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Research Article

AN INVESTIGATION OF THE TBILISI CITY ATMOSPHERE POLLUTION BY ANALYSES OF THE OBSERVATION DATA AND NUMERICAL MODELING RESULTS

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Abstract.

The temporary variations of the dust concentration in Tbilisi city by of the data of natural measurement are investigated and dust propagation at Tbilisi city territory in case of strong background eastern winds by numerical modelling are studied. It is shown that dust propagation substantially depends on both the terrain of city and surrounding territories and on the magnitude and direction of background wind velocity. It is obtained that dust propagation process in case of background eastern light air is characterized by time variation and spatial distribution peculiarities. High pollution zones as well as the reasons of their time variation and dust accumulation are determined. It is established that a high pollution level, 1.2-2.0 maximum allowable concentration MAC = 0.5 mg/m^3), is obtained in the time interval from 3 p.m. to 9 p.m. in the up to 50 m thick lower part of surface layer of the atmosphere.

Key words: numerical modeling, Tbilisi dust pollution, diffusion, gentle breeze wind.

Introduction. Human health substantially depends on atmospheric air purity level [1]. According to the World Health Organization "worldwide, ambient air pollution contributes to 7.6% of all deaths in 2016" [2]. Therefore, study and mitigation of natural environment locations' pollution is one of the most important ecological and human health protection tasks. Though Tbilisi is not ranked among 500 cities worldwide, which are the most polluted by micro particles [3], however according to data of National Environmental Agency of Georgia concentrations of dust and micro particles in its atmosphere frequently exceed maximum permissible values [4].

Tbilisi city dust pollution level evaluation according to observation data. Dust concentration in city air was surveyed from 70's of the 20th century up to and including 2016. Since 2017 $PM_{2.5}$ and PM_{10} concentrations are observed in automatic mode instead of a dust.

In Fig. 1 the monthly average dust concentrations in 2015 are shown [4].

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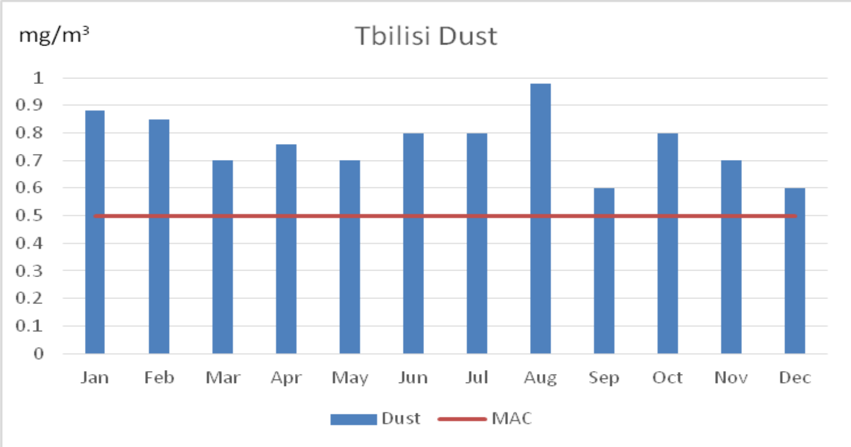

Fig. 1. The monthly average dust concentrations in Tbilisi city

It is seen from Fig. 1 that the monthly average concentration in 2015 is in limit of 1,1-1,96 MAC and it was high in January, February and August. From [5], was also obtained that during last 6 years the average annual concentration varied from 1 to 1,8 MAC.

Diurnal variation of dust concentration in January 2016 is shown in Fig. 2, from where we can see that average diurnal concentration variation is featured by 2-3-day periodicity and negative trend, with trend inclination coefficient 0,096 and dispersion 0.2442.

Dust concentration values at first and second observation points varies within 0.35-0.8 mg/m^3 at 9AM, 0.3-0.8 mg/m^3 – at 1 PM and 0.3-1.0 mg/m^3 at 6 PM. Average concentration in January is within a limit of 0.35-0.7 mg/m^3. As for average concentration values in the beginning, middle and the end of the month, they are roughly the same. Concentration obtained at 1PM in the beginning and in the end of month is less than concentration observed in the mid-month, while in case of 6 PM, on the contrary – mid-month concentration is less than concentration measured in the beginning and in the end of month. Qualitatively similar results were obtained for summer period of 2016.

Tbilisi city dust pollution level evaluation through numerical modeling

In order to evaluate dust distribution at the territory of Tbilisi and its time variation a numerical modeling of dust propagation was carried out using meso-scale numerical model of meteorological processes development in Caucasus [5] and numerical integration of equation of substances' transfer-diffusion in the atmosphere [6]. Modeling was made at the 24.4 x 30 km^2 area, which includes Tbilisi and its adjacent territories. City has very complex terrain and it is confined with mountains of Greater and Smaller Caucasus ridges, while Kura River valley passes through city center. Several small-size hills and gorges are located within its boundaries. Terrain height varies from 70 m to 1.5 km. Due to relief complexity a terrain-following coordinate system is used. Numerical modeling is made with 300 m and 400 m steps along parallel and meridian. Vertical step in the free atmosphere is approx. 300 m, and in the surface layer of the atmosphere vertical step varies from 0.5 m to 15 m.

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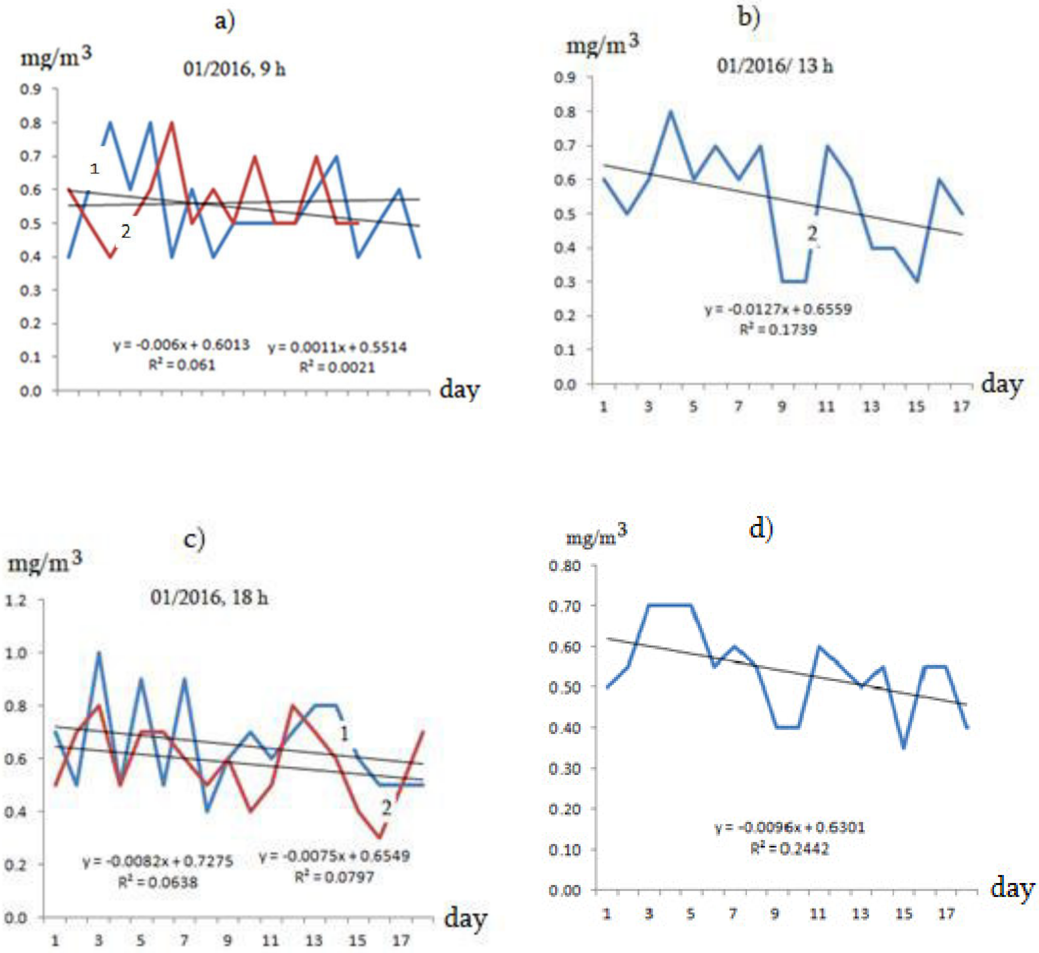

Fig. 2. Concentration values of dust in observation points No. 1 (line 1) and No. 2 (line 2) in 9 AM, 1 PM and 6 PM - (a), (b), (c), respectively, average diurnal concentration throughout a month (d), linear trend equations and dispersions (R^2).

Dust propagation is modeled in case of dry weather of June and an eastern background light air breeze. Wind velocity varies from 1 m/s (at 2 m height) to 20 m/s (at 9 km height). In 100 m thick surface layer of the atmosphere a change of meteorological fields is determined by parameterization model [7], it is presumed that atmosphere pollution source is represented by a dust originated by motor transport traffic, and this dust is dissipated up to 0.5 m height. Dissipated dust quantity varies in time and depends on traffic intensity.

In Fig. 3 the distribution of dust concentration and wind velocity obtained by calculation at the height of z = 2 m from earth surface for 24 hours of the first day are shown. It is seen from the figure that concentration is minimal at the town territory when t = 6 h. At that time the maximum value of concentration varies in interval of 0.3-0.5 MAC at three less populated territories – in vicinity of Tbilisi Sea, south-east and south-west parts of considered area. At the central and densely populated territories of the city, concentration of dust is within 0.1-0.2 MAC. From t = 6 h to t = 12 h in the central part of the city and near the town mains, a concentration rapidly increases with grow of intensity of vehicle traffic.

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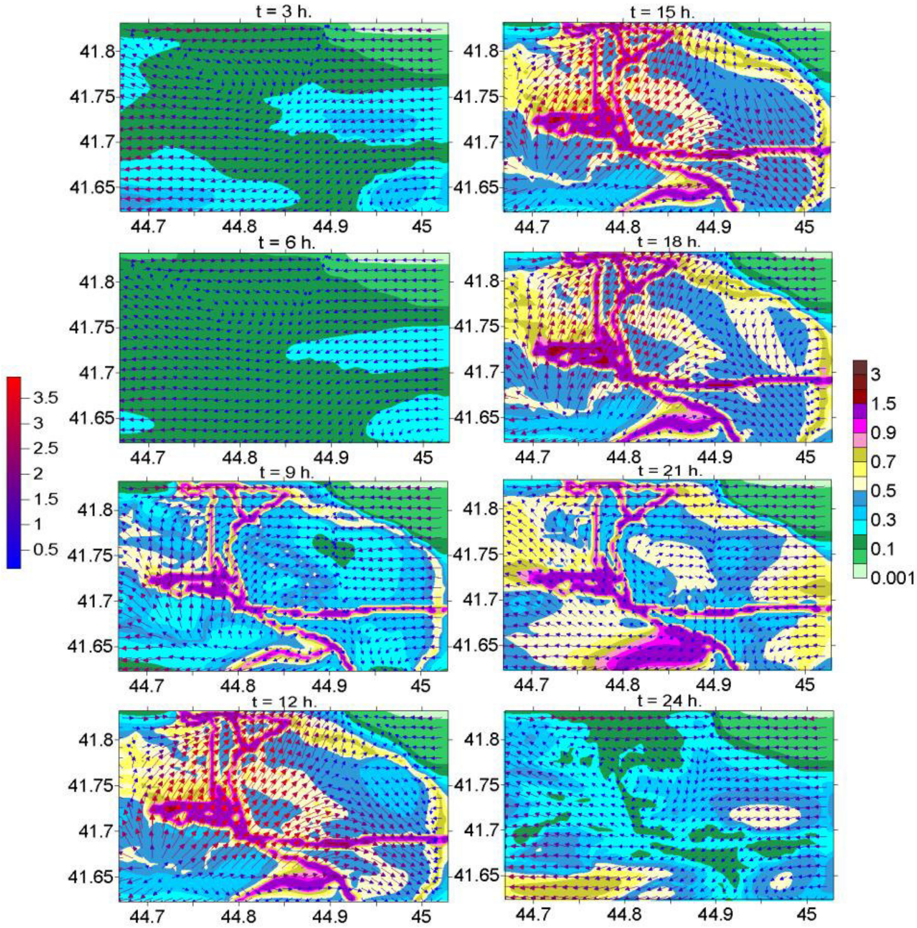

Fig 3. Dust concentration (in MAC) and wind velocity (m/s) fields at the territory of Tbilisi at 2 m height from earth surface in case of background eastern light air, when t = 3, 6, 9, 12, 15, 18, 21, and 24 h.

Maximum values of concentration 1.5-2 MAC are obtained in vicinity of mains and central parts of city from 3 PM to 9 PM. In these parts of city, despite the constant character of vehicle traffic intensity, slow rate of concentration growth and extension of square of relatively severely polluted areas takes place. Areas with severe dust pollution have different forms. Their shape and location depend on the value of surface wind velocity and form of relief (Fig. 3). Closed circulation systems, as well as convergence and divergence areas in the neighborhood of mountains confining separate urban districts are formed. As a result, dust redistribution and accumulation take place in some windward areas of the terrain.

From 9 PM to 12 PM concentration values are getting smaller. This reduction is non-uniform and is not proportional to vehicle traffic intensity change. Dust pollution drastically falls near the town mains at lowland territories of the central part of the city, and less sharply reduces in the neighborhood of inclined slopes of mountains confining the mentioned territory. Dust accumulation occurs in lowland urban districts. After 12 PM hours a quasi-periodic change of dust concentration field takes place.

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Conclusion

The temporary variations of the dust concentration in Tbilisi city by means of the data of natural measurement are investigated. The annual mean concentration of the dust during the 2011-2016 years varies in the interval of 1-1.8 MAC, the month mean in 2015 in the interval 1.1-1.98 MAC are shown.

The kinematics of dust change created by motor transport at Tbilisi territory and daily pattern of its spatial distribution are studied in case of background eastern gentle breeze. Via analysis of wind velocity and concentration fields it is obtained that spatial distribution of heavily polluted areas depends on city mains disposition, and local circulation systems formed under dynamic impact of terrain and diurnal change of thermal regime on the underlying surface. Maximum concentration 1.0-2.0 MAC is formed in t = 12.00-21.00 h time interval in the central, southern and relatively low-lying territories of the city. At 600 m height from earth surface a maximum value of concentration reaches 0.7 MAC, when t = 21.00 h.

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