საქართველოს მეცნიერებათა ეროვნული აკადემიის მოამბე, ტ. 18, №3, 2024
BULLETIN OF THE GEORGIAN NATIONAL ACADEMY OF SCIENCES, vol. 18, no. 3, 2024

Ecology

The Results of Kutaisi City Atmospheric Air Pollution with PM Particles

Natia Gigauri[*], Aleksandre Surmava[*], Vepkhia Kukhalashvili[**], Liana Intskirveli[*]

[*] *The Institute of Hydrometeorology, Georgian Technical University,Tbilisi*
[**] *Mikheil Nodia Institute of Geophysics, Ivane Javakhishvili Tbilisi State University, Georgea*

(Presented by Academy Member Tamaz Chelidze)

Pollution of atmospheric air of Kutaisi city with PM particles has been investigated. Data obtained via operating supervisions and special experimental measurements carried out within atmospheric air pollution monitoring have been used for the study. Annual, monthly and daily values of microaerosol concentrations in the city and its adjacent areas were determined. Using combined integration of 3D regional model of atmospheric process evolution and equation of transfer-diffusion there has been numerically modeled and analyzed a distribution of PM10 emitted by motor transport into Kutaisi air in summer during background calm-wind meteorological conditions. Patterns of time change and spatial distribution of PM10 concentration were obtained. It has been shown that the terrain of the city and its surrounding territories stipulates formation of wind velocity anticyclonic ground vortex. The formed field of wind velocity promotes PM10 carry-over from the city. It has been obtained, that aerosol propagation processes conventionally run in four stages and depends on vehicular traffic intensity, highways location and the city's micro-relief. A decrease in the morning hours of the temperature of the ground surface leads to an increase of the thermal stability of the lower part of the atmosphere surface sublayer, a decrease of vertical turbulence, the accumulation of the micro-aerosols in the atmosphere, and an increase of pollution level. In time interval from 4AM to 7AM a rapid increase of concentration takes place, which is followed by its reduction or constancy from 7AM to 3PM, concentration rise – within an interval from 3PM to 9PM, and from 9PM to 6 o'clock city air self-purification occurs. Numerical experiments have showed that spatial distribution of PM 2.5 particles emitted by motor vehicles is qualitatively similar to that of PM10. *© 2024 Bull. Georg. Natl. Acad. Sci.*

atmosphere, PM2.5 and PM10, pollution, numerical modeling, concentration, calm

PM2.5 and PM10 particles are one of the main air polluting microaerosols. They have a negative impact on human health, cause many diseases including pulmonary cancer, blood stroke, cardiovascular and other illnesses and can even lead to death in frequent cases [1-3].

The issue of atmosphere pollution with PM2.5 and PM10 is of special relevance in the industrial centers, megapolises, and in some small towns, as well, where their air content frequently exceeds several times the maximum permissible levels [4]. PM2.5 and PM10 emissions have been reduced and air purity degree has been improved as a result of air-protection measures taken over the last quarter of a century, however, in a number of cities the air pollution level still surpasses European Union standards [4-6].

PM2.5 and PM10 monitoring in Georgia started in 2018 and has been executed in five cities. These cities aren't ranked among the most heavyly polluted in the world [5], but in some cases microparticle concentrations there exceed maximum permissible levels [7, 8]. Kutaisi is ranged among such cities. It is annually visited by hundreds of thousands people coming here for medical-health and touristic purposes. Proceeding from the city function, the study of environmental conditions, diagnostic forecast of pollution level and preservation of high level of air purity attach as special importance.

The present paper deals with the analysis of microaerosol propagation and time behavior in the atmosphere of Kutaisi city and its adjacent territories in an integrated manner – by means of analysis of field observation data and theoretically – via computer modeling of admixture propagation in the atmosphere.

Materials and Method

In order to study PM2.5 and PM10 pollution of atmospheric air of Kutaisi city, the materials of 2018-2023 routine observations of the air quality station located within the air monitoring area were used. For determination of spatial concentrations of PM2.5 and PM10 particles in Kutaisi city and its adjacent territories, experimental measurements were made in 65 observation points in spring, summer and autumn of 2023 using mobile apparatus "Aeroqual Series 500" and "Trotec PC220".

Experimental measurement data were used for assessment of PM2.5 and PM10 pollution levels of Kutaisi city atmosphere and for numerical modeling of spatial and temporal distribution of concentrations induced by motor-vehicle traffic. Modeling was made at the territory of complex terrain of Kutaisi and its surrounding with an area of 13.4 x 13.4 km. For correct description of the meteorological fields at the territory of complex terrain a terrain-following coordinate system (t, x, y, $\zeta = (z - \delta)/h$) was used, where t is time, x and y – coordinates along parallel and meridian, ζ - non-dimensional vertical coordinate, $\delta(x, y)$ – terrain height above sea level, h = H – δ – troposphere thickness, and H(t, x, y) –altitude (flight level) of tropopause. An equation of passive ingredient transfer-diffusion in the atmosphere will be written as follows:

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + \left(\tilde{w} - \frac{w_0}{h}\right)\frac{\partial C}{\partial \zeta} = \frac{\partial}{\partial x}\mu\frac{\partial C}{\partial x} + \frac{\partial}{\partial y}\mu\frac{\partial C}{\partial y} + \frac{1}{h^2}\frac{\partial}{\partial \zeta}\nu\frac{\partial C}{\partial \zeta} + F, \quad (1)$$

where, C – ingredient concentration, u, v, w and $\tilde{w}$ – wind velocity components along x, y, z and ζ axes; w_o – polluting ingredient deposition rate; $F(t, x, y, \zeta)$ – ingredient sputtering rate in the atmosphere by the source; μ and ν – coefficients of horizontal and vertical turbulence. Wind velocity components and turbulence coefficients in free atmosphere, boundary and surface layers of the atmosphere are calculated by means of equations and formulas given in [9,10].

PM10 aerosol propagation is modeled via numerical integration of the equation (1) using the respective initial and boundary conditions. Numerical grid steps in horizontal direction equal to 200 m, those of vertical direction in boundary layer of atmosphere and in free atmosphere are 300 m, and vertical steps in 100 m thick surface layer of the atmosphere vary from 0.5 to 15 m. Time step is 1 sec. Calculations were made for 3-day period.

Results of measurements. Routine observations over PM2.5 and PM10 concentration in Kutaisi city atmosphere were conducted during 2018-2021 by the National Environmental Agency within the frameworks of atmospheric air pollution monitoring at one surveillance point, which is located at the crossroad very crowded due to intense motor vehicle traffic. As a result of operating supervision it was established that annual average PM2.5 concentrations in 2018, 2019, 2020 and 2021 were equal to 16, 18, 14, and 11 µg/m^3, while that of PM10 – 40, 49, 30 and 43 µg/m^3, respectively. It was observed that annual average values of hourly average concentration reached maximum in 2019 and were less than maximum permissible average daily concentration values (25 µg/m^3 for PM2.5 and 50 µg/m^3 for PM10). Analysis of monthly average concentrations showed that their maximum value was registered in 2021 and was equal to 64 µg/m^3 and 125 µg/m^3 in August and October, respectively. As for annual hourly concentrations of PM2.5 and PM10 the hourly change trend showed that during a day, PM particle concentrations almost always is characterized by upward trend and reaches its maximum after 8PM.

Expeditional measurement carried out in 2023 in Kutaisi city and its surrounding showed that in spring, summer and autumn the average values of PM10 and PM2.5 concentrations are within a range of 8,4-132,5 and 4,6-25,1 µg/m^3.

Extremally high PM10 concentration (> 2,6 MPC; MPC = 50 µg/m^3) was measured at the territory adjacent to Avtomshenebeli Street. High concentrations (> MPC) were observed in the city center (Green Bazaar, Rustaveli Bridge), in the middle part of Tabukashvili Street, and at the intersection of Kutaisi by-pass road and Tabukashvili Street. These high concentrations are mainly related to repair works, industrial activity, heavy traffic etc., which take place at these places. Territorial distribution of PM2.5 particles differs from that of PM10 particles: high concentration values (20-25 µg/m^3) are obtained at Gamarjveba Square, in the beginning of Kutaisi-Tskaltubo road and Avtomshenebeli Street. PM2.5 concentrations are within 5-10 µg/m^3 in the central part of the city. PM2.5 and PM10 concentration measurements were conducted in the settlements located adjacent to Kutaisi city. Their concentration values were equal: Kvitiri village – 6, 12, Partskhanakanebi village – 4,8, Geguti – 6,13, Khoni region – 8,16, Martvili – 19,23 µg/m^3 (in foggy weather), respectively.

Numerical modeling results. A case of Kutaisi atmosphere pollution by PM particles in June was modeled, when at the altitude of surface layer of the atmosphere (100 m) the calm situation takes place – background wind velocity is 0 m/sec. Above the surface layer there is a western wind, and its speed linearly increases with height and reaches 20 m/sec at 9 km altitude. Atmosphere relative humidity is 50%.

Assuming that PM10 pollution of the atmosphere is caused by transport traffic in the city and its adjacent territories. They are emitted from the ground surface to 0,5 m height in areas of 5 types: highways, central streets of the city, residential areas, industrial zones and unsettled territories of villages nearby. Emission speed varies depending on the area, is of periodical nature and proportional to motor-vehicle traffic intensity. It is minimal within 0-4 h time interval, afterwards from 4 to 10AM linearly increases and is constant in time interval from 10AM to 6PM. After 6PM to midnight, the emission rate linearly reduces and becomes equal to that of 0 h.

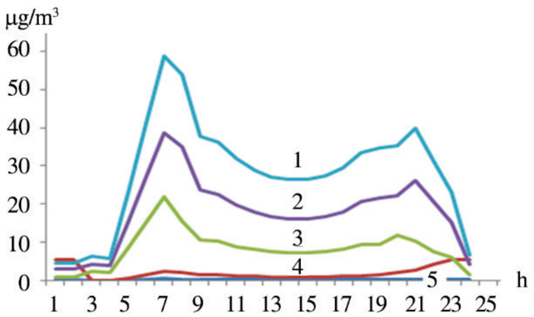

Fig. 1. Time change of PM10 concentrations according to calculations in the following observation points: highways (1), central streets of the city (2), industrial zones (3), rural places (4) and unsettled territories (5).

Figure 1 shows a diagram of concentration change in time, which is obtained via calculations for observation points of 5 basic types. It is seen from Fig. 1 that time change of concentration is qualitatively similar in those points, where heavy vehicle traffic takes place. Time change of concentration in these points is characterized by presence of 2 maximums (at 7AM and 7PM) and two minimums (at 4AM and 3PM). As for settled and unsettled territories of rural type, time change of concentrations in their vicinity is qualitatively analogous, but their values don't exceed 6 μg/m^3 and don't depend on vehicular traffic intensity. Despite the fact that microaerosols emission rate to the atmosphere linearly increases until 10 AM, the maximum concentration is obtained 3 hours earlier – at 7AM. The mentioned effect is related to reduction of surface temperature and its vertical gradient in morning hours. As a result, a thermal stability of surface atmosphere sharply increases, vertical turbulent diffusion reduces and polluting ingredients collect in the lower part of the surface layer. The similar effect takes place after 6 PM.

Figure 2 illustrates the distribution of wind velocity and PM10 particles, obtained via calculations, when t = 6, 9 and 18 h at 2, 100 and 600-meter height from the Earth surface. It is seen from Fig. 3 that Kutaisi city terrain effect on the background wind generates local anticyclone curl of wind velocity. This vortex is quazi-stationary. Its center is located at the lowland territories south-eastward from Kutaisi. Wind velocity field causes respective transfer and spatial distribution of concentration.

Air pollution level at 6AM, induced by motor transport is high in the central urban part of the city (35-65 μg/m^3). 65 μg/m^3 and even higher concentration is obtained in the surroundings of the by-pass road situated southward of Kutaisi. The mentioned effect is caused by divergent nature of wind, peculiar for anticyclonic circulation, which causes admixture transfer from center to peripheries. PM10 concentration in the surroundings of the road connecting central part of the city with suburbs changes within a range of 20-35 μg/m^3. As for a highway connecting Kutaisi with Tskaltubo, concentration in its vicinity doesn't

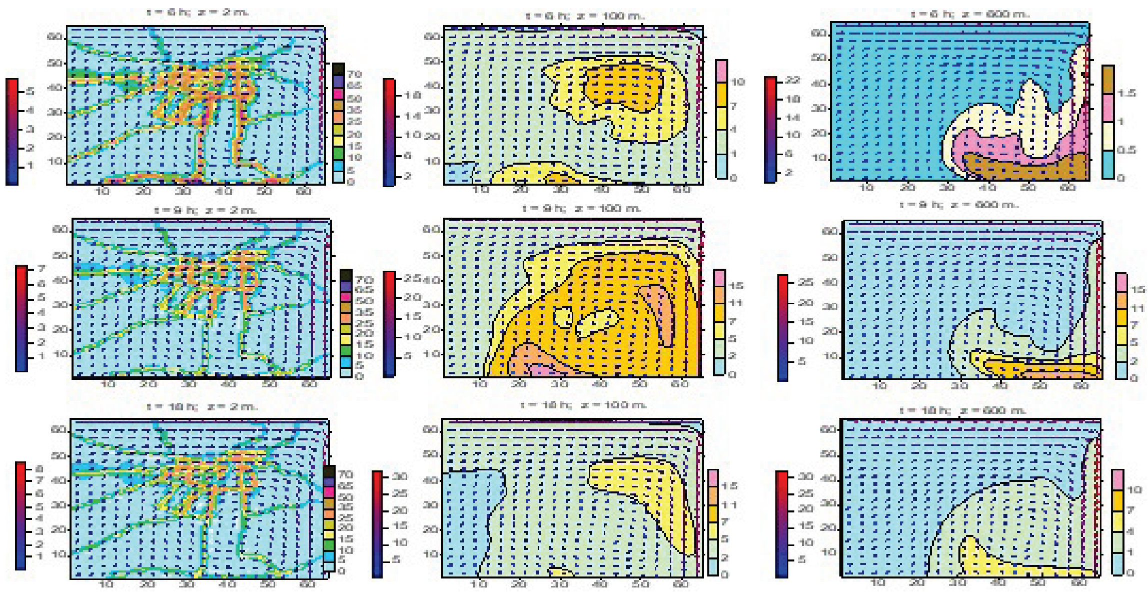

Fig. 2. PM10 concentration (μg/m^3) and wind velocity (m/s) distribution at 2, 100 and 600-meter heights from the Earth surface, when t = 6, 9 and 18 h.

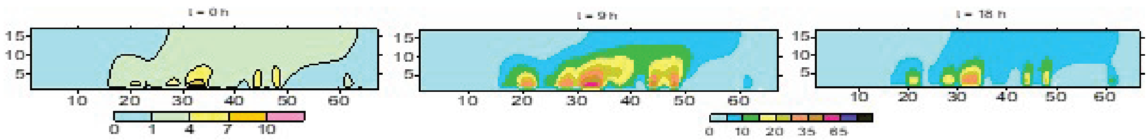

Fig. 3. PM10 concentration (μg/m^3) distribution in surface layer of the atmosphere in vertical sections along the parallel passing through the city center.

exceed 20-35 μg/m^3. PM10 concentration at the unsettled territories adjacent to the city is within 5-10 μg/m^3.

By 9 AM spatial distribution of concentration at 2 m height qualitatively similar to that obtained at 6PM. There is a quantitative difference though. In particular, maximum value of concentration does not exceed 35 μg/m^3, both in the city center and in its southern suburb. At 100 and 600 m heights from the Earth surface maximum values of concentration are 18 μg/m^3 and 15 μg/m^3, respectively. Above 600 m altitude concentration rapidly reduces, and in the boundary atmospheric layer and in free atmosphere is present in form of pollution trace only. In following points of time, the thermal stability of atmosphere reduces, turbulent diffusion increases and concentration values are getting smaller. After 3 PM the second stage of concentration increase begins, which lasts until 9 PM, after 9 PM and until 3 PM of the next day, the process of concentration reduction and atmosphere self-purification occurs.

Figure 3 shows the vertical distribution of PM10 concentration, obtained via modeling in the surface layer of the atmosphere. It is seen from Fig. 3, that an aerosol emitted in the atmosphere by t = 0h creates separate weak thermal-like vertical pollution "clouds". Along with aerosol emission intensity, they grow in size and by h = 12 h occupy significant part of surface layer of the atmosphere. Important role in pollution "clouds" formation and development is acted by hydro-thermodynamics of surface layer of the atmosphere: change of thermal stability of surface layer of the atmosphere, processes of vertical turbulent diffusion, convective and advective transfer.

The carried-out numerical experiment showed that distribution of PM2.5 emitted due to motor vehicle traffic occurs in the atmosphere of Kutaisi city similar to that of PM10, described above, the difference is in quantity only.

Conclusions

Kutaisi city pollution chacteristics in 2018-2022 have been assessed for the first time through analysis of operational data of city atmospheric air pollution with PM10 and PM2.5 particles. Based on the data taken from a single point of operating supervision of atmospheric air quality there have been determined maximum, average and minimum values of average hourly, monthly, daily and hourly concentrations. It has been established by analysis that the average annual value of mean hourly concentration has been maximal in 2019 and less than maximum permissible value of average daily concentration (25 μg/m^3 for PM2.5 and 50 μg/m^3 for PM10). The analysis of average monthly concentrations showed that their maximum values were registered in 2021 and in August and October were equal to 64 and 121 μg/m^3, respectively. As for average hourly concentrations of PM10 and PM2.5, the hourly variation trend indicates that during a day, PM particle concentrations almost always is featured by upward trend and reaches its maximum after 8 PM.

Experimental measurement of PM10 and PM2.5 concentrations have been conducted in spring, summer and autumn of 2023 in 65 observation points of Kutaisi city and its adjacent territories. Relatively high concentration zones have been identified and pollution reasons have been established. Correlation relationship between

PM10 and PM2.5 concentrations and motor-vehicle traffic intensities has been assessed. Spatial distribution substantially depends on both vehicular traffic intensity and on kinematics of surface layer of the atmosphere and local circulation system formed due to daily variation of the underlying surface thermal regime. A structure of concentration vertical distribution has been studied. It has been accepted that high pollution zones in the lower 20 m part of surface layer of the atmosphere are formed in the form of separate surface thermals. During a day they change their form, move upward vertically due to vertical turbulence and form a structure of inverse distribution of pollution.

This research is performed within the frameworks of the grant project FR-22-4765 of the Shota Rustaveli National Scientific Foundation of Georgia.

ეკოლოგია

ქ. ქუთაისის ატმოსფერული ჰაერის PM ნაწილაკებით დაბინძურების კვლევის შედეგები

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

** საქართველოს ტექნიკური უნივერსიტეტი, ჰიდრომეტეოროლოგიის ინსტიტუტი, თბილისი*
*** ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი,*
მიხეილ ნოდიას გეოფიზიკის ინსტიტუტი, საქართველო

(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

გამოკვლეულია საქართველოს ერთ-ერთი ადმინისტრაციული, სამედიცინო-გამაჯანსაღებელი და კულტურულ-ტურისტული ცენტრის, ქ. ქუთაისის ატმოსფერული ჰაერის PM2.5 და PM10–ით დაბინძურება. კვლევისათვის გამოყენებულია ატმოსფერული ჰაერის დაბინძურების მონიტორინგის ფარგლებში ჩატარებული ოპერატიული დაკვირვებებისა და სპეციალური ექსპერიმენტული გაზომვებით მიღებული მონაცემები. განსაზღვრულია მიკროაეროზოლების კონცენტრაციათა წლიური, თვიური და დღიური მნიშვნელობები, ასევე, მათი სივრცული განაწილება ქალაქისა და მის მიმდებარე ტერიტორიაზე. ატმოსფერული პროცესების ევოლუციის 3D რეგიონული მოდელისა და მინარევების დიფუზიის განტოლების ერთობლივი ინტეგრირებით რიცხობრივად მოდელირებული და გაანალიზებულია ავტოტრანსპორტის მიერ გაფრქვეული PM10–ის გავრცელება ზაფხულში ქ. ქუთაისის ჰაერში ფონური შტილური მეტეოროლოგიური პირობების დროს. მიღებულია PM10–ის კონცენტ-

რაციის დროში ცვლილებისა და სივრცული განაწილების სურათები. ნაჩვენებია, რომ ქალაქისა და მიმდებარე ტერიტორიის რელიეფი განაპირობებს ქარის სიჩქარის მიწისპირა ანტიციკლონური გრიგალის წარმოშობას. ფორმირებული ქარის სიჩქარის ველი ხელს უწყობს PM10–ის ქალაქიდან გატანას. მიღებულია, რომ აეროზოლის გავრცელების პროცესი პირობითად მიმდინარეობს ოთხ ეტაპად და დამოკიდებულია ავტოტრანსპორტის მოძრაობის ინტენსივობაზე, მაგისტრალების მდებარეობაზე, ქალაქის მიკრორელიეფსა და თერმულ რეჟიმზე. ქვეფენილი ზედაპირის ტემპერატურის შემცირება დილის საათებში იწვევს ატმოსფეროს მიწისპირა ფენის ქვედა ნაწილის თერმული მდგრადობის გაზრდას, ვერტიკალური ტურბულენტობის შემცირებას, ატმოსფეროში გაფრქვეული მიკროაეროზოლების დაგროვებასა და დაბინძურების დონის ზრდას. დილის 4-დან 7 სთ-მდე ინტერვალში ადგილი აქვს კონცენტრაციის სწრაფ ზრდას, 7-დან 15 სთ-მდე – კონცენტრაციის სუსტ შემცირებას ან მუდმივობას, 15-21 სთ-ის ინტერვალში კონცენტრაციის ზრდას, ხოლო 21-დან დილის 6 სთ-მდე – ქალაქის ჰაერის თვითგასუფთავებას. რიცხვითმა ექსპერიმენტებმა აჩვენა, რომ ავტოტრანსპორტის მიერ გაფრქვეული PM2.5-ის სივრცული განაწილება თვისობრივად PM10–ის განაწილების ანალოგიურია.

REFERENCES

1. Pope C.A., Burnett R.T., Thun M.J., Calle E.E., Krewski D. et al. (2002) Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *J. Am. Med. Assoc.,* 287: 1132–1141.
2. World Health Organization. Regional Office for Europe. Review of evidence on health aspects of air– REVIHAAP Project (2022) First result. https://media.xpair.com › pdf › REVIHAAP
3. Mortality and burden of disease from ambient air pollution-WHO. 2020. https://www.who.int/gho/phe/outdoor_air_pollution/burden/en/
4. World's most polluted cities (historical data 2017-2022). https://www.iqair.com/world-most-polluted-cities?
5. Agrawal G., Mohan D., Rahman H. (2021) Ambient air pollution in selected small cities in India: observed trends and future challenges. IATSS Research. **45**(1): 19-30. https://doi.org/10.1016/j.iatssr.2021.03.004
6. Kobza J., Geremek M., Dul L. (2018) Characteristics of air quality and sources affecting high levels of PM10 and PM2.5 in Poland in Upper Silesia urban area Environmental Monitoring and Assessment **190**, 515.
7. Environmental pollution (2021) https://air.gov.ge/reports_page
8. Amiranashvili A.G., Kirkitadze D.D., Kekenadze E.N. (2020) Pandemic of Coronavirus COVID-19 and Air Pollution in Tbilisi in Spring 2020. *Journals of Georgian Geophysical Society,* 23(1). https://doi.org/10.48614/ggs2320202654
9. Surmava A., Intskirveli L., Kordzakhia G. (2020) Numerical modeling of dust propagation in the atmosphere of a city with complex terrain. The case of background eastern light air. *Journal of Applied Mathematics and Physics,* 8(7): 1222-1228. https://doi.org/10.4236/jamp.2020.87092.
10. Surmava A., Intskirveli L., Kukhalashvili V. (2021) Numerical modeling of the transborder, regional and local diffusion of the dust in Georgian atmosphere, p.139, Publishing House, Technical University", Tbilisi, Georgia. ISBN 978-9941-28-810-4, http//www.gtu.ge (in Georgian).

Received May, 2024