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# Study of Kutaisi City Atmospheric Air Pollution with PM10 Particles using Numerical Modeling. A Case of Fresh Western Background Breeze

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***ABSTRACT***

*Study of Kutaisi city atmospheric air pollution with PM10 particles has been conducted by means of combined integration of 3D regional model of atmospheric processes evolution and equation of admixtures transfer-diffusion. Patterns of PM10 concentration time chance and spatial distribution have been obtained. It has been shown that a formed field of wind velocity promotes PM10 particles transportation from the city and atmosphere "self-purification" process. It has been obtained by calculations that aerosol propagation process conventionally runs by four stages and depends on motor transport traffic intensity, trunk roads' location and city relief. Relatively high pollution zones have been identified. It has been established that thermal stability of the atmosphere in the surface layer of atmosphere plays crucial role in time change of microaerosols' concentration and high concentrations formation process.*

***Key words:*** *PM10 pollution of atmosphere, numerical modeling, concentration, fresh western breeze.*

## Introduction

Protection of atmospheric air of urbanized environment from aerosol pollution is a topical problem of the modern ecology. It is of great medical and socioeconomic importance [1]. Among numerous substances polluting the atmospheric air a special place is held by the smallest particles, sizes of which don't exceed 2.5 and 10 μm (PM2.5 and PM10). They are originated as a result of both current natural processes taking place on the Earth (rock erosion, desert winds etc.), and agricultural, industrial and transport-related human activity. Due to small sizes, PM2.5 and PM10 easily penetrate human cardiovascular system, precipitate there and cause numerous diseases, and even death on frequent occasions [2-4].

Problem of atmospheric air protection from microparticles pollution is very important not only in large cities and industrial regions, but also in resort-recreation centers and separate small cities. Cities of Georgia aren't ranked among heavily polluted cities of the world [5], however in some cases microparticle concentrations there exceed maximum permissible concentrations [6-8] and have a negative impact on human health.

Some air-protection measures have been scheduled over the recent years for improvement of atmospheric air purity of Georgian cities [9, 10]. In order to enhance their efficiency, it is necessary to carry out these measures based on scientifically substantiated studies.

In the presented article, the problem of PM10 pollution of atmospheric air of Kutaisi – the second largest city of Georgia and its adjacent territories resulted from motor transport traffic has been studied theoretically, using the computer modeling of admixtures propagation in the atmosphere.

## Research method

The atmosphere of Kutaisi city and its adjacent territory with an area of 13.4 x 13.4 km has been selected for studies (Fig. 1). This territory is of complex orography – terrain height varies from 80 to 450 m. The orography is confined by ranges and separate mountains from north and east, while the western and southern parts of city and its surroundings are located at the Kolkheti lowland.

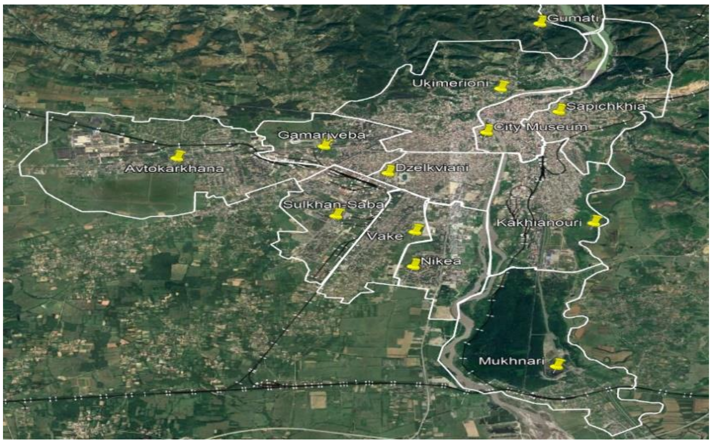


Fig. 1. Urbanized relief of Kutaisi and adjacent territories, and administration units (AU).

This work studies spatial distribution and time change of concentration of microparticles discharged into surface layer of the atmosphere over the mentioned territory, using numerical modeling. Regional model of atmospheric processes development at the Caucasus territory and the method of numerical integration of equation of admixtures transfer-diffusion in the atmosphere are used for modeling [13-15]. Integration is made at the numerical grid composed of 67×67×31 points. Numerical grid steps along meridian and parallel are equal to 200 m. A vertical dimensionless step in free atmosphere equals to 1/31, that approximately corresponds to 300 m. A vertical step in 100 m thick surface layer of the atmosphere varies from 0.5 to 15 m. Time step is 1 sec. Calculations are made for 3-day period. A case of background fresh western breeze under dry weather conditions of June is considered. Wind velocity at surface layer height (100 m) is 11 m/sec. Above the surface layer wind velocity linearly increases and reaches 20 m/sec at 9 km altitude. Relative atmospheric humidity is 50%.

It is assumed that PM10 pollution of the atmosphere is caused by motor transport traffic in the city and its adjacent territory. Emissions occur at 0.5 m height from the earth surface in 5 types of areas: trunk roads, central streets of the city, residential areas, industrial zones and unpopulated territories of surrounding villages. Emission rate is different depending on the area, is of 24 hour-periodic nature and proportional to motor transport traffic intensity. It is minimal in the interval from 0 to 4AM, then linearly increases from 4AM to 10AM and remains constant from 10AM to 6PM. From 6PM to midnight a discharge rate linearly reduces and becomes equal to emission rate of 0 AM.

### Numerical modeling results

Spatial concentration and time change of PM10 concentration discharged by motor transport into atmosphere of Kutaisi obtained using numerical modeling in case of fresh western breeze are given in Fig. 2.

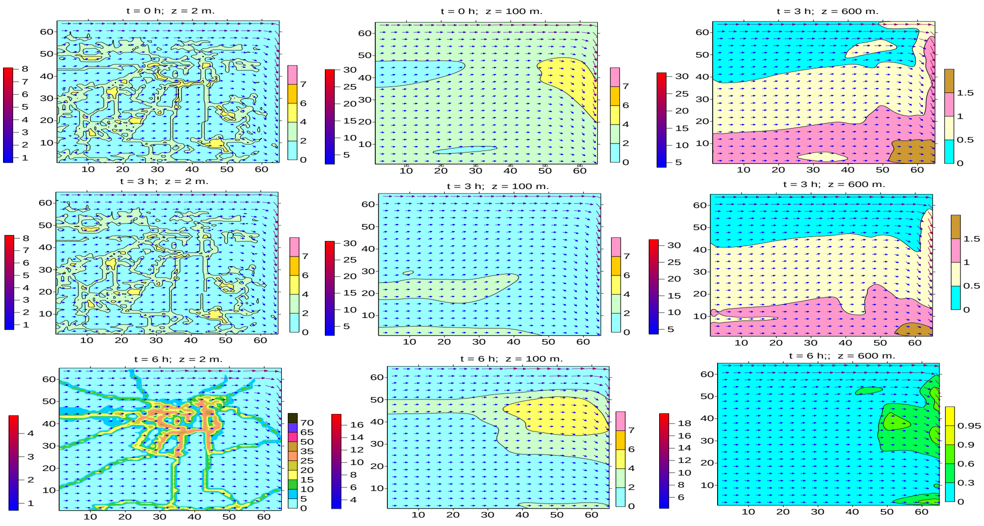

Fig. 2. Spatial concentration of PM10 concentration (μg/m$^3$) and wind velocity vector (m/sec), obtained using numerical modeling, when t = 0, 3 and 6 h.

As is seen from Fig. 2, a terrain effect on background fresh western breeze doesn't cause significant change of wind velocity in the surface layer and the lower part of boundary layer of the atmosphere. Terrain effect is manifested in wind velocity reduction at the city territory and emergence of a component directed north-eastward. In a whole, in the modeling area, wind velocity at 2 m height from earth surface increases from south to north and from west to east from 0.8 to 8 m/sec. With the distance from the Earth ground a terrain effect gradually weakens, wind keeps its western direction, while a wind velocity values at 600 m height vary within a range of 4-30 m/sec.

The analysis of time change of microaerosol concentration field, obtained by calculations, shows that concentration values are minimal within an interval of t = 0-3 h. At 2 m height when t = 0 h, PM10 concentration value is within 0-2 μg/m$^3$ at the major part of the city. Concentration equal to 2-4 μg/m$^3$ is obtained in the surroundings of main city streets. Maximum concentrations, 4-6 μg/m$^3$, are registered at the territories of administration units (Gamarjveba, Dzelkviani, City-Museum) located in the city center, as well as in suburban areas (Kakhianouri and Avtokarkhana AUs, Baloji village) and territories situated south-westward and south-eastward of the city.

At 100 m height from the earth surface, when t = 0 h, PM10 concentration value is 2-4 μg/m$^3$ in the major part of the modeling area, and 0-2 and 4-6 μg/m$^3$ in two areas of small size. Concentration value at 600 m height doesn't exceed 2 μg/m$^3$. By t = 3h, a pattern of spatial concentration of the surface concentration at 100 and 600 m height doesn't experience qualitative change, and small reduction of concentration takes place in quantitative terms. Rise of atmospheric air pollution level starts in parallel with increase of motor transport traffic intensity. When t = 6h, concentration values are within limits of 15-20 μg/m$^3$ at 2 m height from the earth surface at urbanized territories and in the close proximity of central streets. In the mentioned period of time, a weak substance transfer from surface layer of the atmosphere to its upper parts occurs. As a result, by t = 6 h, at 100 and 600 m from the earth surface, maximum concentration values reach 6 and 1 μg/m$^3$, respectively. Increase of atmospheric concentration lasts until 10-11AM. This increase is especially intense in the city center and its north-eastern part (Ukimerioni, Gamarjveba, Sapichkhia, Dzelkviani and City-Museum) (Fig. 3). Concentration value at this territory reaches 35 μg/m$^3$. Concentration increase also takes place at the highways connecting Kutaisi with Khoni, Tskaltubo resort, Samtredia and at the Kutaisi by-pass road.

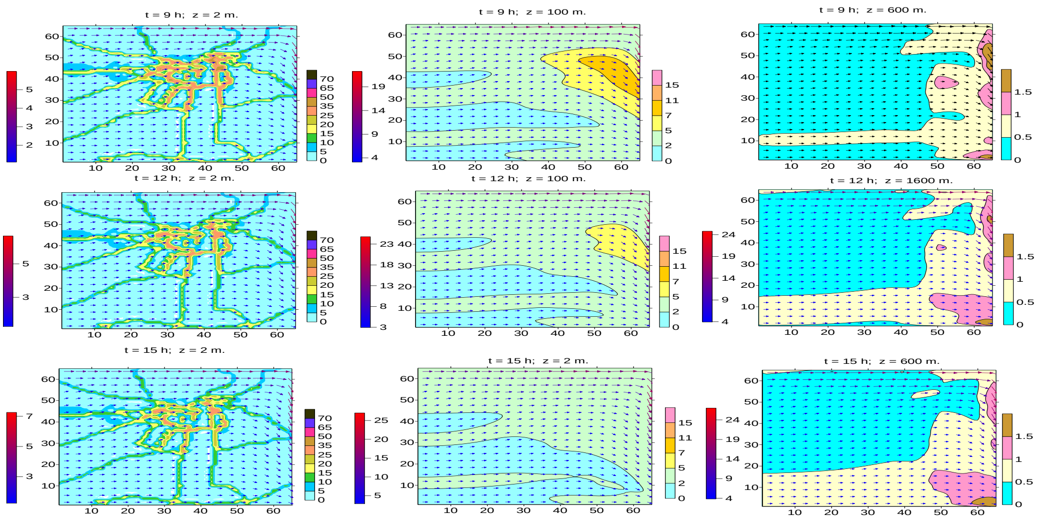


Fig. 3. Spatial distribution of PM10 concentration (μg/m$^3$) and wind velocity vector (m/sec), obtained by numerical modeling, when t = 9, 12 and 15 h.

After 11 AM, concentration starts to reduce throughout the modeling area. This reduction lasts until 3 PM. A uniform increase of concentration takes place after 3PM, as well. Maximum concentration 30-35 μg/m$^3$ is registered at 6-7PM in the surroundings of main avenues of the city (Fig. 4). In the ensuing points of time concentration quickly reduces until the midnight, and afterwards the pollution change process lasts on a quasi-periodical basis.

At 100 and 600 m level from the surface, concentration value is mainly within the limits of 2-7 μg/m$^3$ and a time of achievement of its maximum values (7-11 μg/m$^3$) by 2-3 hours lags behind a time of achievement of maximum surface concentration.

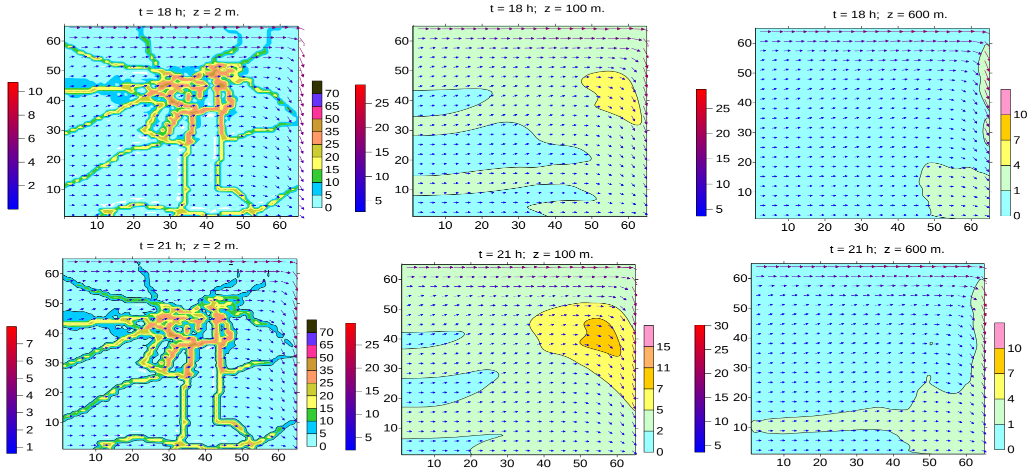


Fig. 4. Spatial distribution of PM10 concentration (μg/m$^3$) and wind velocity vector (m/sec), obtained by numerical modeling, when t =18 and 21 h.

In Fig. 5 there is shown the diagram of PM10 concentration time change obtained via calculations for main types of observation points. It is seen from Fig. 5 that time change of concentration at trunk roads, main city streets and urbanized territories is characterized by presence of 2 maximums (when t = 8-9 h and 19-21 h) and 2 minimums (when t = 4 and 14-15 h) of concentration. The more is PM10 emission rate, the more apparent are mentioned extremums. It is worth noticing the presence of local concentration maximums by 6AM.

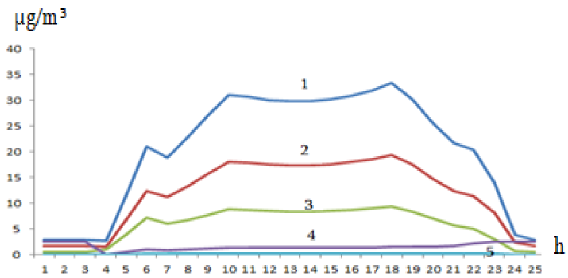


Fig. 5. Time change of PM10 concentration at trunk roads (1), central city streets (2), along industrial (3) and rural (4) zones and in unpopulated points at 2 m height from the earth surface.

As for rural-type settled and unpopulated territories, concentrations values in their surroundings don't exceed 5 μg/m$^3$ and their time change is not clearly expressed.

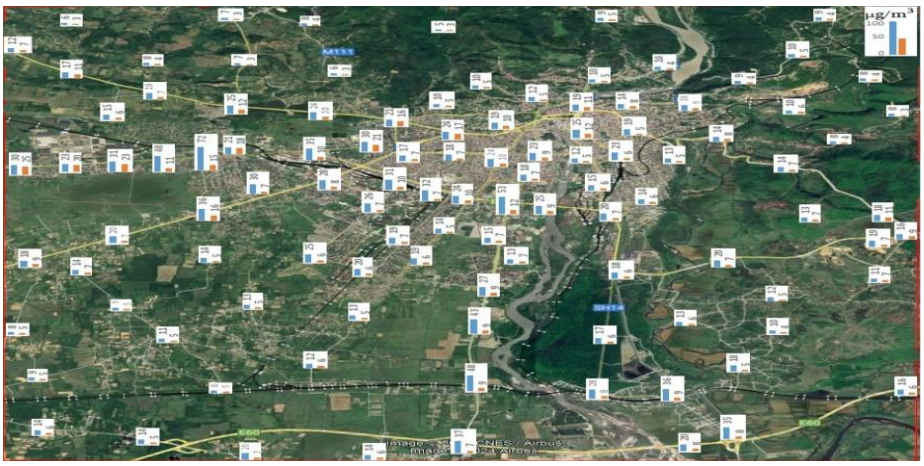


Fig. 6. Column diagrams and numerical values of PM2.5 (red) and PM10 (blue) concentrations (μg/m$^3$ ) obtained by experimental measurements.

Numerical modeling results have been compared with the results of carried-out special expedition measurements (Fig. 6). As the comparison showed, the results of theoretical and experimental measurements are close to each other. The mentioned fact points at the great importance of motor transport traffic in the process of microaerosol pollution of Kutaisi atmosphere.

**Conclusions**

Peculiarities of spatial distribution and time change of PM10 concentrations generated by motor transport at the territory of Kutaisi city in case of background fresh breeze in June have been studied by means of numerical modeling. It has been shown that the values of calculated concentrations are within the values observed. Patterns of spatial distribution of concentration in the city and its adjacent territories have been established at different parts of a day. It has been shown that spatial distribution of concentration significantly depends on both motor transport intensity and kinematics of surface layer of the atmosphere and local circulation system formed by diurnal change of thermal regime on the underlying surface.

**Acknowledgments.** The scientific research has been funded and performed with financial support of the Shota Rustaveli National Science Foundation within the grant project FR-22-4765.

## ლიტერატურა - REFERENCES - ЛИТЕРАТУРА

[1] Integrated Science Assessment for Particulate Matter. EPA. United States Environmental Protector Agency, 2019, p.1967. EPA/600/R-19/188. www.epa.gov.isa.

[2] Pope C.A., Burnett R.T., Thun M.J., Calle E.E, Krewski D., et al. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. J. Am. Med. Assoc, 287, 2002, pp. 1132–1141.

[3] World Health Organization. Regional Office for Europe. Review of evidence on health aspects of air– REVIHAAP Project. First result.

[4] Mortality and burden of disease from ambient air pollution-WHO. https://www.who.int/gho/phe/outdoor_air_pollution/burden/en/

[5] World's most polluted cities (historical data 2017-2022). https://www.iqair.com/world-most-polluted-cities.

[6] Kobza J., Geremek M., Dul L. Characteristics of air quality and sources affecting high levels of PM10 and PM2.5 in Poland, Upper Silesia urban area Environmental Monitoring and Assessment. 190, Article number 515, 2018.

[7] Girish Agrawal, Dinesh Mohan, Hifzur Rahman. Ambient air pollution in selected small cities in India: Observed trends and future challenges. IATSS Research. Volume 45, Issue 1, April 2021, pp 19-30. https://doi.org/10.1016/j.iatssr.2021.03.004.

[8] Air quality in Tbilisi. IQ Air. https://www.iqair.com/georgia/t-bilisi/tbilisi

[9] National Environment and Health Action Plan of Georgia 2018-2022 (NEHAP-2) https://test.ncdc.ge/Handlers/GetFile.ashx?ID=951a795c-ab20-4bdd-8f32-57959e3e1728

[10] ქ. რუსთავის ატმოსფერული ჰაერის ხარისხის გაუმჯობესების სამოქმედო გეგმა 2020-2022. https://mepa.gov.ge/Ge/PublicInformation/27987

[11] Amiranashvili A. G., Kirkitadze D. D., Kekenadze E. N. Pandemic of Coronavirus COVID-19 and Air Pollution in Tbilisi in Spring 2020. Journal of Georgian Geophysical Society, 23(1), 2020. https://doi.org/10.48614/ggs2320202654

[12] Surmava A.A., Kukhalashvili V.G., Gigauri N.G., Intskirveli L. N. PM2.5 and PM10 in the Atmosphere of Kutaisi City. Journal of Georgian Geophysical Society, 26(2), 2023. https://doi.org/10.60131/ggs.2.2023.7445

[13] Surmava A., Intskirveli L., Kukhalashvili V. Numerical Modeling of the Transborder, Regional and Local Diffusion of the Dust in Georgian Atmosphere, p.139, Publishing House, Technical University", ISBN 978-9941-28-810-4, Tbilisi, Georgia, 2021. http//www.gtu.ge (in Georgian).

[14] Kazakov A. L., Lazriev G. L. On Parametrization of Atmospheric Boundary Layer and Active Soil Layer. Izvestiya, Atmospheric and Oceanic Physics, 15, 1978, pp. 257-265.

[15] Marchuk G.I. Mathematical modeling in the problem of the environment. Moscow, Science, 1982, 320 p. (in Russian).

# ქ. ქუთაისის ატმოსფერული ჰაერის PM10–ით დაბინძურების გამოკვლევა რიცხვითი მოდელირებით. ფონური დასავლეთის ძლიერი ქარის შემთხვევა

ა. სურმავა, ვ. კუხალაშვილი, ნ. გიგაური, ლ. ინწკირველი

## რეზიუმე

ქ.ქუთაისის ატმოსფერული ჰაერის PM10–ით დაბინძურების კვლევა განხორციელებულია ატმოსფერული პროცესების ევოლუციის 3D რეგიონალური მოდელისა და მინარევების გადატანა - დიფუზიის განტოლების ერთობლივი ინტეგრირებით. მიღებულია PM10–ის კონცენტრაციის დროში ცვლილებისა და სივრცული განაწილების სურათები. ნაჩვენებია, რომ ფორმირებული ქარის სიჩქარის ველი ხელს უწყობს PM10–ის ქალაქიდან გატანა და ატმოსფეროს ,,თვითგასუფთავების" პროცესს. გამოთვლებით მიღებულია, რომ აეროზოლის გავრცელების პროცესი პირობითად მიმდინარეობს ოთხ ეტაპად და დამოკიდებულია ავტოტრანსპორტის მოძრაობის ინტენსივობაზე, მაგისტრალების მდებარეობაზე და ქალაქის რელიეფზე. განსაზღვრულია შედარებით მაღალი დაბინძურების არეები. მიღებულია, რომ ატმოსფეროს მიწისპირა ფენაში ატმოსფეროს თერმული მდგრადობა თამაშობს მნიშვნელოვან როლს მიკროაეროზოლის კონცენტრაციის დროში ცვლილებისა და მაღალი კონცენტრაციების ფორმირების პროცესში.
**საკვანძო სიტყვები:** ატმოსფეროს PM10–ით დაბინძურება, რიცხვითი მოდელირება, კონცენტრაცია, ფონური დასავლეთის ძლიერი ქარი.

# Исследование загрязнения атмосферного воздуха г. Кутаиси частицами PM10 численным моделированием. Случай сильного фонового западного ветра

**А. Сурмава, В. Кухалашвили, Н. Гигаури, Л. Инцкирвели**

## Резюме

Путем численного моделирования исследованы особенности пространственного распространения и изменения во времени частиц PM10, образованных автотранспортом на территории г. Кутаиси в случае сильного фонового западного ветра в июне. Показано, что значения вычисленных концентраций находятся в пределах наблюдаемых величин. Установлены картины поверхностного распределения концентраций в городе и на прилегающих к нему территориях в разное время дня. Показано, что пространственное распределение концентрации в значительной степени зависит как от интенсивности движения автотранспорта, так и от кинематики приземного слоя атмосферы и локальной циркуляционной системы, сформированной суточным изменением термального режима на подстилающей поверхности.

**Ключевые слова:** загрязнение атмосферы частицами PM10, численное моделирование, концентрация, сильный фоновый западный ветер.