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Geophysics

Numerical Simulation of Distribution of Contaminants Discharged to Kura River

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ABSTRACT. Numerical simulation of distribution of contaminants discharged to Kura river is elaborated using nonstationary linear three-dimensional equation of transition-diffusion of substances in continuous medium. Model is meant for study of distribution of polluting agents in Kura river in the first approximation. Kura river is divided in 10 conventionally uniform linear sections and annual average values of hydrological parameters specific for the river are used for each section. Distribution of passive polluting agents thrown to Kura river near Georgian-Turkish state border is modeled using numerical experiment in case of stationary source. The time, which is necessary for polluting agent to reach the points located along the river, to pass various sections of river, to reach Georgian-Azerbaijan border and Mingachevir Reservoirs is determined. Distribution pattern of polluting agent concentration in the river bed, as well as concentration change, when passing from one section to another are determined, and relative change of concentration in 10 conventional river sections is estimated. Distribution of passive contaminant thrown to Kura river by salvo for 6 hours near Georgian-Turkish state border is studied. Pattern of gradual shift of the contamination plume in Georgian section of Kura river and gradual concentration change are shown. Ammonium ions (NH_4^+) distribution discharged from cities situated at Kura river is modeled. Distribution pattern for ammonium ions concentration in Kura river is received using numerical experiment. It is shown that values of concentration received via mathematical modeling with permissible accuracy coincide with the data of field observations. *© 2015 Bull. Georg. Natl. Acad. Sci.*

Key words: *numerical simulation, equation of mass transfer, pollution of Kura, ammonium, passive contaminant.*

1. Introduction

Kura river has an important role in the economy of the Georgian and Azerbaijan Republics. It is one of the main sources of the drinking water in the South Caucasus and is intensively used for agricultural and industrial purposes. Georgian part of the Silk Road – main traffic artery of Georgia, the oil and gas pipelines, railways and highways are passing along it. Therefore, Kura river is the water object of high ecological risk factor.

Annually rising turnover between Europe and

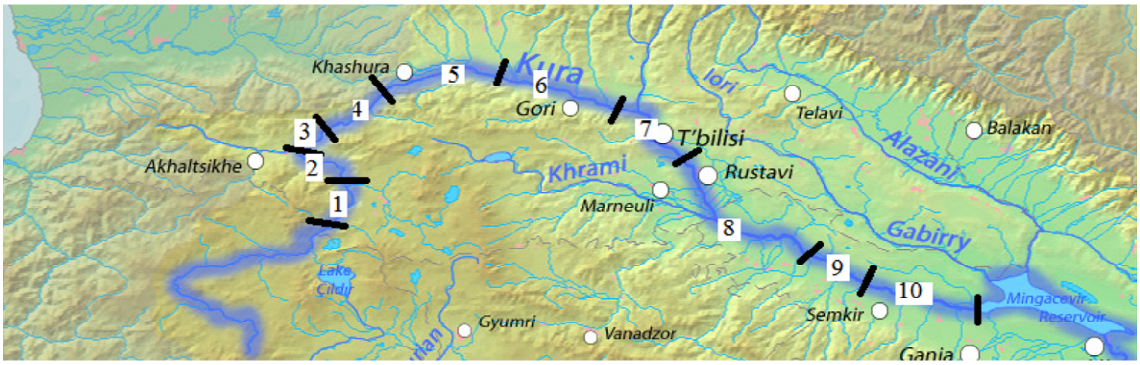

Fig. 1. The scheme of Kura river division into conventional sections.

China and Middle Asia causes a threat of ecological disasters in this transport corridor and therefore ecological protection of Kura river is one of the topical problems of the Georgian government.

The developed countries widely use the software packages for investigation of surface water pollution and the optimal control systems [1-5]. These packages are mainly elaborated for large waters, require a special personnel training and are difficult for use in case of mountain rivers.

In [4, 5] we elaborated a simple numerical method for calculation of diffusion of passive admixtures to Kura river and investigated kinematics of propagation of contaminants. This work is considered to be the first stage in elaboration of the method for prediction of pollution of Georgian mountain rivers in case of disasters.

2. Materials and Methods

For numerical modeling of the pollution distribution the 513 km long Georgian part of Kura river from Georgian-Turkish border to the Mingachevir Reservoir is divided into ten hydrological conventionally uniform sections [6] (Fig. 1). It is assumed that each of the sections is a linear canal and river's hydrological parameters are constant along it. Therefore, in these sections the distribution of pollution may be described by transfer-diffusion equation according to [7, 8]

$$\frac{\partial C_i}{\partial t}+u_i\frac{\partial C_i}{\partial x}+w_o\frac{\partial C_i}{\partial z}=$$

$$=\mu_x\frac{\partial^2 C_i}{\partial x^2}+\mu_y\frac{\partial^2 C_i}{\partial y^2}+\mu_z\frac{\partial^2 C_i}{\partial z^2} \qquad (1)$$

where t is time; x, y and z are the Cartesian coordinates; x axis is horizontally directed along the river flow; y is the horizontal axis directed perpendicularly to the canal; z axis is directed upward vertically from river bottom; u_i is the river flow velocity at i section along x axis; river flow velocity is equal to zero along y axis; w_o is the velocity of sedimentation of polluting agent; μ_x, μ_y and μ_z are kinematic coefficients of turbulent viscosity along the x, y and z axes, respectively; C_i is the concentration of the contaminant in the i section of the river.

The river water velocity u_i in each river section is known, which is a constant value along the axis x, and changes along y and z axes as follows: $u_i\ (x,y,z) = 1.5U_{i,0} \times \sin(\pi\ y/Y_i)\sin(0.5\pi\ z/H_i)$. $U_{i,0}$=constant is a known value of the river water velocity in the i section. Y_i and H_i are the width and depth of the section i. $U_{i,0}$, Y_i, H_i are taken from [6]. Since the values of coefficient of turbulent diffusion for Kura river were not determined on the basis of observation data, we used the values given in [8] as follows: $\mu_x = 5\times 6.4\times 10^4$ m²/s and μ_y=μ_z= $5\times 5.57\times 10^3$ m²/s for territory with complex mountain relief (section 1-4) and $\mu_x = 6.4\times 10^4$ m²/s and μ_y=μ_z=5.57×10^3 m²/s for sections placed at plain territory (section 5-10).

For integrating the equation (1) the corresponding initial and boundary conditions are used: the concentrations of the contaminant in the points of dis-

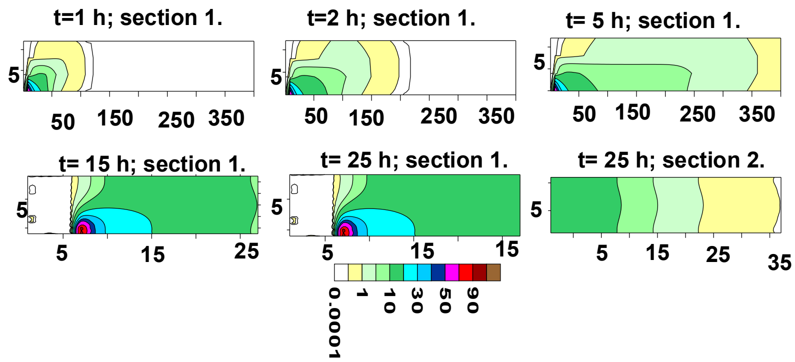

Fig. 2. The distribution of the concentration (in c.u.) on river surface in the sections 1 and 2, when t = 1, 2, 5, 15 and 25 h. The step Δx = 20 m, when t ≤ 5 h and Δx = 1 km, when t ≥ 15 h.

charge source, in the beginning of section and at the initial time are known values. The gradient of concentration in the end points of sections $x_i = K_i$, in the river bank and bed points $y_i = 0.10$ and $z_i = 0.10$ are equal to zero, respectively. The concentrations of the contaminant during the whole interval of time of spilling at the source points are known values. An inflow of tributaries into Kura river is taken into account using change in the parameters $U_{i,0}$, Y_I and H_i.

The numerical integration and solution of equation (1) is made using the split method and balance numerical scheme [7] on the rectangle numerical grid. The grid step along the x axis depending on goals of concrete numerical experiment varies within the interval of 20 m – 1000 m; the grid steps along y and z axes are equal to Yi /11 and Hi /11, respectively.

3. Results of Simulation

For investigation of kinematics of contaminants propagation in Kura river the series of numerical experiments were conducted. First, we considered the case, when the contaminant is discharged into Kura river in the points located near Georgian-Turkish State border (section 1). The concentration of polluting agent is equal to 100 conventional units (c.u.) in the area of the pollution source during all modeling time. Calculation shows that during the first 6 minutes the polluted area has an elliptic form and it is distributed at the distance of about 300 m in the direction of flow and takes the whole width of the river. The main part of polluting agents is located along the bank, where the discharge takes place and is spread approximately at $0.6H_i – 0.7H_i$ distance in width.

In Fig. 2 the distribution of the contaminant for the first 25 hours of discharge is shown. By means of Fig. 2 and Table 1 we can see that pollution is distributed in sections 1, 2 and reaches section 3. The contaminant passes the first river section in 6 hours, section 2 in 17 hours, etc. The average velocity of passing the section 1 is equal to 0.8–1 m/s and is in correspondence with the average river flow velocity in the first section. Similar results are obtained for the other sections of the river. The time of reaching the beginning of the river section by contaminants and establishment of their constant concentration in these sections are given in Table 1.

The quantitative accuracy of simulation may be estimated by means of numerical simulation of ammonium diffusion, for which the values of river discharge and concentrations obtained by natural ob-

Table 1. Time of destination the section by pollution substance (t_{min}) and time of constant concentration (t_{max})

Section №	1	2	3	4	5	6	7	8	9	10
t_{min} (h)	0	6.2	17.8	23.4	37.1	53.7	65.8	74.7	98.1	117.1
t_{max} (h)	83.3	91.0	103.3	122.1	178.6	196.8	210.7	247.7	277.6	307.0

Table 2. Concentration (mg/l) of ammoniun obtained via natural measurement

Towns	Borjomi	Gori	Zahesi	Tbilisi	Rustavi
Average Multiyear Value of 2007-2010	0.49	0.52	0.53	0.95	0.88
September 2013	0.48	0.51	0.47	1.02	0.72

servation are known. The mass of ammonium discharged to Kura river from Georgian towns are calculated by means of formula $Q = 7 \times \mathrm{N} / 24 \times 3600$ in (g/s), where N is a number of city residents. This formula implies that one citizen discharges about 7 g NH_4^+ per day [9]. On the basis of experimental measurement the value of background concentration near the Georgian-Turkish state border is equal to $C_{1,0} = 0.4$ mg/l.

In Fig. 3 the distribution of ammonium along the Kura river obtained using numerical modeling is given. When comparing these results with the data of Table 2 we can conclude that results of numerical simulation are in good correspondence with observation data. The ammonium concentration gradually increases from Borjomi to Rustavi. The rapid growth of concentration takes place in vicinity of the points of discharge. The maximum growth of concentration is obtained in the vicinity of Tbilisi in the areas of sewage network attached to the river. The area of rapidly increased concentration is about 5 km near small towns and 25 km for Tbilisi. With the increase of distance from the discharge points due to diffusion and dilution caused by waters of influent rivers the concentration gradually decreases. As the calculations show, the concentration of ammonium in River Kura under the impact of pollution sources located both in Turkey and Georgia, gradually increases along the river and, as a result, near Mingechavir Reservoir its value exceeds twice the maximum permissible concentration (MPC).

Simulation of propagation of the passive pollutant accidentally discharged for short interval of time (6 h) is conducted. In Fig. 4 the results of numerical modeling are shown. We see that contamination plume that is formed in discharge place, is getting wider due to transfer and diffusion processes and in 75 hours its length reaches 80 km. Calculations show that it will take about 190 hours for contamination plume to pass the Georgian part of Kura river.

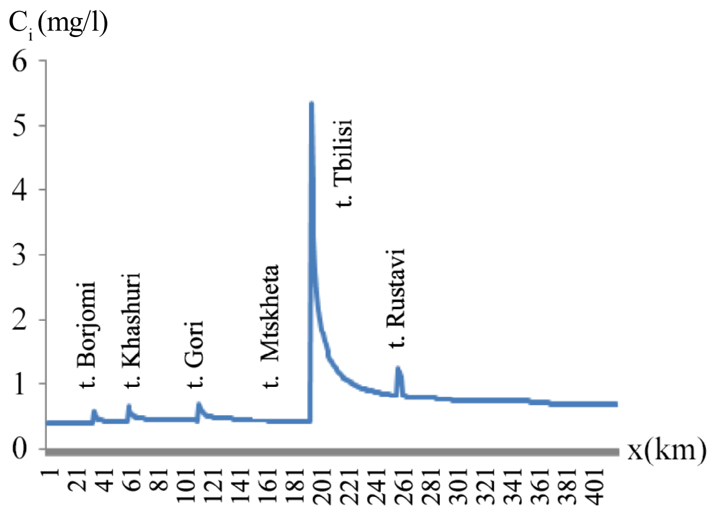

Fig. 3. Distribution of ammonium concentration in Kura river. City names show discharge points.

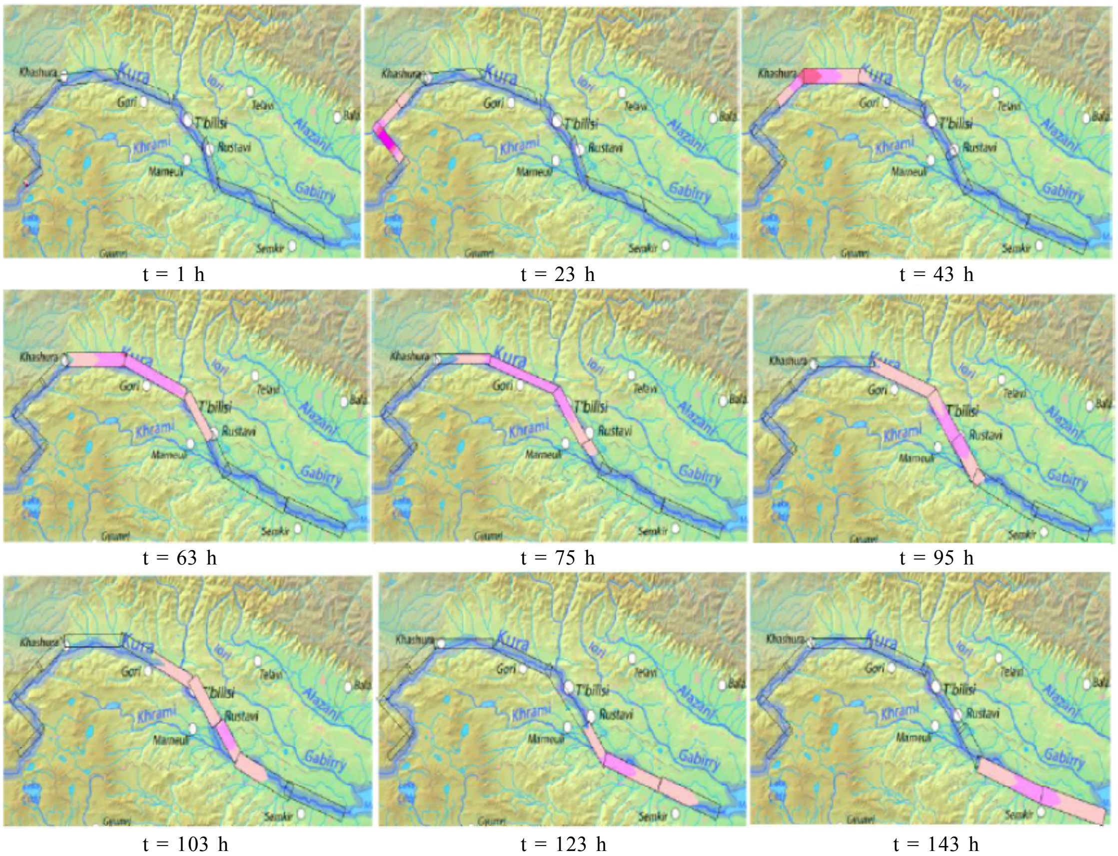

Fig. 4. Displacement of contamination plume in Kura river for 43 hours.

4. Discussion

On the basis of nonstationary three-dimensional equation of mass transfer the numerical model of transfer of contaminant through Kura river is elaborated. The model is created for the area of Kura river from Georgian-Turkish state border to Mingechavir Reservoir that is divided into ten parts. For each part the river flow velocity is taken as a well-known value from the materials of hydrological observation. The study of river pollution by ammonium ions is carried out. Comparison of simulation results with observation data shows that the model describes the average pattern of pollution correctly.

The numerical experiments that investigate the kinematic features of distribution of pollution are carried out. Some parameters characterizing the process of pollutants' diffusion are obtained by means of these experiments, namely: time necessary to pass Georgian section and its separate areas etc.

It should be noted that calculations are carried out for average annual river flow velocity. This fact limits the area of application of this model because the velocity of water flow for mountain rivers may change in a wide area in relation with the precipitations taking place in the basin of the separate tributaries. Such limitation can be overcome in two ways: 1) for each section the velocity of flow can be calculated using the equation of the river water momentum, or 2) database for velocities of flow observed in different situations must be created by means of hydrological observation and used in equation (1). It is necessary also to obtain semi-empirical formulas for kinematic coefficients of vertical and horizontal turbulence of Kura river and to conduct numerical simulation using them.

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გეოფიზიკა

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

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(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

უწყვეტ გარემოში ნივთიერების გადატანა-დიფუზიის არასტაციონარული წრფივი სამგანზომილებიანი განტოლების გამოყენებით დამუშავებულია მდ. მტკვარში მოხვედრილი დამაბინძურებელი ნივთიერების გავრცელების რიცხვითი მოდელი. მდ. მტკვარი დაყოფილია 10 პირობითად ერთგვაროვან წრფივ უბნად და თითოეული უბნისათვის გამოყენებულია მდინარის მახასიათებელი ჰიდროლოგიური პარამეტრების საშუალო წლიური მნიშვნელობები. მოდელირებულია საქართველო-თურქეთის სახელმწიფო საზღვართან მდ. მტკვარში ჩაღვრილი პასიური დამაბინძურებელი ნივთიერების გავრცელება სტაციონარული წყაროს შემთხვევაში. მოდელირებით განსაზღვრულია დრო, რომელიც საჭიროა იმისთვის, რომ დამაბინძურებელმა ნივთიერებამ მიაღწიოს მდინარეზე განლაგებულ პუნქტებს, განვლოს მდინარის სხვადასხვა უბანი, მიაღწიოს საქართველო-აზერბაიჯანის საზღვარს და მინგეჩაურის წყალსაცავს. განსაზღვრულია დამაბინძურებელი ნივთიერების კონცენტრაციის მდინარის კალაპოტში განაწილების სურათი, კონცენტრაციის ცვლილება მდინარის ერთი უბნიდან მეორეში გადასვლისას, შეფასებულია კონცენტრაციის ფარდობითი ცვლილება მდინარის 10 პირობით უბანში. შესწავლილია საქართველო-თურქეთის სახელმწიფო საზღვართან მდ. მტკვარში 6 სთ განმავლობაში ჩაღვრილი პასიური დამაბინძურებელი ნივთიერების გავრცელება. ნაჩვენებია მდინარეში დაბინძურების თანდათანობითი გადაადგილების სურათი და კონცენტრაციის ცვლილება. მოდელირებულია მდ. მტკვარზე განლაგებული ქალაქების კოლექტორებიდან ჩაშვებული ამონიუმის (NH_4^+) იონის გავრცელება. რიცხვითი ექსპერიმენტით მიღებულია მდ. მტკვარში ამონიუმის იონის კონცენტრაციის განაწილების სურათი. ნაჩვენებია, რომ მათემატიკური მოდელირებით მიღებული კონცენტრაციების მნიშვნელობები დასაშვები სიზუსტით ემთხვევა ნატურული დაკვირვებების მონაცემებს.

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