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Ecology

Study of Rustavi City Atmospheric Pollution with Particulate Matters – PM2.5 and PM10

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

[*] *Institute of Hydrometeorology, Georgian Technical University, Tbilisi, Georgia*
[**] *M. Nodia Institute of Geophysics, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*

(Presented by Academy Member Tamaz Chelidze)

Due to complicated ecological situation established, the Georgian government has developed the "2020-2022 Action Plan for the Improvement of Air Quality in Rustavi", which foresees a whole range of air-protecting measures. One of the main problems of air protection is monitoring of PM2.5 and PM10 particles available in the atmospheric air. Average monthly concentrations of micro-aerosols in the city, concentration change along the central town mains and spatial distribution of contaminants are determined in this study in an integrated manner, by means of field observations, experimental measurement data, and theoretically, via analysis of results obtained through computer modeling. It is determined that average monthly concentrations of PM2.5 and PM10 vary within the range of 15-40 and 25-84 μg/m^3, while average monthly maximum concentrations reach 100 μg/m^3 and 180 μg/m^3. Microaerosol concentrations are high in the surroundings of separate industrial facilities. The distribution of microaerosols currently present in Rustavi city to its adjacent territories during northern light air and fresh breeze is simulated and studied via combined integrating of regional model of meso-scale atmospheric process development at the territory of Georgia and equations of passive admixture transfer-diffusion in the atmosphere. The impact of local wind formed via interaction of terrain and background winds on polluting ingredients distribution is analyzed. © *2023 Bull. Georg. Natl. Acad. Sci.*

atmosphere, pollution, PM2.5, PM10, numerical modeling

Atmospheric air pollution is an environmental phenomenon of high risk for human health. According to estimations of the World Health Organization [1], pollution of indoor and outdoor air causes 6.7 mln premature deaths every year.

Availability of microaerosols in the atmospheric air is especially hazardous. PM2.5 and PM10 particles, due to their small sizes, easily penetrate human cardiovascular system and cause extremely dangerous diseases [2-4].

The negative impact of PM2.5 and PM10 particles on human health still has not been assessed in Georgia. One may assume that it is substantial in large cities and industrial centers. At the same time, the strategy of sustainable development of national economy and solution of related ecological issues requires an in-depth study of problems of atmospheric air pollution with microaerosols, diagnostic forecast and elaboration of mitigating measures. Separate aspects of the mentioned problems have been reflected in [5-7].

Problem statement and obtained results. Rustavi city atmospheric air pollution with PM2.5 and PM10 particles and their distribution to the adjacent territory during different meteorological situations is studied in this work holistically – via experimental observations and theoretically through numerical modeling.

Field measurement results. Experimental study has been carried out based on the analysis of standard data obtained from atmospheric air quality routine observation station [8] and materials of measurements conducted using portable apparatus „TROTEC PC220“. Minimum, average and maximum values of annual concentrations of PM2.5 and PM10 particles observed at the Rustavi fixed surveillance point in 2022 are shown in Fig. 1 [8]. It is seen from Fig.1 that the level of atmospheric air pollution with microparticles is relatively high in autumn-winter period and low in spring-summer period. The only exception is PM10 concentration in August. Average monthly concentrations of PM2.5 and PM10 particles vary within a range of 15-40 μg/m^3 and 25-84 μg/m^3. Average maximum concentration of PM2.5 reaches 100 μg/m^3, while the same value for PM10 attains 185 μg/m^3. In general, the values of minimum monthly concentrations are less than maximum permissible concentrations (MPC); maximum monthly concentrations are higher than MPC, and average monthly concentrations surpass MPC in winter period and are less than MPC in summer period.

In Fig. 2 there are shown the results of experimental measurements of PM2.5 and PM10 conducted on 03.06.2022 along the whole length of the central town main. It is seen from Fig. 2 that PM2.5 and PM10 concentrations vary within a range of 25-70 and 70-180 μg/m^3. Maximum concentrations are registered in such main polluting sources of the city

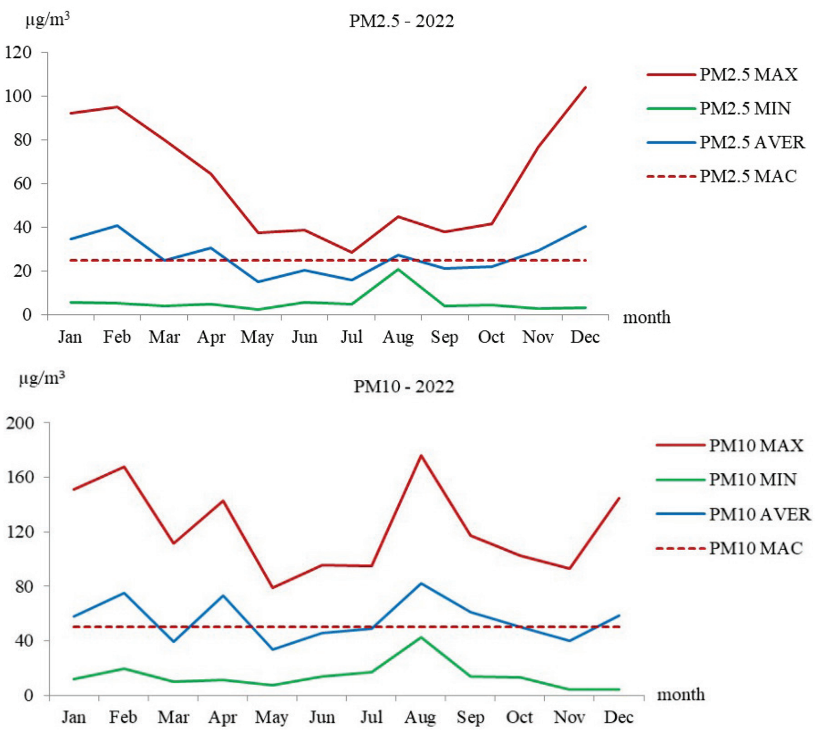

Fig. 1. Monthly maximum, average and minimum concentrations of PM2.5 and PM10 particles in 2022.

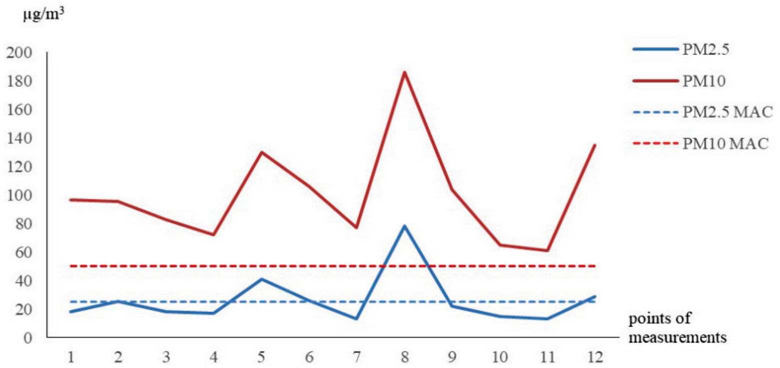

Fig. 2. PM2.5 and PM10 concentrations in different surveillance points of Rustavi city, June 3, 2022.

as "Heidelberg Cement" (point 8) production and construction organizations. At that, concentration values are comparable to each other and PM10 concentration is 2-3 times higher than PM2.5 concentration.

Numerical modeling results. Distribution of PM10 particles in Rustavi atmospheric air to its adjacent territory during background northern wind, when polluting agents are transferred from industrial part of Rustavi to the populated areas is studied via numerical modeling. Modeling is made through combined integrating of regional model of meso-scale atmospheric processes development at the territory of Georgia and equation of passive admixture transfer-diffusion in the atmosphere at 118km·90km·9km area with 1 km horizontal step [5]. A vertical step varies from 0.5 m to 15 m in the surface layer with 100 m thickness. In the atmospheric boundary layer and in free atmosphere a vertical step is 300 m. The background concentration of PM10 in the city is equal to 1.5 MPC.

It should be noted that the processes of PM2.5 and PM10 particles transfer and diffusion are similar to each other. They are described using the same equations [5]. The difference is between microparticle sedimentation rate only. It is less than 10^{-4} m/sec and is unable to have significant impact on distribution process. Therefore, the processes of distribution of PM2.5 and PM10 are analogical.

Light air. Fig. 3 shows the wind velocity and PM10 concentration fields in the surface and boundary layers of the atmosphere, during established background northern light air (1 m/sec). It is seen from Fig. 3, that the relief of Rustavi city adjacent territory causes substantial changes in background wind direction during a day. By t = 12 h in the north-western part of the modeling area, in close proximity to the earth surface a north-western wind current is formed, which transforms into western and south-western winds at the territory of Rustavi and its southern part. Wind direction changes with altitude increase. As a result, a wind formed over city territory at 600 m height has north-western direction and in the southern part of the modeling area gradually transforms into a northern wind.

Along with wind change the direction of PM10 microparticles transfer is changed, too. In the surface layer of the atmosphere, it is propagated in south-eastern direction first, and then – to the south. During 12 h at 2 m height from the earth surface, an ellipse-like shaped pollution area of 20 km length is formed. Concentration in the center of this area is 1-1.5 MPC, while at the major part out of center it equals to 0.01-0.1 MPC.

By t = 12 h the vertical transfer of aerosols becomes intense. As a result, particles hit the atmospheric boundary layer propagate at large territory, mainly in the direction of local wind formed southeastward. Ingredients propagation is relatively low in the opposite directions and

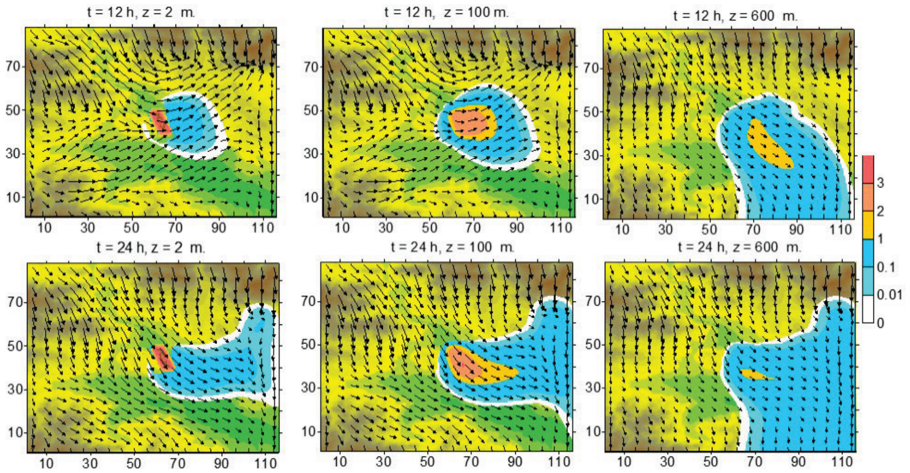

Fig. 3. Wind velocity and PM10 concentration (in terms of MPC) distribution at z=2, 100 and 600 m height during background northern light air, when t=12 and 24 h.

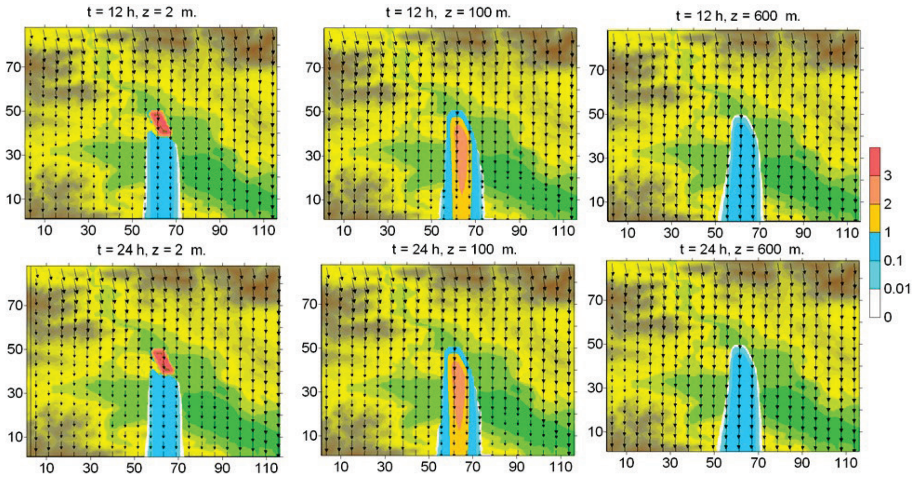

Fig. 4. Wind velocity and PM10 concentration (in terms of MPC), distribution at z=2, 100 and 600 m heights during background northern fresh breeze, when t=12 and 24 h.

perpendicular to the current. Horizontal distribution of concentration manifests advective transfer predominance compared to horizontal turbulent diffusive transfer, while vertical distribution points at the important role of vertical diffusion in contamination propagation process.

After t=12 h, a change in surface field of temperature at the territory of complex terrain leads to corresponding changes in wind velocity field. When t=24 h, a north-western wind is formed in surface layer of the atmosphere in the south-eastern part of Rustavi, while at 600 m height from the earth surface the northern and north-western winds are developed. PM particles are transferred in the mentioned direction.

In surface layer of the atmosphere, a pollution cloud has an ellipse-like shape directed to the east. Concentration > 0.01 MPC is obtained in the area 10-15 km in width. Above surface layer of the atmosphere, at 600 m height from the ground, microparticles are transferred to the eastern part of modeling area, where pollution level varies within a range of 0.01-0.5 MPC.

Fresh breeze. Figure 4 shows wind velocity and PM10 concentration fields in the surface and boundary layers of the atmosphere, during established background northern fresh breeze (10 m/sec). It is seen from Fig. 4 that a local relief and diurnal change of temperature have no effect on wind velocity and contamination propagation direction. Microaerosols present in the Rustavi atmosphere propagate at quite large distances to the south in the shape of a narrow flow. When t=12 h and 24 h, a maximum concentration 1.5 MPC at 2 m height from the earth surface is obtained at the city territory only. Pollution area is presented in the form of a narrow and long plume, which width is 4-5 km, and length reaches 40 km.

With the height increase, a strong vertical turbulent diffusion in surface layer of the atmosphere causes vertical transfer of significant portion of pollution, as a result, throughout the contamination plume PM10 concentration is within 0.5-1 MPC at 100 m height. Above surface layer of the atmosphere, in the atmospheric boundary layer, it becomes lower and doesn't exceed 0.1 MPC at 600 m height.

Conclusions

The change in the average monthly concentrations of PM2.5 and PM10 particles in the atmosphere of Rustavi city is studied by means of analysis of routine observations and experimental measurement data made in 2022. Their maximum, average and minimum values and variation intervals are determined. It is shown that concentrations of PM2.5 and PM10 particles are comparable to each other that points to the common source of their origin. Diurnal pattern of PM10 spatial distribution and peculiarities of propagation are obtained via numerical modeling. Through analysis of wind velocity and concentration field it is established that spatial distribution of ingredient areas depends on local circulation systems formed due to background wind, dynamic impact of terrain and diurnal change of underlying surface temperature. The change of background wind velocity causes corresponding changes of local circulation and spatial distribution of concentration.

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ეკოლოგია

ქ. რუსთავის ატმოსფეროს მყარი ნაწილაკებით PM2.5 და PM10 დაბინძურების გამოკვლევა

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

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

(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

შექმნილი მძიმე ეკოლოგიური მდგომარეობიდან გამომდინარე, საქართველოს მთავრობის მიერ შემუშავდა „ქ. რუსთავის ატმოსფერული ჰაერის ხარისხის გაუმჯობესების სამოქმედო გეგმა 2020-2022“, რომელიც გულისხმობს მთელი რიგი ჰაერდამცავი ღონისძიებების გატარებას. ჰაერის დაცვის ერთ-ერთ ძირითად პრობლემას ატმოსფერულ ჰაერში არსებული PM2.5 და PM10-ის მონიტორინგი წარმოადგენს. ნაშრომში კომპლექსურად – ნატურული დაკვირვებების, ექსპერიმენტული გაზომვების მონაცემების და თეორიულად – კომპიუტერული მოდელირებით მიღებული შედეგების ანალიზის საშუალებით განსაზღვრულია მიკროაეროზოლების საშუალო თვიური კონცენტრაციების მნიშვნელობები ქალაქში და კონცენტრაციის ცვლილება ქალაქის ცენტრალური მაგისტრალის გასწვრივ. დადგენილია, რომ PM2.5 და PM10-ის საშუალო თვიური კონცენტრაცია იცვლება 15-40 და 25–84 მკგ/მ^3-ის ინტერვალში, საშუალო თვიური მაქსიმალური კონცენტრაციები აღწევს 100 და 180 მკგ/მ^3. მიკროაეროზოლების კონცენტრაციები მაღალია ცალკეული ინდუსტრიული საწარმოს მიდამოებში. საქართველოს ტერიტორიაზე მეზომასშტაბის ატმოსფერული პროცესების განვითარების რეგიონალური მოდელის და ატმოსფეროში პასიური მინარევის გადატანა-დიფუზიის განტოლების ერთობლივი ინტეგრირებით მოდელირებული და შესწავლილია ქ. რუსთავში არსებული მიკროაეროზოლების გავრცელება მის მიმდებარე ტერიტორიაზე ჩრდილოეთის სუსტი და ძლიერი ქარის დროს. გაანალიზებულია რელიეფისა და ფონური ქარის ურთიერთქმედებით ფორმირებული ლოკალური ქარის გავლენა დამაბინძურებელი ინგრედიენტების გავრცელებაზე.

REFERENCES

1. World Health Organization. Ambient (outdoor) air pollution. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health-Accessed on: 04.Jul.2023.
2. Juginovich A.,Vukovich M., Aranza Iv., Bilosh V. (2021). Health impacts of air pollution exposure from 1990 to 2019 in 43 European countries**.** *Scientific Reports* **- 11,** 22516.
3. Pope C.A., Burnett R.T., Thun M.J., Calle E.E. et al. (2002) Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *J. Am. Med. Assoc,* **287**: 1132–1141.
4. Hadei M., Shahsavani A. et al. (2020) Burden of mortality attributed to $PM_{2.5}$ exposure in cities of Iran; contribution of short-term pollution peaks. *Atmospheric Environment*, **224**, 117365. https://doi.org/10.1016/j.atmosenv.2020.117365
5. Surmava A., Kukhalashvili V., Gigauri N., 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.
6. Surmava A., Intskirveli L., Kukhalashvili V., Gigauri N. (2020) Numerical investigation of meso-and microscale diffusion of Tbilisi dust. *Annals of Agrarian Science*, **18**, 3: 295-302.
7. Surmava A., Gverdtsiteli L., Intskirveli L., Gigauri N. (2021) Numerical simulation of dust distribution in city Tbilisi territory in the winter period. *Journal of the Georgian Geophysical Society, Physics of Solid Earth, Atmosphere, Ocean and Space Plasma*, **24** (1): 37-43.
8. National Environmental Agency. Environmental pollution. https://air.gov.ge/reports_page-Accessed on: 04.Jul.2023.

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