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Numerical Modelling of PM10 Propagation in Rustavi City Atmosphere During the Southern Background Wind

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Abstract

According to observations, experimental measurements, and numerical modelling, the atmospheric pollution caused by microaerosols PM2.5 and PM10 in Rustavi city, one of Georgia's industrial centres, has been estimated. Analysed were the fluctuations in concentration of pollutants in the urban atmosphere on a monthly, daily, and hourly basis. The particle concentrations in the atmosphere of Rustavi City reach their highest levels at any hour of the day due to the combined influence of motor vehicle traffic and industrial facilities. The distribution of PM10 particles in the atmosphere has been determined using numerical modelling for scenarios involving background light air, a mild breeze, and a fresh breeze. Calculations demonstrated that light air and mild breeze cause a rise in the concentration of microaerosols in the urban atmosphere, but fresh breeze facilitates the dissipation of the pollution cloud, albeit expanding its distribution area.

Keywords: atmosphere, pollution, microaerosols, concentration, monitoring

Introduction

Atmospheric air pollution represents a significant environmental challenge globally, including Georgia, as humans constantly reside in this environment and are consistently exposed to polluted air. Microaerosols PM2.5 and PM10 are atmospheric pollutants that require particular attention. They are introduced into the atmosphere through both natural and human activities. These particles consist of microscopic solid substances or liquid droplets that are of such a small size that they can be consumed and lead to significant health issues. PM2.5 and PM10 refer to particulate matter that consists of solid and liquid particles with diameters ranging from 1 to 10 µm. They are composed of particles of organic pollutants, carbon particles, road tar, rubber from tyres, mineral salts, acids, and other solid or liquid particles. The maximum allowable values for PM2.5 are 10 µg/m3 (daily average) and 25 µg/m3 (one-time maximum). For PM10, the maximum allowable concentrations are 20 µg/m3 (daily average) and 50 µg/m3 (one-time maximum).

PM2.5 and PM10 particles pose the greatest risk to human life as they can lead to significant deterioration in human health, often resulting in fatal consequences. Specifically, an immense number of individuals perish annually due to atmospheric pollution caused by microparticles [1]. According to the World Health Organisation, 3% of cardiovascular diseases and 5% of cancer diseases are attributed to the influence of these particles [1]. In addition, it is highly probable that viruses, like Covid-19, attach to dust microparticles and spread in the atmosphere.

The objective outlined above is to investigate the dispersion patterns of PM2.5 and PM10 particles in densely populated urban areas, with a particular focus on the influence of various wind directions. Rustavi is a highly industrialised and densely populated metropolitan area. This area is home to cement and nitrogen facilities, along with a range of medium and small businesses. Consequently, a variety of particles, including PM10 particles, are released into the air.

The present research examines the patterns of PM10 distribution in the atmosphere of Rustavi city through numerical simulations, taking into account the influence of a southerly wind.

Methods and Materials

Based on the analysis of routine observation data [2] the content and peculiarities of microaerosols (PM2,5 and PM10) distribution in the atmosphere of the Rustavi city, one of the industrial centres of Georgia are studied. Their maximum and minimum values are identified. Through analysis of the curve of concentration hourly variation there is estimated a period of maximum pollution during a day. It is

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established that manifestation of maximum concentration is mainly related to the motor transport traffic intensity, industrial facilities operation mode and meteorological conditions.

Rustavi city atmospheric air quality measurements are made by means of only one automatic background monitoring station and 7 quarterly indicating measurement. Based on the results of current monitoring it is impossible to see a complete picture of city atmospheric air quality, that is why for its estimation we have used three-year (2020-2022) observation data of automated station and results of our experimental measurement, which means measuring the concentration of PM10 particles (µg/m3) using indicators such as air temperature and atmospheric pressure, as well as wind speed and direction. One of the indicators was the number of vehicles.

Dust dissipation in the free atmosphere and surface layer of the atmosphere is modelled through numerical integration [3], using respective initial and boundary conditions.

It is assumed that the atmosphere is polluted by a dust originated at city mains and streets due to motor transport traffic. Its quantity changes in time and is determined according to assessment of continuous surveillance materials and transport traffic intensity.

Results

Analysis of everyday values of microparticle concentrations showed that very high indices are recorded in a majority of days over the month. As the example, in fig. 1 there is shown the microaerosols concentration change in Rustavi city atmosphere in February 2022. It is seen from the figure, that over the period taken PM 2,5 and PM10 concentrations exceed two and more times their respective MPC values.

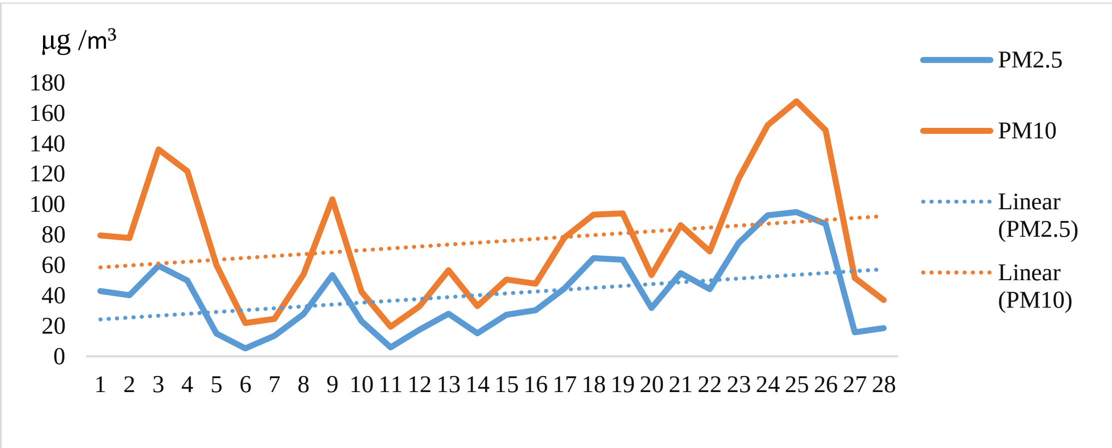

Figure 1. Hourly variation of PM2.5 and PM10 concentrations in Rustavi city in February 2022

Hourly variation of PM particles concentration in Rustavi atmosphere is analyzed (Fig. 2). As the example, there is given the course of data in the interval from 20 to 26 February, 2022, from where it is almost impossible to draw any conclusion, since concentration maximums are recorded in different time intervals of a day, in contradistinction from Tbilisi city [4], where the maximums have been always reached in the second half of a day, after 8PM, that is associated with motor transport traffic intensity in rush hour period. In case of Rustavi, the dust from industrial facilities is added to motor transport emission, therefore concentration increase depends both on motor transport traffic intensity and on plants operation intensity.

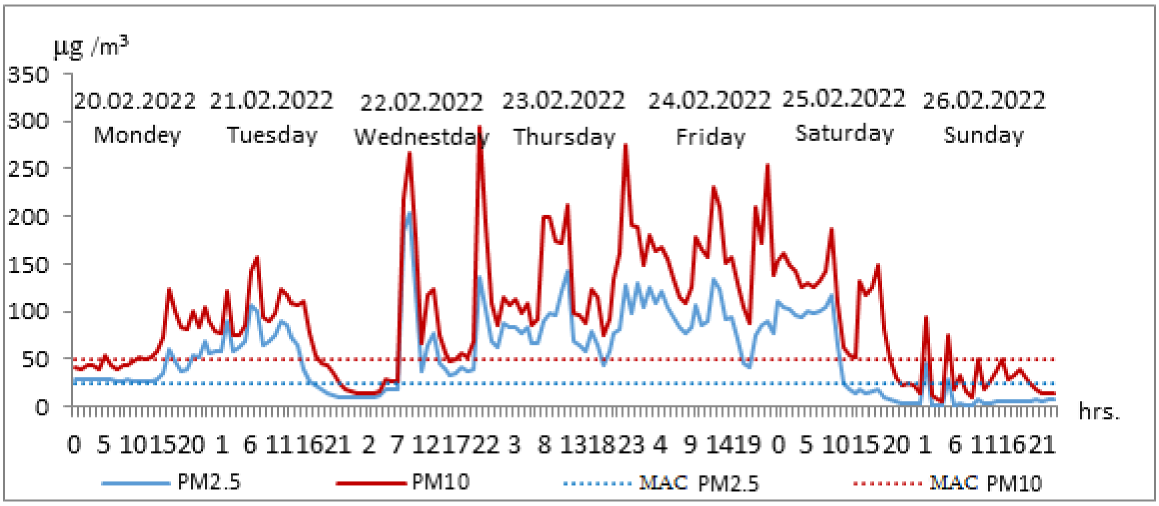

Figure 2. Hourly variation of PM2.5 and PM10 concentration in Rustavi city in February, 2022

Experimental measurement results

Experimental measurements cover Tbilisi-Rustavi main highway, central areas of the city and territories adjacent to the industrial facilities. Mobile apparatus "TROTEC PC220" has been used for experimental measurements. Expeditions have been made three times in different meteorological situations. In Fig. 3 there are shown the results of expedition taken on 9th of April, 2022, and we see that PM particles concentrations given in item 7 (territory adjacent to Heidelberg Cement) 8 times exceed the data taken in other observation points. There was a windy weather (approx. 9 m/sec), and a windstorm perceptible to the eye during measurements that has had an impact on the graph.

It may be said that PM2,5 particle concentrations in Rustavi city atmosphere, as a rule, are less than PM10 concentrations, but the nature of their change curve is almost identical. Their maximum values almost always surpass the corresponding maximum permissible concentrations. Experimental observations showed that PM particles concentration increase in Rustavi city is induced both by motor transport and by emissions of available plants and meteorological conditions.

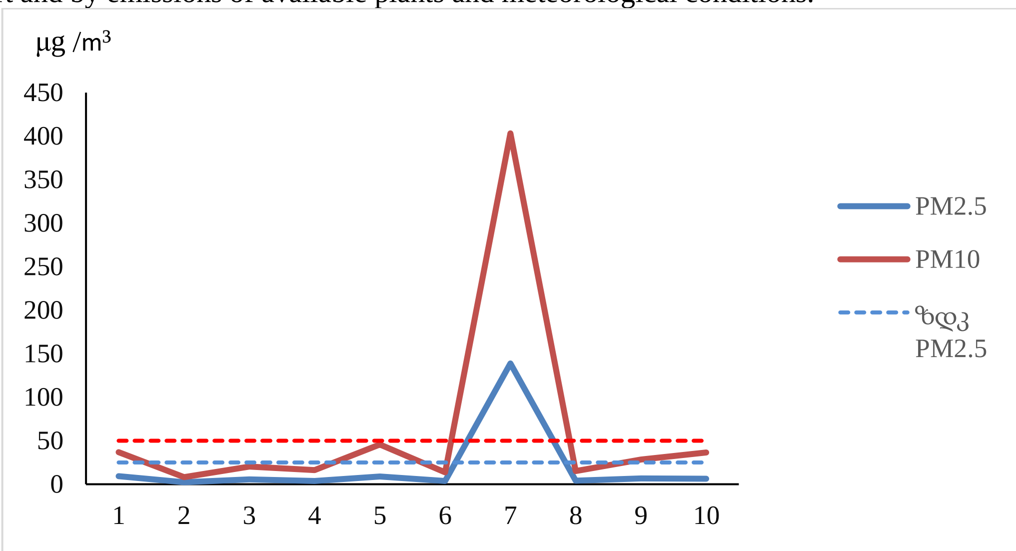

Figure 3. PM2.5 and PM10 concentrations in different points of Rustavi city, 9th of April, 2022

Distribution of PM10 particles dissipated in the atmosphere of Rustavi city and its adjacent territories during light air, gentle and fresh breeze is studied. Modeling is implemented at 118×91×31 numerical grid with 1000 m horizontal steps and 1/31 dimensionless vertical steps. In the atmospheric boundary layer and in the free atmosphere a vertical step approximately equals to 300 m. In the 100 m thick lower surface layer of the atmosphere 17 vertical grid points are selected, while step varies from 0.5 m to 15 m. It has been assumed during modeling that PM10 concentration at the territory of Rustavi city is constant in time, maximal and equals to 50 µg/m3. The adjacent territories of Rustavi city have a rugged relief, and altitude varies there from 370 to 1400 m. Numerical calculations have been made within three-day interval. Calculations showed that polluting ingredients are propagated quasi-periodically with 24 h period.

Light air

In Fig. 4 there are shown the fields of wind velocity and PM10 concentrations in the surface and boundary layers of the atmosphere, in case of background southern light air. Background wind velocity changes from 1 m/sec (at 100 m height from the earth surface) to 20 m/sec (in tropopause). It is seen from fig. 4 that terrain effect and change in diurnal thermal regime cause formation of local wind, which partly differs from the background one. In particular, at Kvemo Kartli plain, along the Mtkvari River valley and in the northern-western part of the region the south-western wind is formed. In the northern and southern parts of the region there is a southern wind. Wind direction slightly changes with altitude and time.

Spatial distribution of microparticles is less altered, as well. Resulting from dominant influence of formed local wind, microparticles are transferred to the north-west direction and form pollution cloud of elongated ellipse-like shape. The cloud width reaches 50 km, while length substantially surpasses it.

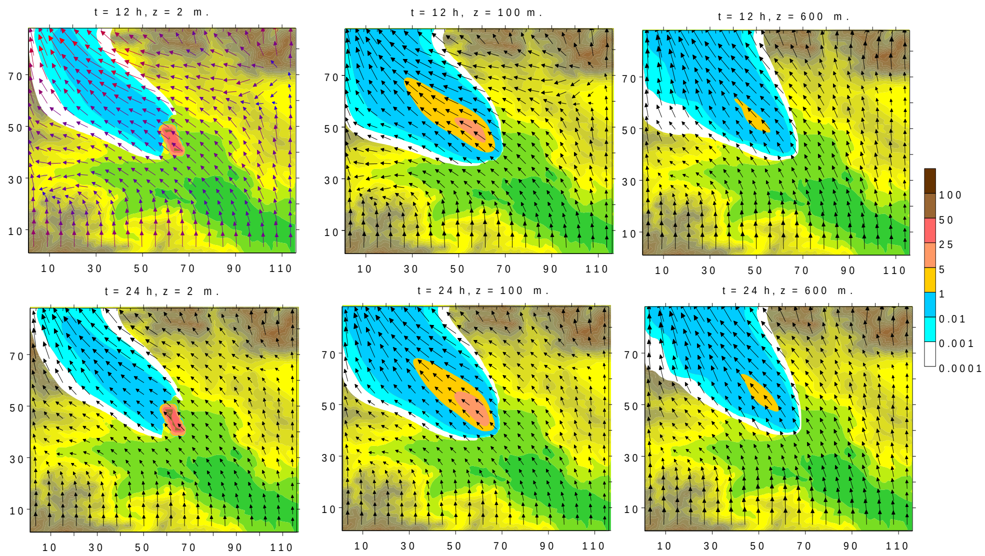

Figure 4. Wind velocity and PM10 concentration distribution at z = 2, 100 and 600 m height during background southern light air, when t = 12 and 24 h

Gentle breeze

In Fig. 5 there are shown the fields of wind velocity and PM10 concentration in the surface and boundary layers of the atmosphere, obtained during background southern gentle breeze. It is seen from Fig. 5 that when t = 12 and 24 h, the spatial distribution of wind velocity obtained via modeling is qualitatively similar to the wind velocity field received during light air. PM10 concentration spatial distribution is qualitatively similar, as well. Microparticles available in the city air move north-westward along the formed local wind, first along the Kartli plain and then along Mtkvari River valley. Therefore, a cloud polluting atmosphere with microparticles is oriented to the north-west, its shape is uniform in the surface and boundary layers of the atmosphere, while its width slightly rises with altitude increase.

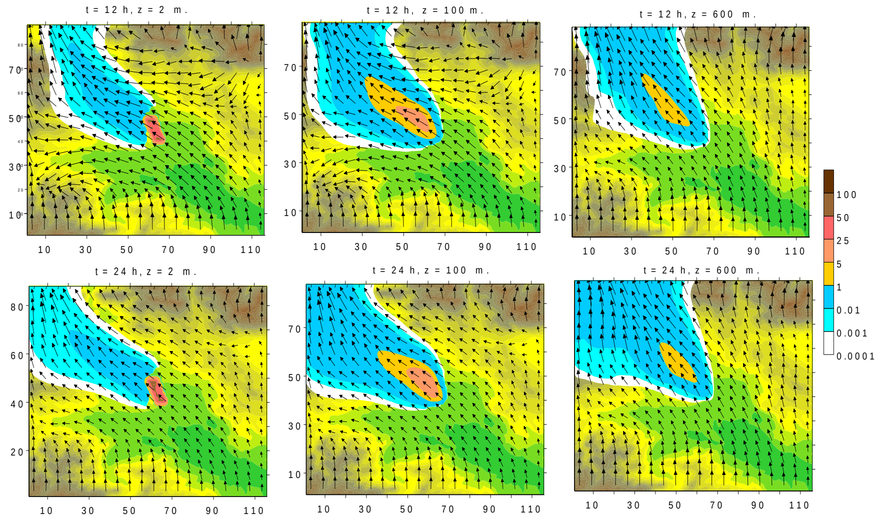

Figure 5. Wind velocity and PM10 concentration distribution at z = 2, 100 and 600 m height during background southern gentle breeze, when t = 12 and 24 h

Fresh breeze

During background southern fresh breeze, the impact of orography on local wind formation prevails the influence caused by diurnal variation of temperature. As a result, a local south-eastern wind, which slightly changes during a day is formed at Kartli plain and Mtkvari River valley (Fig. 6). Microaerosols propagation process is quasi-stationary, as well. Microaerosol cloud has a shape of cigar plume directed from south to the north-west, and its width slightly increases from surface layer to boundary layer of the atmosphere.

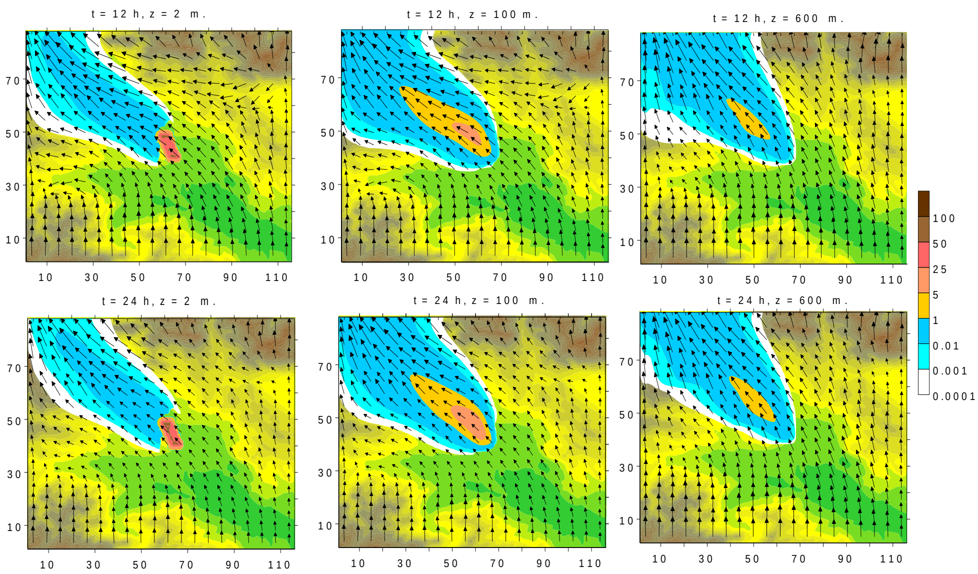

Figure 6. Wind velocity and PM10 concentration distribution at z = 2, 100 and 600 m height during background southern fresh breeze, when t = 12 and 24 h

Conclusion

According on the analysis of data from the NEA, we can make the following conclusions:

Typically, the levels of PM2.5 particles in the atmosphere of Rustavi city are lower than the levels of PM10 particles, while the pattern of their change is comparable. On nearly a daily basis, their maximum values exceed the associated maximum permissible concentrations (MPC).

The hourly variation trend of PM particle concentration reveals that the highest concentrations occur at various times throughout the day. This is due to the combination of dust emissions from industrial facilities and motor vehicle exhaust. Therefore, the increase in concentration depends on both the intensity of motor vehicle traffic and the operation of industrial plants.

A study was conducted in Rustavi city to numerically model the local propagation of microparticles in the presence of background light air, a soft and fresh breeze. The modelling results indicate that the presence of southern light air in Rustavi, together with the topography impact and changes in the daily temperature patterns, lead to the production of local winds that are partially distinct from the prevailing winds. Specifically, a south-northern wind is generated in the Kvemo Kartli plain, Mtkvari River valley, and the north-western portion of the region. A southerly wind is generated in the northern and southern regions. The wind direction undergoes small variations in relation to altitude and time. Due to the prevailing impact of local wind patterns, microparticles are transported in a north-west direction, resulting in the formation of a pollution cloud with an elongated, elliptical shape. The breadth of the cloud measures 50 kilometres, while its length significantly exceeds that measurement. The spatial distribution of wind velocity derived through modelling during a background southern gentle breeze is qualitatively comparable to the wind velocity field seen during light air. The regional distribution of PM10 concentration exhibits qualitative similarity. Amidst a gentle wind blowing from the south, the influence of the local terrain on the creation of winds is more significant than the impact of daily temperature changes. Consequently, a regional south-eastern breeze, which undergoes modest variations throughout the day, is generated in the vicinity of the Kartli plain and Mtkvari River valley. The microaerosol cloud takes the form of a cigar-shaped plume that extends from the south to the northwest. Its width gradually grows from the surface layer to the boundary layer of the atmosphere.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

N.G. contributed to the execution of model calculations, analysis of the results, experimental measurements, and text revision for the article. A.S. conducted model computations, analysed the results, and oversaw the composition of the paper. L. I. was responsible for creating the monitoring database, actively contributed to the experimental measurement, conducted analysis on the obtained results, and reviewed the article manuscript. M.P. performed empirical measures and analysed the resulting data, participated in the evaluation of the manuscript.

Acknowledgements

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