Investigation of Tbilisi City Atmospheric Air Pollution with PM in Usual and Emergency Situations Using the Observational and Numerical Modeling Data

N. Gigauri, V. Kukhalashvili, V. Sesadze, A. Surmava, L. Intskirveli

***Abstract*—**Pollution of the Tbilisi atmospheric air with $PM_{2.5}$ and PM_{10} in usual and pandemic situations by using the data of 5 stationary observation points is investigated. The values of the statistical characteristic parameters of PM in the atmosphere of Tbilisi are analyzed and trend graphs are constructed. By means of analysis of pollution levels in the quarantine and usual periods the proportion of vehicle traffic in pollution of city is estimated. Experimental measurements of $PM_{2.5}$, PM_{10} in the atmosphere have been carried out in different districts of the city and map of the distribution of their concentrations were constructed. It is shown that maximum pollution values are recorded in the city center and along major motorways. It is shown that the average monthly concentrations vary in the range of 0.6-1.6 Maximum Permissible Concentration (MPC). Average daily values of concentration vary at 2-4 days intervals. The distribution of PM_{10} generated as a result of traffic is numerical modeled. The modeling results are compared with the observation data.

***Keywords*—**Air pollution, numerical modeling, $PM_{2.5}$, PM_{10}.

I. Introduction

Tbilisi is one of the biggest administrative centers of the South Caucasus and, respectively, its highways are overloaded with motor transport, that is encouraged by the fact that Georgia is a transit country between the Near East and Europe. It is known that the motor transport is one of the main sources of atmosphere pollution with PM. $PM_{2.5}$ and PM_{10} are so small-size particles that they easily penetrate the human organism through breathing ways and cause different kinds of diseases dangerous to health [1], [2].

II. Statement of the Problem

PM concentrations in the atmospheric air of Tbilisi city are measured at 5 fixed surveillance points in a continuous mode 24 hours a day (Fig. 1).

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In the present work, on the basis of the National Environment Agency data [3], there is analyzed a change in PM concentrations in both the routine rhythm of city life (2019) and during emergency situation caused by COVID-19 pandemic (2020). Maximum, minimum and average values of the monthly concentrations are estimated. Hourly and daily change trends of $PM_{2.5}$ and PM_{10} concentrations are considered. Numerical modeling of PM_{10} propagation in the atmospheric air of Tbilisi city is carried out in Georgia during western light air using the regional model of atmosphere pollution research [4].

III. Research Results

The graphs for maximum, minimum and average monthly values of $PM_{2.5}$ and PM_{10} concentrations throughout 2020 are shown in Fig. 2. It is seen from Fig. 2 that maximum values of PM concentrations exceed MPC in winter period, while in spring and summer their concentrations are within normal limits. It should be noted that concentrations registered in March sharply drop in April (e.g., from 183 to 61 $\mu g/m^3$ for PM_{10}).

Interesting pattern was obtained, when comparing the average monthly concentrations of 2019 and 2020. In the first three months of 2020, including March, $PM_{2.5}$ and PM_{10} concentrations are relatively higher compared with the last year and their values approach MPC magnitudes (Fig. 3). As for the April data, we have a different picture. Concentrations registered in 2020 are roughly twice lesser than in 2019 and 2,5-times smaller than MPC (Fig. 4). This circumstance can be explained by the fact that the emergency situation was declared in April on a national scale in Georgia and motor transport traffic was limited.

In Fig. 5 daily concentrations in April 2020 are shown, it is seen that the highest concentrations of $PM_{2.5}$ and PM_{10} throughout a month were registered as 18 and 35 $\mu g/m^3$, respectively. On April 17, concentrations were even more dropped, as far as the Georgian government has declared the state of emergency namely that day motor transport traffic was limited. On April 27-28, inter-city borders were open, transport has started to operate and heavy increase of PM concentrations were registered, though their values in none of the cases exceed MPC.

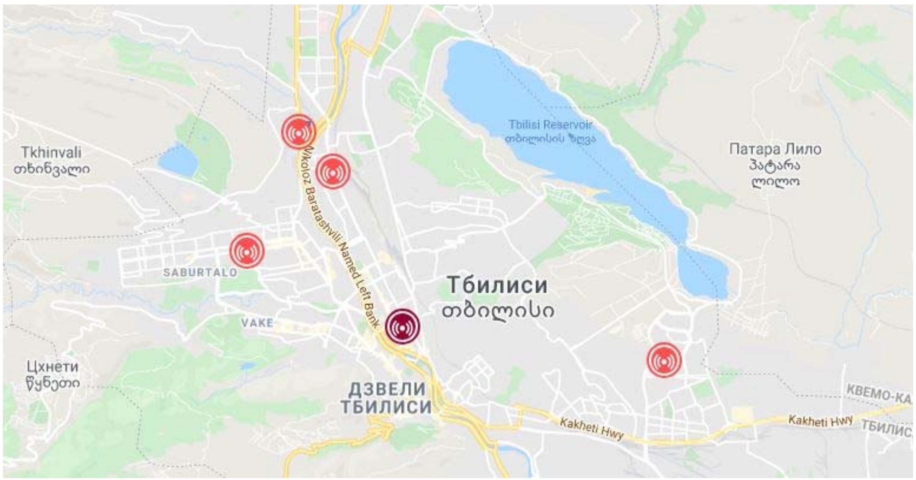

Fig. 1 Disposition of observation points for control over atmospheric air polluting ingredients

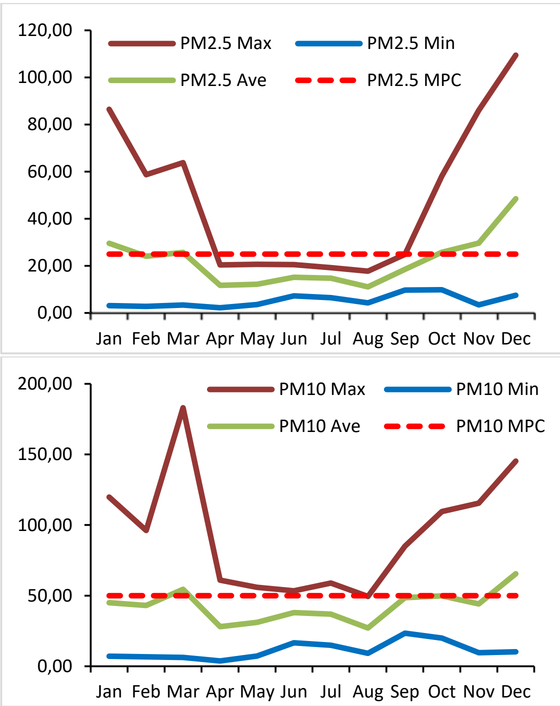

Fig. 2 Maximum, minimum and average monthly concentrations of $PM_{2.5}$ and PM_{10} in 2020

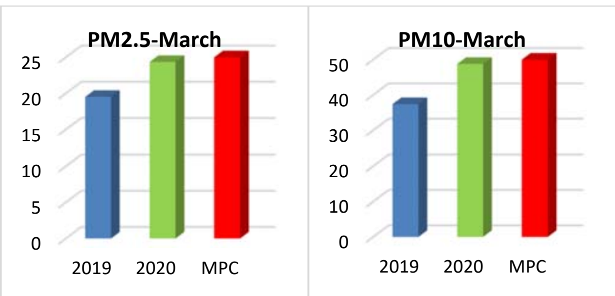

Fig. 3 Average monthly concentrations of $PM_{2.5}$ and PM_{10} in March of 2019 and 2020

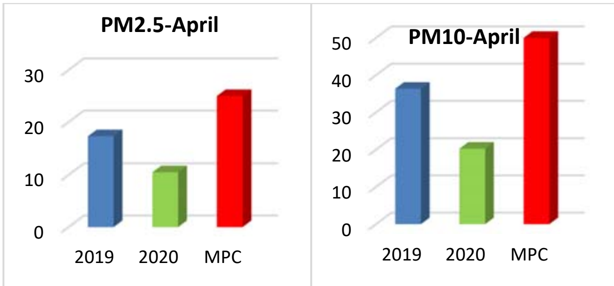

Fig. 4 Average monthly concentrations of $PM_{2.5}$ and PM_{10} in April of 2019 and 2020

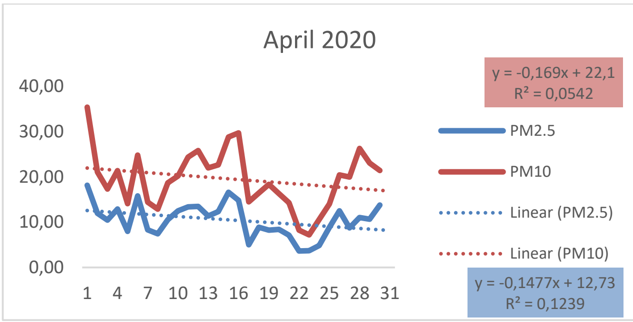

Fig. 5 Daily concentrations of $PM_{2.5}$ and PM_{10}, trend equations and lines in April of 2020

Observation data analysis revealed the effect of pandemic on reduction in dust particles' concentrations in the city atmosphere and clearly demonstrated that the main contribution to Tbilisi city atmosphere pollution by PM is made by the motor transport. Interesting patterns were shown by the curve of PM concentrations hourly change in the atmosphere (Figs. 6, 7), from where is clearly seen that in both summer and winter takes place concentrations' increase in the second part of the day and they reach the maximum after 7 pm.

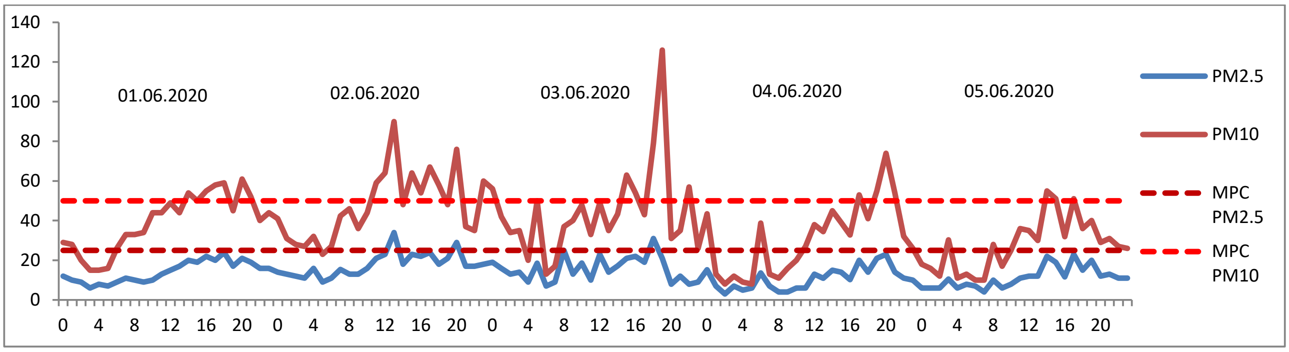

Fig. 6 Hourly flow of $PM_{2.5}$ and PM_{10} concentrations on June 1-5, 2020

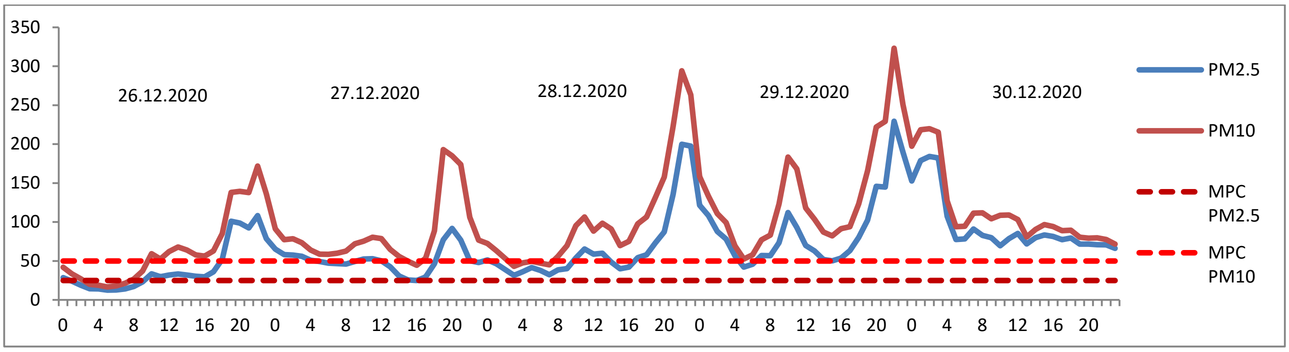

Fig. 7 Hourly flow of $PM_{2.5}$ and PM_{10} concentrations on December 26-30, 2020

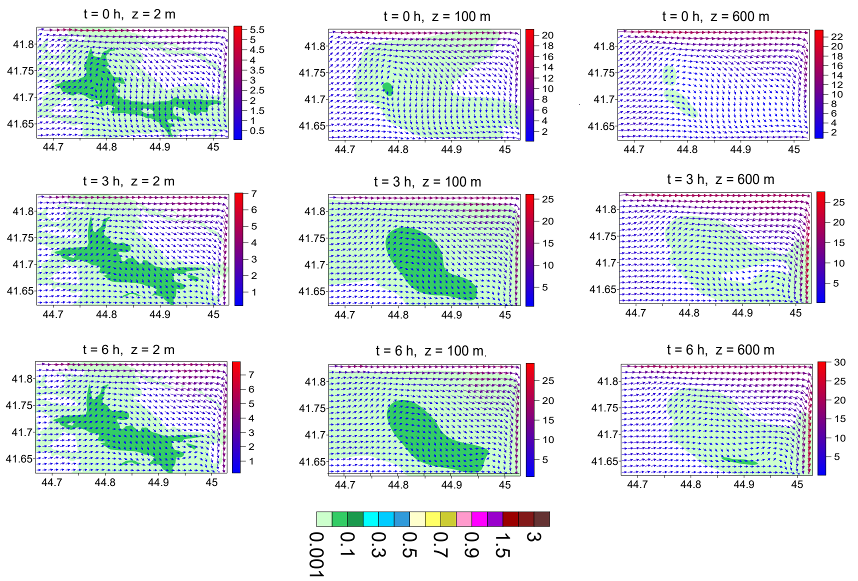

Fig. 8 Wind velocity and PM_{10} concentration fields at 2, 100 and 600 m height when t = 0, 3, 6 h, in case of western background light air

Based on the analysis of available data and using initial and boundary conditions the numerical modeling is carried out. For numerical investigation of distribution of polluting ingredients in the atmosphere, the regional numerical model of evolution of the atmospheric processes in Caucasus is used, which is developed in the M. Nodia Institute of Geophysics at IV. Javakhishvili Tbilisi State University [4], [5]. Calculations are made on the rectangular numerical grid with 61x103x31 nodes, horizontal grid axes are directed along parallel and meridian, and grid steps are 300 m and 400 m, respectively. Vertical step equals to 300 m in the free atmosphere. In the 100 m thick surface layer of the atmosphere the vertical step varies from 0.5 to 15 m. Tbilisi city is located in the center of modeling area. It is assumed that PM_{10} is emerged in the atmosphere as a result of motor transport traffic on the city mains and the streets. Its quantity changes in time and is determined via estimation of fixed surveillance data and transport traffic intensity. Calculations are carried out for 3-day period. A case of western background light air for dry weather conditions of June is considered. Wind velocity varies from 1 m/s (at 100 m height from the earth surface) to 20 m/s (in the tropopause, 9 km). Relative humidity of the atmosphere is 50%.

In Figs. 8-11 there are shown PM_{10} concentration distribution (in MPC = 50 μg/m^3) and wind velocity field (in m/s) at 2, 100 and 600 m height from the terrain surface, when t = 0, 3, 6, 9, 12,15, 18, 21 and 24 h, obtained using numerical modeling.

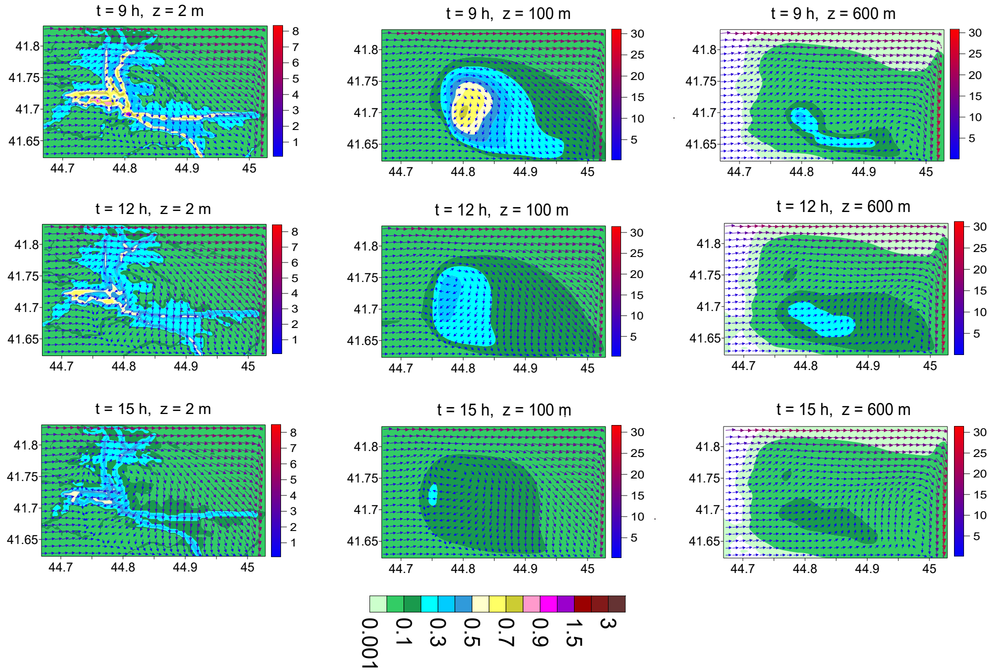

Fig. 9 Wind velocity and PM_{10} concentration fields at 2, 100 and 600 m height when t = 9, 12, 15 h, in case of western background light air

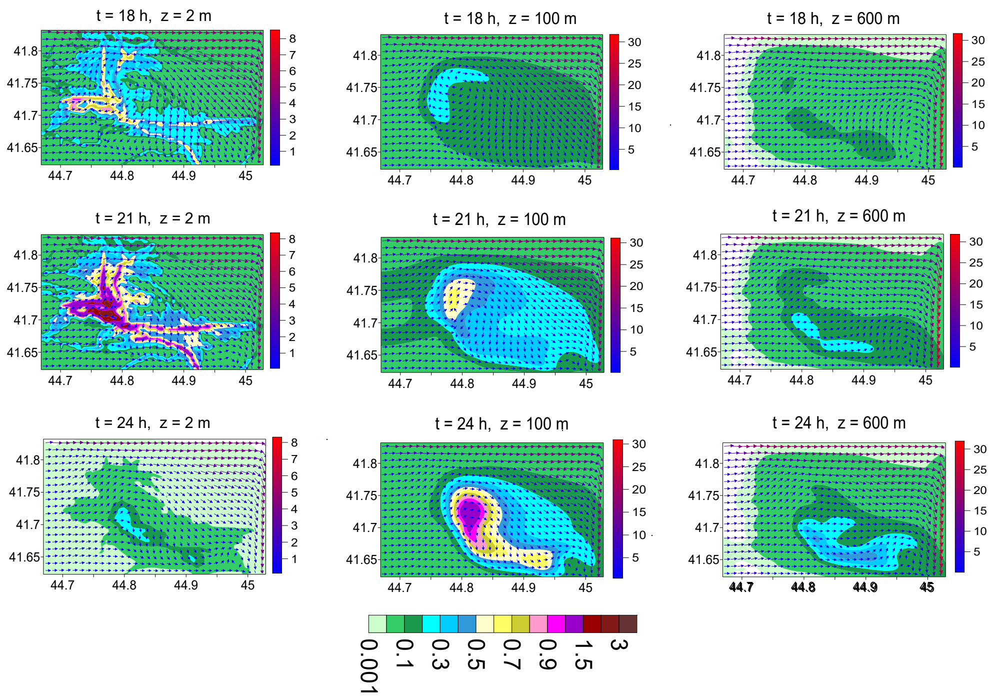

Fig. 10 Wind velocity and PM_{10} concentration fields at 2, 100 and 600 m height when t = 18, 21, 24 h, in case of western background light air

Calculations showed that when t = 0, 3 and 6 h, the concentration field at 2 m height from the earth ground has roughly the same spatial distribution (Fig. 8). The concentration value at the central and densely populated territories of the city is approx. 0.1 MPC, in the peripheral part – less than 0.1 MPC, while at less loaded, underpopulated and recreation territories the atmospheric air is virtually clean, and concentration value is less than 0.001 MPC. At 100 m height from the earth ground the level of atmosphere pollution with PM_{10} when t = 3 and 6 h is higher than when t = 0 h. Concentration above the surface layer of the atmosphere sharply drops and at 600 m height it roughly equals to 0.001 MPC.

After 6 am, the level of atmosphere pollution with micro-aerosols starts to grow with the increase of motor transport traffic intensity (Fig. 9). Heavy pollution is registered in the motor transport traffic rush hours, from 9 to 10 am. In this time interval the concentration is especially increased in the central part of the city and in the surroundings of city mains connecting with it. In these urban districts the level of atmosphere pollution reaches 1-1.2 MPC. In the lower part of the atmospheric boundary layer the concentration rapidly grows with increase of surface concentration. Quick growth of concentration along with turbulent diffusion process is caused by ascendant air movement at the windward side of the orography.

From 10 am to 4 pm, concentration decrease is registered in the atmospheric boundary layer. After 4 pm, a rapid growth of PM_{10} concentration related to the second peak of motor transport traffic begins. Maximum air pollution (2.5 MPC) is obtained at 2 m height at the central part of the city and at the leeward side of Mtatsminda mountain (Fig. 10). In the major part of the city PM_{10} concentration value is within the limits of 0.8-1 MPC.

The modeling showed that in the summer in the surface layer of the atmosphere the vertical distribution of PM_{10} concentration has some featured by peculiarities. It is seen from Fig. 10 that in the period from t = 12 h to 15 h at 2, 100 and 600 m heights the synchronous reduction of concentration takes place. After that, in the interval of time from 18 h to 24 h the grow of the concentration with 3-hour phase retardation is obtained: at z = 2 m height a concentration is maximal when t = 21 h, while at z = 100 m height – when t = 24 h. The mentioned effect is presumably caused by the dependence of turbulent and convective transfer processes on time change of local circulation. In particular, the local anticyclone vortex of wind velocity, which is formed at 100 m height when t = 18h, after 3 hours (when t = 21h) becomes weaker and moves to the south, and at t = 24h, it virtually disappears.

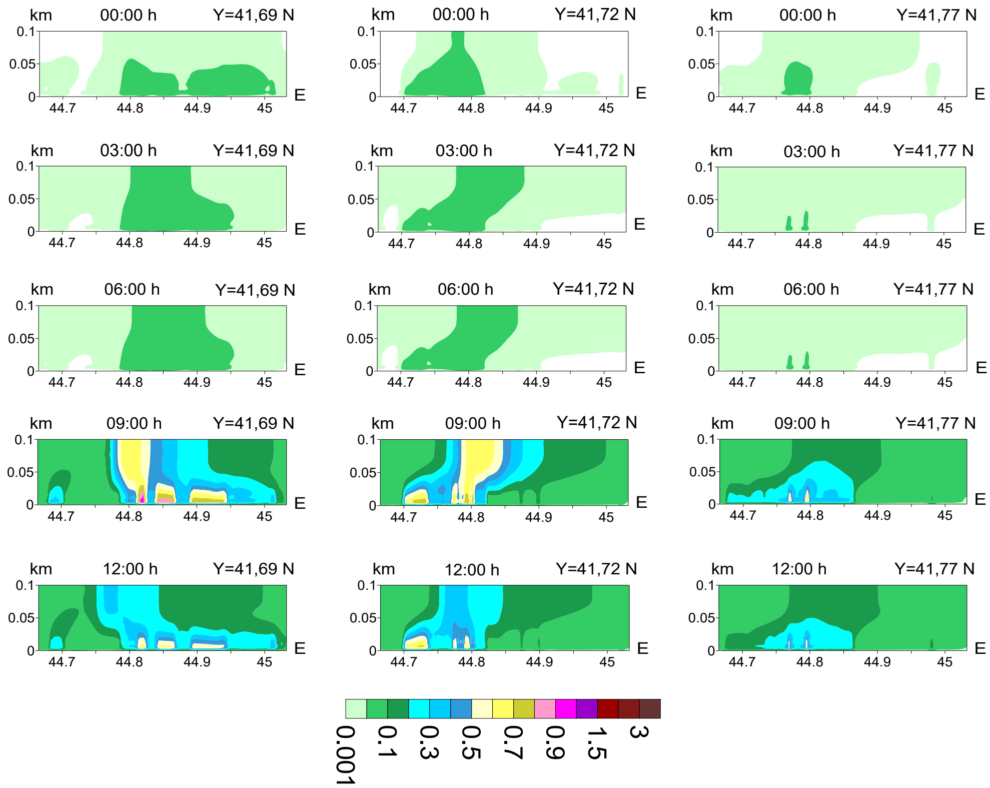

Fig. 11 PM_{10} concentration distribution in the atmospheric boundary layer in 3 vertical cross-sections along a parallel, when t = 0, 3, 9, 12, 15, 18, 21 and 24 h, in case of western background light air

In Fig. 11 there is shown PM_{10} concentration distribution in the atmospheric boundary layer in 3 vertical cross-sections along a parallel. It is seen from Fig. 11 that the vertical distribution of PM_{10} concentration has a form of a convective thermal, which experiences slight deformation in the upper part of surface layer of the atmosphere due to advective transfer of aerosol. Transfer direction changes in time and depends on the velocity of local wind formed under influence of terrain.

When t = 24 h, an aerosol cloud pulls away from underlying surface due to ground surface cooling, moves upward vertically by means of formed local convective streams and at 100 m height creates the zone of maximum pollution with 1 MPC concentration.

It should be noted that the pattern of daily changes of concentration obtained through modeling qualitatively coincides with daily changes of the concentrations of PM_{10} obtained by observations (Figs. 6, 7) wherein concentration values measured and obtained via modeling are close to each other from the quantitative viewpoint, and the difference between them is within tolerable limits.

IV. Conclusion

Concentrations of $PM_{2.5}$ in Tbilisi city atmosphere, as a rule, are less than of PM_{10}, but the character of changes of their curve is similar. In winter period their maximum values almost always exceed the corresponding MPC, while in the summer they are frequently lesser than corresponding MPC.

Hourly change trend of PM concentrations showed that during a day the $PM_{2.5}$ and PM_{10} concentrations are featured by a growth trend and reaches its maximum in evening hours, after 7 pm. Carried-out analysis showed the influence of pandemic on dust particles concentration drop in the city atmosphere and clearly demonstrated that a main contribution to Tbilisi atmosphere pollution with PM is made by motor transport.

It is obtained through modeling that the dust dissipated in Tbilisi city is mainly concentrated in the lower 600 m part of atmospheric boundary layer. At 2 m height from the earth surface the maximum concentration 1.0-2.5 MPC is formed in the interval from t = 15 h to 21 h in the central and southern parts of the city and at relatively deepened territories.

Peculiarities of vertical and horizontal distribution and time change of PM_{10} concentration are studied, as well.

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