Journal of the Georgian Geophysical Society,
Issue A. Physics of Solid Earth, v.20A, 2017, pp.37 -43

Numerical Simulation of Dust Distribution Over the Complex Terrain Region of Georgia

[1,2]Aleksandre A. Surmava, [3]Leila V. Gverdtsiteli, [3]Natia G. Gigauri, [2]Liana N. Intskirveli

[1] M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University, Tbilisi, Georgia.
E-mail: aasurmava@yahoo.com
[2] Institute of Hydrometeorology of Georgian Technical University. 150 G, Agmashenebeli ave., 0012, Tbilisi, Georgia.
[3] Georgian Technical University, Tbilisi, Georgia. E-mail: natiagigauri18@yahoo.com

ABSTRACT

Kinetics of dust propagation in Kakheti region is numerically studied. It is determined that in 100 m layer of atmosphere the process of turbulent diffusion take precedence in the process of dust propagation. From 100 m to 1 km the processes of diffusive and advective transfers are identical, while above 1 km the preference is given to advective transfer. Maximum values of dust concentration are obtained in 100 m surface air layer. Spatial dust distribution region increases and concentration decreases along with height increase. Urban influence zone is determined.

Key words: Atmospheric air pollution, urban dust propagation, numerical simulation.

Introduction

Studies of environmental pollution have important role for solution of ecological problems and implementation of practical environmental protection measures. One of the basic directions of studies is creation of mathematical models of substance propagation in continuous medium and their numerical integration. Semiempirical theory is noteworhty from this viewpoint [1,2]. On the basis of this theory were processed guideline documents [3], which are widely used in post-Soviet space when assessing the level of air local pollution by enterprises.

In the works [4-8] non-stationary three-dimensional models of transfer-diffusion of substances in the atmosphere and methods of their numerical integration are elaborated. Models describe the processes of propagation, dynamics and kinetics of small admixtures and solid aerosols in the atmosphere.

Elaborated numerical methods became widely used for solution of many practical ecological problems. Among them should be noted the study of atmospheric pollution by aerosols' propagation as a result of forest fires [9, 10] by harmful agents and solid aerosols [11-13] released from enterprises located in regions with complex terrain [14-17], urban territories [18] with the use of numerical simulation and method of experimental observations.

There are ecological problems in separate regions of Georgia, too. From this viewpoint Kakheti should be noted. Kakheti is near-border region with complex terrain and 11,3 sq. km area located in the eastern part of Georgia. It is the main agricultural region of Georgia and is known for production of many export products, including high-quality brand wines. Kakheti region borders basic industrial centers of Georgia – Tbilisi, Rustavi, Marneuli etc. Propagation of agents discharged in the atmospheric air in settlements and along highways causes pollution of neighbour territories and has an impact on population health and quality of manufactured production.

There are no routine observations over atmospheric pollution at the territory Kakheti. No numerical or online models of research purposes that would enable us to determine expected concentrations of dust and other air polluting agents in the atmosphere are elaborated for Kakheti territory.

In the presented work numerical model of dust propagation at Kakheti territory is elaborated using regional model of atmospheric process studies in Caucasis region [19], methods of meteorological field parametrization in surface layer of atmosphere [20] and equations of transfer-diffusion of small admixtures in continuous medium. Peculiarities of dust propagation at Kakheti territory for four basic meteorological situations typical for this region are studied.

Formulation of the Problem

The area 236×180 km^2 of size is considered, in the centre of which Kakheti is placed, while to the west, north and north-west are located the Main Caucasus and Small Caucasus mountain chains, while to the south-east are placed Shirvan steppes. Orography height varies from 70 m to 3 km.

The relief is very complicated here. That is why for proper description of atmospheric processes is convenient to use the relief succeeding coordinate system $\zeta = (z - \delta)/h$, where z is vertical orthogonal coordinate, $\delta = \delta_0(x, y)$, δ_0 - altitude of relief; h = H - δ ; $H(t, x, y)$ - tropopause height; t is a time; *x* and *y* – orthogonal coordinate axes directed to the east and north.

Equation for dust atmospheric propagation in the taken coordinate system will be written in following form

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

where C is dust concentration in atmosphere u, v, w and $\tilde{w}$ are the components of wind velocity along x, y, z and ζ axes; ; w_o - rate of dust particle sedimentation determined according to Stoke's formula; μ and ν – kinematic coefficients of horizontal and vertical turbulence; values of wind velocity and turbulence factor in surface layer of atmosphere and in free atmosphere are defined by means of regional models [19, 20].

The distributions of the anthropogenic dust emitted in the atmosphere from Tbilisi and Rustavi cities and 19 little towns of Kakheti and 3 towns of Azerbaijan are numerically modeled. The data of National Environment Agency [21] are taken as the initial and boundary values of the monthly average concentrations at the height of 2 m in atmosphere at the territories of Tbilisi and Rustavi, while for territories of other cities, where observations over dust pollution were not conducted, concentration values are calculated according to given methodology [22]. The initial concentration of dust at the points of the network that don't belong to cities is considered equal to zero. The diameter of dust particle is assumed to be equal to 10 µm.

Numerical integration of equation (1) with the use of corresponding initial and boundary conditions is executed using Crank-Nicolson method and using the splitting method and monotonous scheme [4]. The rectangular numerical grid with $118 \times 90 \times 31$ points and the horizontal step equal to 2 km and the vertical step equal to 1/31 were used. In surface layer 17 vertical grid points with grid steps from 2 to 15 m are taken. Time step is 10 sec. The numerical integration is continued more than 3 days.

Results of modeling

Spatial distribution of dust concentrations in June during background eastern wind, when t = 14 hours, obtained by calculations, is shown on Fig. 1. Values are calculated in units of daily maximum allowable concentration (MAC = 0.015 mg/m^3) of dust.

As is seen from the Figure 1, dust concentrations at a height of 2 and 10 m are maximal at the territory of cities and in their direct vicinity (Fig. 1, a, b). In horizontal direction the dust is propagated only at small distances. In particular, at 2-4 km distance from point of pollution the value of concentration is roughly 10 times, while at 20-30 km distance – 10^2-10^3 times less than concentrations at the territories of cities. Such distribution is caused by smallness of horizontal turbulent and advective transfer and shows us the limits of urban exposure from the viewpoint of surface air pollution. Influence area is different for different directions and is depended on orography. Horizontal dust transfer mainly occurs along the gorges, both in case of Tbilisi, Rustavi and other cities.

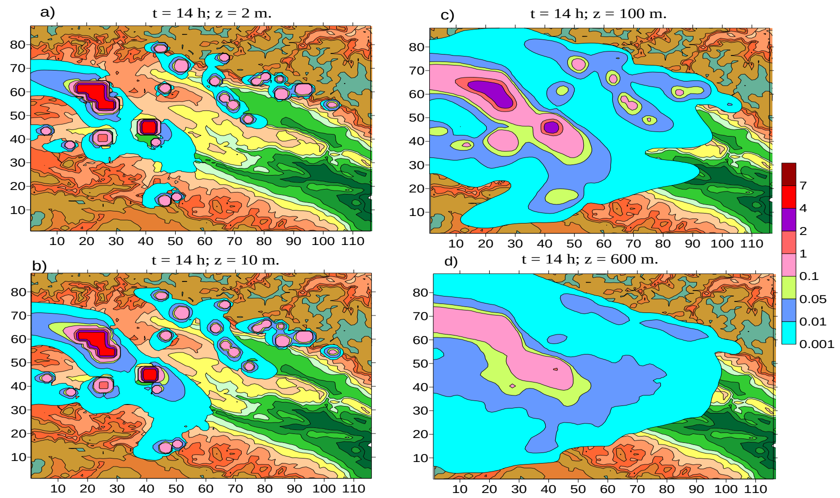

Fig. 1. Distribution of isolines of dust concentration C in MAC at a height of z = 2, 10, 100, 600 m from earth surface during background eastern winds, when t = 14 hours.

Processes of vertical, horizontal turbulent diffusions, advective and convective transfers become intensive in the area at a height of 10-600 m from earth surface. As a result the dust propagates at large territory, mostly in western direction.

Along with height increase takes place decrease in maximum concentrations (Fig. 1 c, d). When z = 100 m, two zones of maximum concentration are formed: one (2-4 MACs) in the vicinity of Tbilisi and Rustavi and second (1-0.1 MAC) in the neighborhood of Alazani River.

Orography influence on dust pollution form is gradually reduced and at a height above 600 m the form of dust pollution zone is predominantly determined by wind direction and velocity.

Calculations showed that in case of background western wind the kinematics of propagation of received dust pollution is qualitatively similar to the described above. Basic difference is the form of dust pollution cloud (Fig. 2). Dust pollution zone formed in 1 km layer of atmosphere is a single cloud, which has a trail oriented in background wind direction in atmospheric zone 100 m in thickness. Zone with maximum concentration is formed above Tbilisi and Rustavi. The dust cloud takes a single ellipse-like form for z > 100 m.

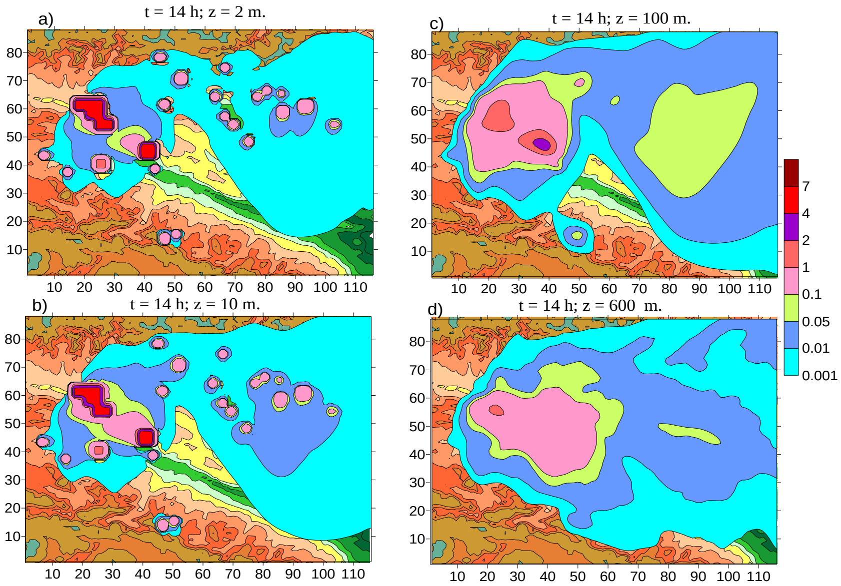

Fig. 2. Distribution of isolines of dust concentration C in MAC at a height of z = 2, 10, 100, 600 m from earth surface during background western winds, when t = 14 hours.

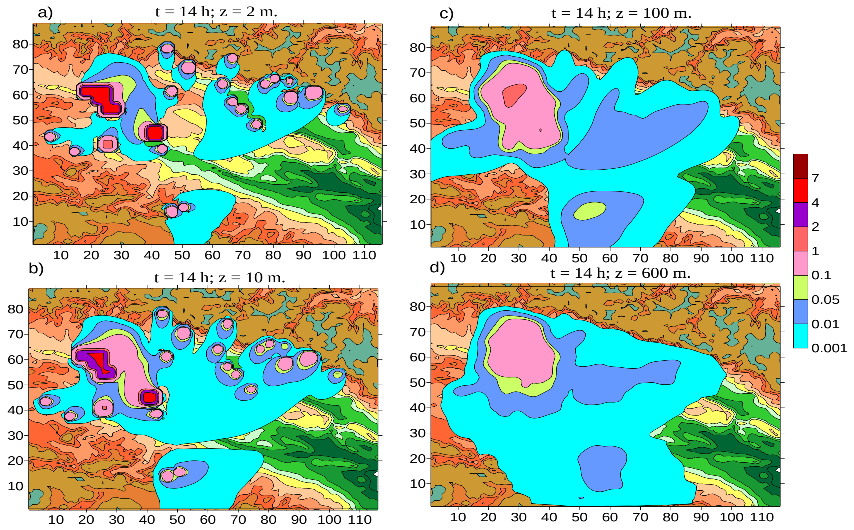

Fig. 3. Distribution of isolines of dust concentration C in MAC at a height of z = 2, 10, 100, 600 m from earth surface during background northern winds, when t = 14 hours.

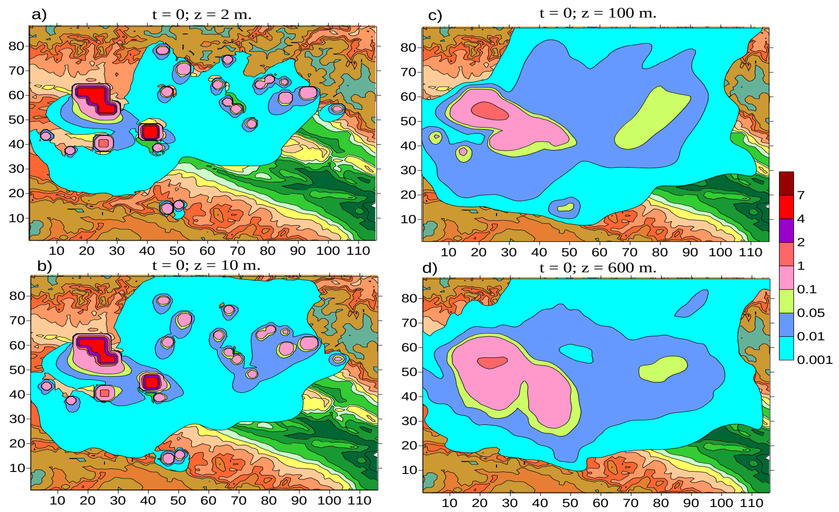

Fig. 4. Distribution of isolines of dust concentration C in MAC at a height of z = 2, 10, 100, 600 m from earth surface during background southern winds, when t = 14 hours.

In case of background northern winds (Fig. 3) three dust pollution zones are formed in air layer 2-100 m in thickness. One of them is Tbilisi, Rustavi, Marneuli, Gardabani and Bolnisi, second is the zone of Azerbaijan cities and third is the zone of Shida Kakheti cities (Fig. 3, a, b). In first and second zones advective transfer of dust occurs in north-eastern direction, while in the third zone – in south-western direction. Maximum dust pollution takes place in the neighborhood of Tbilisi and Rustavi. Away from the cities the level of dust pollution rapidly decreases and at a distance of 20-30 km concentration value is within 0,001- 0,05MAC. Dominance of advective transfer over diffusive transfer is characteristic for the third zone. As a result we have dust propagation at the most part of territory of Kakheti. At heights of z > 100 m the role of turbulent diffusion becomes prevalent and we receive a single dust cloud formed above the central part of region.

During background southern winds, local circulation system of air current originated by orography creates complicated picture of dust propagation (Fig. 4). Back flow formed in Mtkvari River valley and in Jeiran field causes dust propagation in southern direction in 1 km boundary layer of atmosphere. Afterwards the wind changes its direction and dust transfer occurs in north-eastern direction. Increased air turbulization related to rapid change of velocity causes dust propagation throughout whole territory of Kakheti.

In the described numerical experiment, dust pollution zones of upper part of boundary layer of atmosphere (z >1000m) are represented by single cloud in the form of elongated ellipse formed under influence of orography and directed along local wind. Maximum concentration in dust cloud is getting smaller along with increase in height from 0,01 to 0,001 MAC, when z = 1 and z = 3 km, respectively.

Numerical experiment is conducted for various meteorological situations. Calculations were made for stationary and non-stationary sources. Analysis of calculation results enables us to study features of background pollution of territory of Kakheti

Discussion

Dust propagation at the territory of Kakheti in case of four basic meteorological situation and non-stationary pollution sources is studied in the Caucasus with the use of regional model of atmospheric process development and non-stationary three-dimensional equation of transfer-diffusion of passive admixtures. Through modeling are obtained dust concentration pictures, which qualitatively coincide with dust distribution based on physical arguments.

It is shown that in 10 m zone of surface layer of atmosphere the dust propagation is determined by horizontal and vertical turbulence. At a height of 100 m the processes of advective transfer make significant contribution along with turbulence into dust propagation, while in upper part of boundary layer of atmosphere the dominant role is attached to advective transfer of dust.

The complex terrain, displacement of the sources of urban pollution and the wind fields, formed by interaction of background wind and orography, promotes dust existence in the central part of the region between two main ridges – the Main Caucasus and Small Caucasus Mountains.

By means of obtained results one can determine the following values of background concentration: 0,05MAC can be taken as background concentration for 20-30 km region adjacent to Tbilisi and Rustavi, while for other cities – 0,01 MAC.

In this model the fields of velocities and vertical turbulence in the surface layer of atmosphere are described for uniform relief. That’s why is expedient to further develop a model through use of different parametrization methods of surface sub-layer of atmosphere.

There are no ongoing natural observations over air pollution at the territory of Kakheti, and therefore is impossible to determine quantitative accuracy of obtained results. Aiming the determination of modeling accuracy it is planned to carry out experimental measurements and compare them with modeling results.

Acknowledgements. This work was supported by the Program Funding Plan **Doc-009** of the Institute of Hydrometeorology at the Georgian Technical University.

References

[1] Berliand M E. Modern Problems of Atmospheric Diffusion and Atmospheric Pollution. Gidrometeoizdat, Leningrad, 1975, (in Russian).
[2] Berliand M E. Forecast and Adjustment Atmospheric Pollution. Gidrometeoizdat, Leningrad, 1985, (in Russian).
[3] Methods of Calculating Pollutant Concentrations in Atmospheric Air as Present in Factory Discharges. OND-86. Gidrometeoizdat, Leningrad, 1987, (in Russian).
[4] Marchuk G. I. Mathematical Modeling in the Environmental Problem. Gidrometeoizdat, Leningrad, 1982, (in Russian).
[5] Penenko V. V., Aloyan A. E. Models and Methods for Environmental Protection Tasks. Nauka, Novosibirsk, 1985, (in Russian).
[6] Aloyan A. E., Penenko V. V., Kozoderov V. V. Mathematical Modeling in Environmental Issues. Modern Problems of Computational Mathematics and Mathematical Modeling, 2, 2005, pp. 279-351, (in Russian).
[7] Aloyan A. E., Arutinian V. O. Modeling of Gaseous Admixtures and Aerosols Evolution in Atmosphetic Disperse Systems. www.sscc.ru/Conf/mmg2008/papers/aloyan.doc, 2008.
[8] Aloyan A. E. Modeling of Dynamics and Kinetics of Gaseous Admixtures and Aerosols in the Atmosphere. Nauka, Moscow, 2008, (in Russian).

[9] Grishin A. M. Mathematical Modeling of Forest Fires and New Methods of Struggle Against Them. Nauka, Novosibirsk,1992, (in Russian).
[10] Aloyan A. E. Modeling of Aerosols Dynamics During Forest Fires. Izvestiya, Atmospheric and Oceanic Physics, 45, 2009, pp. 62-75, (in Russian)
[11] Long J., Cheng S., Li J., Chen D., Zhou Y., et al. A Monitoring and Modeling Study to Investigate Regional Transport and Characteristic of $PM_{2,5}$ Pollution. Aerosol and Air Quality Research. 13, 2013, pp. 943-956.
[12] Ginoux P., Chin M., Tegrn I., Prospero J. M., Holben B., et al. Sources and Distributions of Dust Aerosols Simulated with the GOCART Model. J. of the Geophysical Research, 106, 2001, pp. 255-273.
[13] Perez C., Hausten K., Janjic Z., Jorba O., Huneeus N., et al. Atmospheric Dust Modeling from Meso to Global Scales with the Online NMMB/BSC-Dust Model - Part 1: Model Description, Annual Simulations and Evaluation. Atmospheric Chemistry and Physics, 11, 2011, pp. 13001-13027. doi:10.5194/acp-11-13001-201.
[14] Shlichkov V. A., Malbakhov V. M., Leghenin A. A. Numerical Modeling of Atmospheric Circulation and Transfer of Contaminating Impurities in Norilsk Valley. Atmospheric and Oceanic Optic, 18, 2005, pp. 490-496, (in Russian).
[15] Surmava A. A., Mishveladze B. A., Davitashvili T. Numerical Modeling of the Pollution Transfer in the Caucasus Atmosphere from Hypothetical Source in Case of the Background Western Wind. Journal of the Georgian Geophysical Society, ISSN: 1512-1127, vol. 13B, 2009, pp. 15-21.
[16] Surmava A. A. Numerical Investigation of the Modeling of Transportation and Deposition of the Radioactive Pollution in the Caucasian Region in Case of the Hypothetical Accident on the Armenian Nuclear Power Plant. Journal of the Georgian Geophysical Society, ISSN: 1512-1127, vol. 15B, 2012, pp. 32-45.
[17] Kordzadze A., Surmava A., Kukhalashvili V. Numerical Investigation of the Air Possible Pollution in Case of Large Hypothetical Accidents at Some Industrial Territories of the Caucasus. Journal of the Georgian Geophysical Society, ISSN: 1512-1127, vol. 16 B, 2013, pp. 13-23.
[18] Selegei T. S., Shlichkov V. A., Leghenin A. A., Malbakhov V. M. Model of Local Forecast of Formaldehyde Pollution of Atmosphere in Tomsk on the Basis of Statistical and Hydrodynamic Methods. Russian Meteorology and Hydrology, 4, 2012, pp. 35-44, (in Russian).
[19] Kordzadze A. A., Surmava A. A., Demetrashvili D. I., Kukhalashvili V. G. Numerical Investigation of Impact of Caucasus Region Relief on Distribution of Hydrometeorological Fields. Izvestiya, Atmospheric and Oceanic Physics, 43, 2007, pp. 783-791.
[20] 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.
[21] Ed. Georgian National Environmental Agency. Short review of Georgia environment pollution. www.nea.gov.ge, 2017, (in Russian).
[22] Ed. Bezuglaia E. U., Berliand V. E., Volberg N. Sh., Zaitsev A. S., Sidorenko G. I., et al. Guidance on Atmospheric Pollution Control (RD 52. 04. 186-89). Goskomgidromet, Russia, 1991, (in Russian).

საქართველოს რთული რელიეფის ტერიტორიაზე მტვრის გავრცელების რიცხვითი მოდელირება

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

რეზიუმე

რიცხობრივად შესწავლილია მტვრის გავრცელების კინემატიკა კახეთის რეგიონში. მიღებულია, რომ ატმოსფეროს მიწისპირა 100 მ ფენაში მტვრის გავრცელების პროცესში უპირატესი მნიშვნელობა გააჩნია ტურბულენტური დიფუზიის პროცესს. 100 მ-დან 1 კმ-დე დიფუზიური და ადვექციური გადატანის პროცესები ტოლფასია, ხოლო 1კმ-ის ზევით უპირატესობა ენიჭება მტვრის ადვექციურ გადატანას. ნაჩვენებია, რომ ქალაქებიდან ატმოსფეროში გაბნეული მტვერი

ძირითადად კონცენტრირებულია სასაზღვრო ფენაში. მტვრის კონცენტრაციის მაქსიმალური მნიშვნელობები მიღებულია ჰაერის მიწისპირა 100 მ ფენაში. სიმაღლის ზრდასთან ერთად იზრდება მტვრის სივრცული გავრცელების არე და მცირდება კონცენტრაცია. განსაზღვრულია ქალაქების გავლენის ზონები.

Численное исследование распространения пыли над сложным рельефом Грузии

А. А. Сурмава, Л.В. Гвердцители, Н. Г. Гигаури, Л. Н. Инцкирвели

Резюме

Численно исследована кинетика распространения пыли в Кахетском регионе. Установлено, что основным механизмом распространения пыли в приземном слое атмосферы толщиной 100 м является процесс турбулентной диффузии. В слое 100 м - 1км турбулентная диффузия и горизонтальная адвекция имеют одинаковые значения, а выше 1 км - преобладает процесс горизонтальной адвекции. Показано, что пыль, поступающая в атмосферу из городов, в основном концентрирована в приземном 100 м слое атмосферы. С удалением от поверхности земли увеличивается область распространения пыли и уменьшается её концентрация. Определены зоны влияния городов в загрязнении окружающей территорий.