mass starts an intense relocation upward vertically from the ground and takes the available microparticles away.

A picture similar from the viewpoint of temporal change and significantly different according to spatial distribution was obtained in winter, during numerical modelling of PM10 distribution in case of light background southern wind. The similarity lies in the pattern of concentration's temporal variation. In particular, it was established that a pollution level is minimal in time interval from t = 00:00 to 06:00 and maximal is during rush-hour situations (t = 09:00 – 10:00 and 18:00 – 21:00).

Temka districts and near Guramishvili Avenue, Kakheti and other highways. Pollution level increases at 100 m altitude from the earth surface, as well, and less 600 m height. Concentration values at 100 and 600 m heights are within the limits of 20-30 μg/m^3 and 10-15 μg/m^3, respectively.

In the time interval from t = 09:00 to 15:00, a slight reduction of concentration is obtained. It is related to the reduction of traffic intensity and to the approach of formed local anticyclonic whirl center to the sources of pollution. The same situation occurs at 100 and 600 m height above the ground level. Calculations showed that maximum values of PM10 concentration are equal to 20-25, 10-15 and 5-10 μg/m^3 at 2, 100 and 600 m altitudes from the earth's surface, respectively. At 100 m height from the earth's surface, the difference between concentration distributions at t = 09:00 and 12:00, is very small.

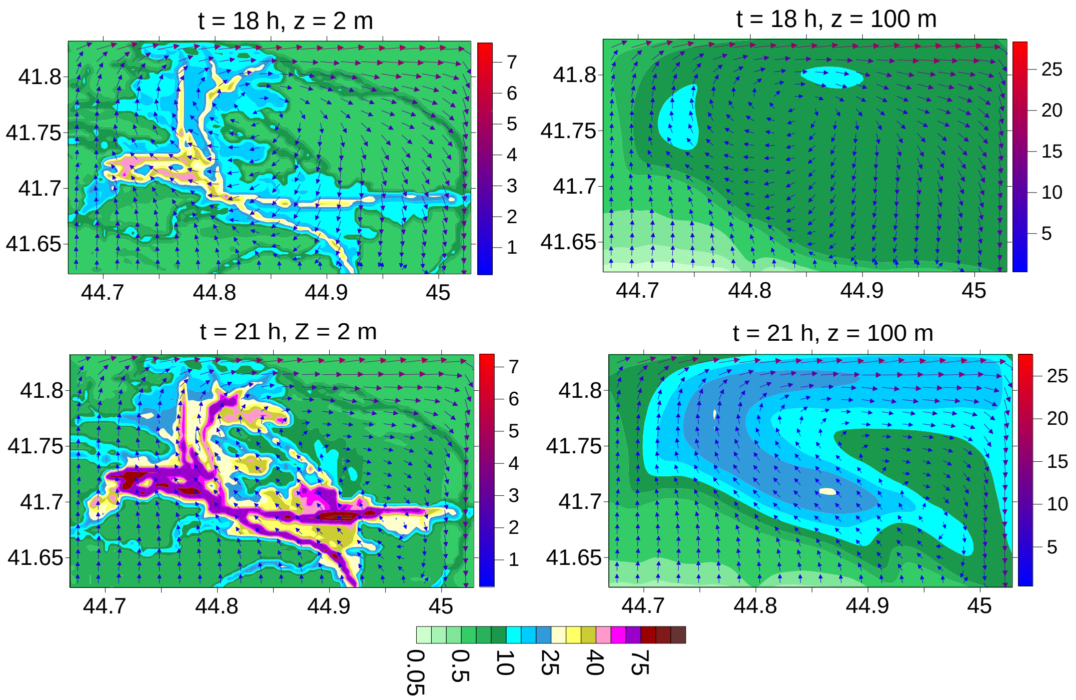

Fig. 4. Wind velocity (m/s) and PM10 concentration (μg/m^3) fields in winter, in the surface layer of the atmosphere, when t = 18:00 and 21:00.

The calculation results showed that, at t = 09:00, concentration is relatively high at 2 m height above ground level, both at main trunk road and urbanized territories, as well as in the suburbs. 25-40 μg/m^3 concentration is obtained in the neighbourhood of Vake, Saburtalo, Gldani, and

After t = 16:00, the ground-level concentration starts to rise. This increase is primarily noticeable at 2 m height. At 100 and 600 m altitudes, no concentration growth virtually occurs. By t = 18:00, PM10 concentration at 2 m height from the earth surface equals to 35-40 μg/m^3 in the vicinity of Vazha-Pshavela, Chavchavadze, Rustaveli avenues, and Liberty and Erekle squares. Near other central avenues, the concentration reaches 30 μg/m^3 (Fig.4).

The especially rapid growth of atmospheric pollution with PM10 takes place after t = 18:00. Intensive growth of pollution occurs not only in the central part of the city, but also in the periphery. At t = 21:00, maximum concentration values are high in some small areas of polluted territory and they vary within 80-100 μg/m^3, while in other heavily polluted territories, they vary within the range of 50-70 μg/m^3.

Ground-level concentration rise is accompanied by its growth in the upper surface layer and lower boundary layer of the atmosphere. At t = 21:00, concentration values equal 20-25 μg/m^3 and 5-10 μg/m^3 at 100 and 600 m height above ground level, respectively. The area of increased pollution is horseshoe-shaped (U-shaped) and covers a large territory of the central and northern parts of the city. After t = 21:00, a rapid decrease of ground-level pollution starts, due to which the ground-level concentration value drops to 5 μg/m^3. A similar process takes place at 100 and 600 m altitudes, as well.

In conclusion it can be noted that the temporal and spatial variations of PM2.5 and PM10 concentrations in the surface and boundary layers of atmospheric air in main trunk roads of Tbilisi and adjacent territories in 2020 and 2021 was studied through the analysis of routine observations and experimental measurement data. It was shown that hourly variation of concentration is characterized by two maximums in t = 09:00 – 10:00 and 18:00 – 21:00 time intervals. It was established that measures related to Lockdown cause a significant reduction of microaerosols concentration in urban air. Kinematics of PM2.5 and PM10 concentration change generated by motor transport in the territory of Tbilisi in summer and winter conditions, in case of background light southern air was investigated through numerical modelling. The diurnal pattern of dust spatial distribution was studied. Concentration values were determined via modelling, and they are within the limits of values obtained through routine observations. It was established that spatial distribution of heavily polluted areas depends on motor transport traffic intensity, trunk roads location, on the one hand, and on dynamic impact of terrain and local circulation systems formed by diurnal change of thermal regime at the underlying surface, on the other hand.

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გეოფიზიკა

ქ. თბილისის ატმოსფეროში PM 2.5 და PM 10 განაწილების რიცხვითი და ექსპერიმენტული გამოკვლევა

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სტატიაში გამოკვლეულია PM2.5 და PM10 კონცენტრაციების განაწილება თბილისის ატმოსფეროში COVID-19 პანდემიის პერიოდში (2020-2021) საქართველოს გარემოს დაცვის ეროვნული სააგენტოს რეგულარული დაკვირვებების, მობილური აპარატებით „Aeroqual Series 500" და „TROTEC PC220" სპეციალური ექსპერიმენტული გაზომვის მონაცემების ანალიზისა და რიცხვითი მოდელირების მეშვეობით. ნაჩვენებია, რომ კონცენტრაციის საათობრივი ცვალებადობა ხასიათდებოდა ორი მაქსიმუმით 09:00 – 10:00 და 18:00 – 21:00 საათის ინტერვალებში და ერთი მინიმუმით 00:00-დან 06:00 სთ-მდე. გზის ზოგიერთ მონაკვეთზე შეინიშნებოდა კონცენტრაციის მკვეთრი მატება, რაც გამოწვეული იყო ადგილობრივი ეკოლოგიური პირობებით. ამ მონაკვეთებში PM2.5 და PM10 კონცენტრაციები ზამთარში აღწევდა 1.5 და 2 მაქსიმალურ დასაშვებ კონცენტრაციის მნიშვნელობებს. დადგენილია, რომ სატრანსპორტო მოძრაობის „ლოქდაუნთან" დაკავშირებული ღონისძიებები იწვევს მიკროაეროზოლების კონცენტრაციის მნიშვნელოვან შემცირებას ქალაქის ატმოსფეროში. თბილისის ტერიტორიაზე საავტომობილო ტრანსპორტით გამოწვეული PM2.5 და PM10 კონცენტრაციის ცვლილებების კინემატიკა შესწავლილია ატმოსფეროში მინარევების გადატანა-დიფუზიის 3D მოდელის გამოყენებით, რომელიც შემუშავებულია ივანე ჯავახიშვილის სახელობის თბილისის სახელმწიფო უნივერსიტეტის მ. ნოდიას სახ. გეოფიზიკის ინსტიტუტში. შესწავლილია მიკროაეროზოლების სივრცითი განაწილების დღეღამური სურათი. მოდელირებით მიღებული კონცენტრაციის მნიშვნელობები რეგულარული დაკვირვებით მიღებული მნიშვნელობების ფარგლებშია. დადგენილია, რომ ძლიერ დამტვერიანებული არეების მდებარეობა დამოკიდებულია ავტოტრანსპორტის მოძრაობის ინტენსივობაზე, ავტომაგისტრალების მდებარეობაზე, რელიეფის დინამიკური და თერმული ზემოქმედებით გამოწვეულ ლოკალურ ცირკულაციურ სისტემებზე.

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