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Modeling of the movement of debris flows in river basins

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ABSTRACT

In the article presented, the movement of debris flows is investigated using methods of hydraulics of multicomponent media with variable flow rates and with a free boundary. Simple estimated relations obtained in this way, when applied to practical engineering problems, often give satisfactory results. The maximum velocity in any cross section of the flow is usually little different from the average velocity, and this is especially true for debris flows hyperconcentrated with sediments. In such cases, the movement can be considered as one-dimensional with some average cross-section velocity.

1. Introduction

To predict and promptly assess the impact of debris flows in river basins on hydraulic and other economic facilities, it is necessary to use intelligent expert systems based on mathematical methods with application of modern information and communication technologies, taking into account geomorphological and climatic factors of the area, as well as to study changes in characteristic fractal parameters of the region, which are taken into account when calculating destructive processes of the land surface. Assessment of the ecological situation in the river basin requires the study of changes in the degree of damage of fractal parts, the establishment of the current value of the erosion coefficient, which make it possible to predict the volume of mass denuded from the slopes and accumulated in the river channels. In the framework of the one-dimensional approach, the velocity, pressure, density and other parameters of the flow depend on a single coordinate. Depending on the velocity of the debris flow in each cross-section of a natural watercourse, the bed formation process takes place. When the solid phase is deposited, part of its mass is separated from the main flow, and when it is washed away, it joins it. These issues can be investigated taking into account the movement of viscous debris flows, taking into account the flow variability in a channel with an irregular bottom.

The movement of mudflow streams consisting of a mixture of liquids and solid particles is very complicated. Data from scientific and technical literature [1-4] allow us to identify the basis for developing a suitable hydrodynamic theory of movement of debris flows. Despite a large number of studies addressing this problem, a general theory of investigating the processes of dynamics of channel flows with variable flow rates and a free boundary has not yet been developed. Existing mathematical models are very closely related to hydrogeological data of a particular river bed. Therefore, a thorough study of such movements requires a fundamentally new mathematical approach

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that takes into account the irregularity of the basin bottom and the flow rate variability. Calculation of the capacity of debris flow on active river tributaries requires combining the analytical and modeling capabilities of geographic information systems (GIS) to create forecast-simulation complexes for prevention, minimization and elimination of the consequences of emergencies. Methods and algorithms for calculating hydraulic characteristics of flows in different parts of the basin are given in many works, in particular in [1-7]. Therefore, we will not repeat these approaches. Our goal is to develop a fundamentally new approach suitable for a quality study of this phenomenon, allowing the calculation of quantitative values of the parameters in the subsequent stages.

2. Main part

The movement of flows consisting of a mixture of liquid and solid particles (including debris flows) is investigated using the methods of hydrodynamics of multicomponent media with variable flow rates. Depending on the velocity over the time t in each cross section of a natural watercourse, a process of bed deformation takes place. When the solid phase is deposited, part of its mass is separated from the main flow, and when it is washed out, it joins it. These issues can be investigated on the basis of the theory of multiphase media motion taking into account flow variability in a channel with an irregular bottom (Fig. 1).

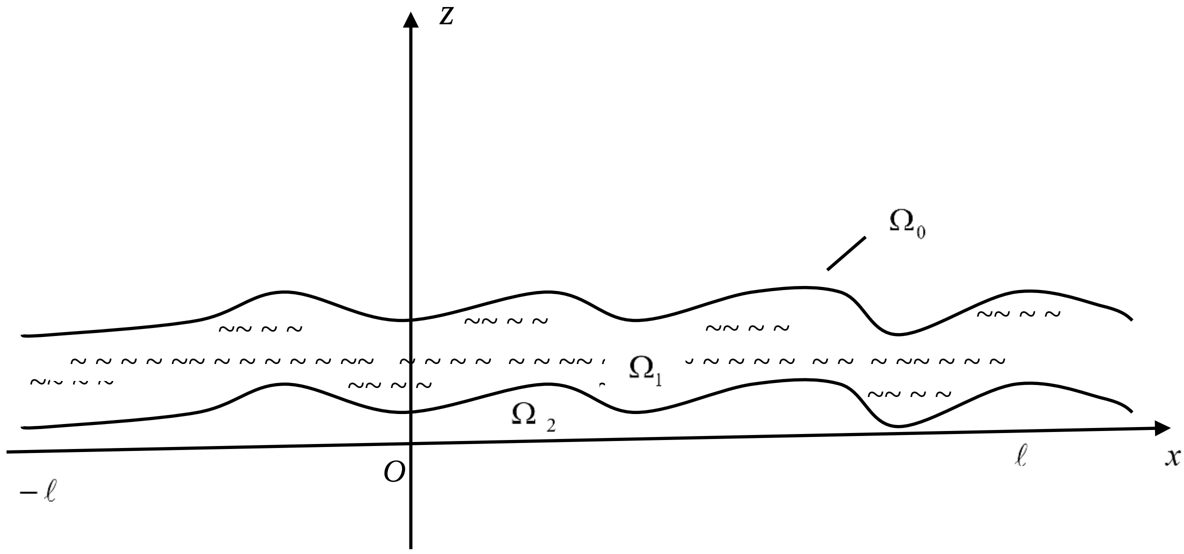

Fig.1. Flow in a flat channel with an irregular bottom.

Here, Ω_1 is flow area, Ω_2 is boundary of the solid bottom, which in general can be specified as a continuous or discrete, even random function, Ω_0 is free surface of the flow.

Similar problems in different aspects are set and investigated in [1]. Analysis of the studies in this area reveals the need to build the most improved models, taking into account the forces acting in the flow, the irregularity of the bottom and the flow rate variability.

We will write the equations of movement of real fluid in the form:

$$(V\nabla)V = -\nabla P, \qquad \nabla = \frac{\partial}{\partial x_1} + \frac{\partial}{\partial x_2}, \qquad x = (x_1, x_2) \in \Omega_1 \tag{1}$$

$V = (V_1; V_2)$ is velocity, p is pressure. We introduce the flow function φ with the relations:

$$V_1 = \frac{\partial \varphi}{\partial x_2}; \qquad V_2 = -\frac{\partial \varphi}{\partial x_1} \tag{2}$$

We satisfy the incompressibility condition and denote by ω vorticity vector, which is determined from the expression:

$$\omega = \frac{\partial V_2}{\partial x_1} - \frac{\partial V_1}{\partial x_2} \tag{3}$$

$$\Delta\varphi = \frac{\partial^2 \varphi}{\partial x_1^2} + \frac{\partial^2 \varphi}{\partial x_2^2} = -\omega, \qquad x \in \Omega_2 \tag{4}$$

We will write (1) in the coordinate form:

$$V_1 \frac{\partial V_1}{\partial x_1} + V_2 \frac{\partial V_2}{\partial x_2} = -\frac{\partial P}{\partial x_1} \tag{5}$$

$$V_1 \frac{\partial V_2}{\partial x_1} + V_2 \frac{\partial V_2}{\partial x_2} = -\frac{\partial P}{\partial x_2} \tag{6}$$

Differentiating (5) with respect to x_2 and (6) with respect to x_1, subtracting them from each other, after some simple algebraic transformations we obtain:

$$\frac{\partial \varphi}{\partial x_1} \cdot \frac{\partial \omega}{\partial x_2} - \frac{\partial \varphi}{\partial x_2} \cdot \frac{\partial \omega}{\partial x_1} = 0 \tag{7}$$

It follows that φ and ω are linked with a functional dependence

$$\omega = \omega(\varphi) \tag{8}$$

Substituting (8) into (4), we obtain the following nonlinear Poisson equation for the flow function φ in the flow area Ω_2:

$$\Delta\varphi = -\omega(\varphi), \tag{9}$$

with some right-hand side. In the simplest case without a vortex potential flow $\omega(\varphi) = 0$, we obtain

$$\Delta\varphi = 0, \tag{10}$$

the solution of which is $\varphi = \varphi_0$. The general solution of equation (9) will be obtained by the method of successive approximations, i.e. we assume that at the initial time instants, when the flow enters the channel, the movement is vortex-free, and at subsequent time instants, some "fictitious forces" emerge in the flow due to the emergence of vortex, calculated using the solutions of previous iterations. Then the general solution of equation (9) will be in the form:

$$\varphi = \varphi_0 + \varphi_1 + \varphi_2 + ... = \sum_{k=0}^{\infty} \varphi_k \tag{11}$$

To find φ_1, substituting the obtained expression φ_0 into the right-hand side of (9), we obtain an inhomogeneous Poisson equation with known right-hand side and solving it we find φ_1, at zero boundary conditions, etc.

Consider now the boundary conditions for equations (9) and (10), which must satisfy the solution φ_0.

Suppose that at the inlet and outlet of the channel, the height of the location of which is equal to h, the bottom is even, and the velocity of the fluid is constant and given. In this case

$$V(x) = V_0, \quad x_1 = \pm l, \qquad x_2 \in (0; h) \tag{12}$$

From (2) and (12) it follows that

$$\varphi(x) = U_0 \cdot x_2, \quad \text{when} \qquad x_2 = \pm l, \quad x_2 \in (0; h) \tag{13}$$

If the bottom Ω_2 is solid, we apply the impermeability conditions:
$(V \cdot \vec{n}) = 0 \qquad x \in \Omega_2$, which, given (13), give the relation

$$\varphi(x) = 0, \quad x \in \Omega_2 \tag{14}$$

The condition on the unknown boundary, i.e., on the free surface, we obtain in the form (impermeability condition):

$$\varphi(x) = V_0 \cdot h, \quad x \in \Omega_0 \tag{15}$$

In order to derive the equation of one-dimensional movement of a viscous debris flow with variable flow rate along the path, we use the well-known equation of hydraulics, which is based on the energy principle.

Besides, on Ω_0, as on the flow line, the constant value has the obtained expression (similar to formula 3.1 in [2]). Denoting by P_0 the atmospheric pressure, we get:

$$P_0 + \frac{1}{2}\left(V_1^2 + V_2^2\right) + \rho g x_2 = P_0 + \frac{1}{2} V_0^2 + \rho g h \tag{16}$$

where ρ is density, g is gravitational acceleration. From (15), (16) the following condition follows

$$\left(\frac{\partial \varphi}{\partial \vec{N}}\right)^2 = \left|\nabla \varphi\right|^2 = V_0^2 + 2\rho g (h - x_2), \quad x \in \Omega_0, \tag{17}$$

where $\vec{N}$ is a normal to Ω_0. As a result, we arrive at a free-boundary problem, which is solved using numerical methods.

When solving the theoretical problem to illustrate the results, the channel profile (area Ω_2) can be represented, for example, as $z_0 = z_1 \cos^2 \frac{k\pi}{2L} x$ D, or in another form, as a continuous, discrete or random function. The following input data can be used for numerical calculations:

$L = 1000m,\ z_1 = 0{,}1m,\ k \in Z, \quad h = 20\,m,$ and corresponding hydraulic characteristics of turbid flow mixture, given, for example, in [7]. As a result, we obtain the values of force characteristics of the flow: the flow travel time depending on different starting values of hydraulic parameters, the values of other force actions on the incidental obstacles when the mixture moves in the channel by the known methodology given in [3, 5], etc. The main difference of the proposed methodology is a more extended approach to the investigation of the task at hand, in which calculation modules are an integral intermediate part of the forecasting system. The knowledge base has a dynamic structure and is constantly fed with new information from the continuous monitoring system (CMS), etc. A flow chart of the prospective intelligent expert system is as follows:

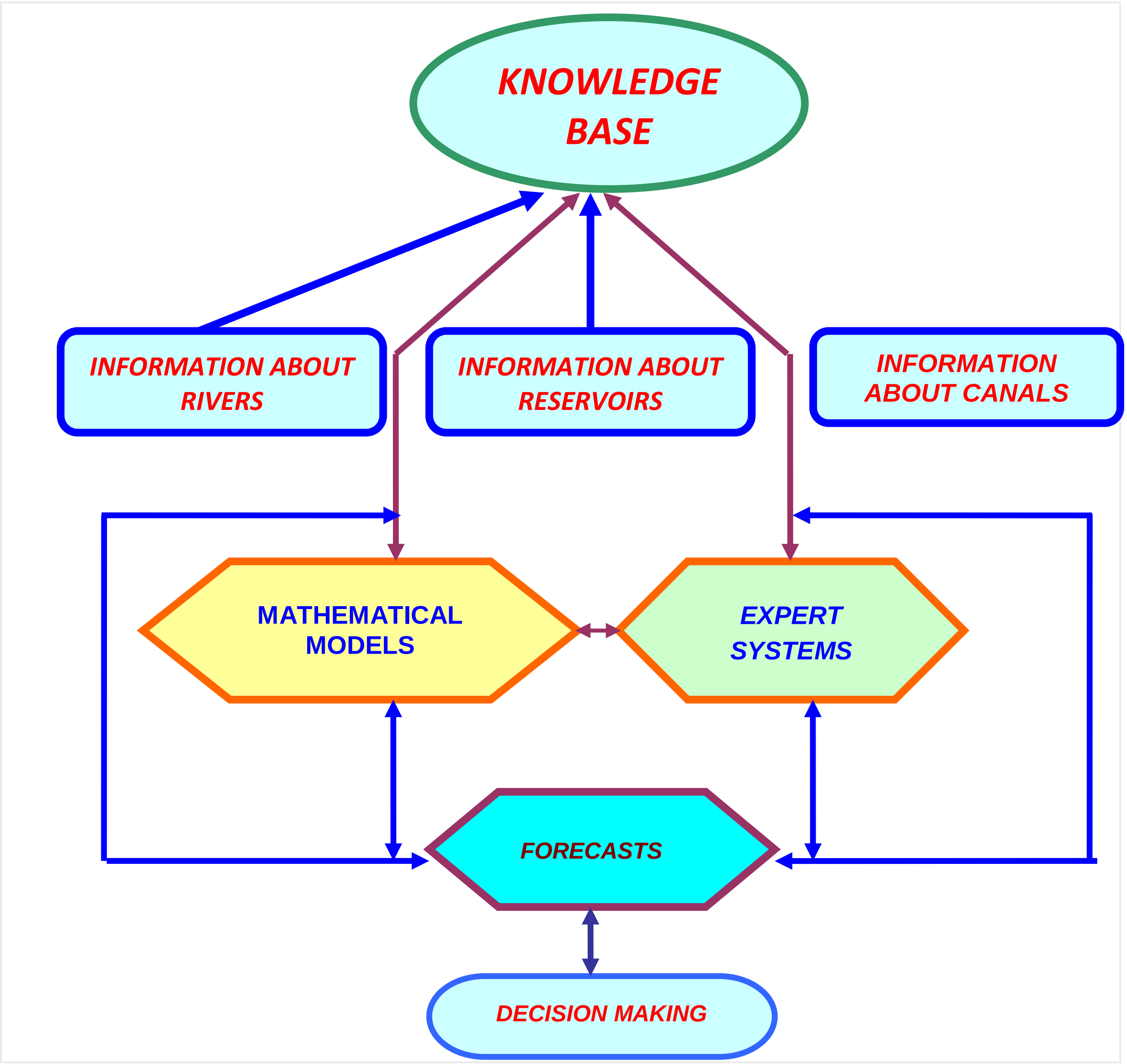

Fig.2. Functional scheme of computer modeling of flood and flood phenomena in water basins and rivers

The main purpose of the proposed system will be operational monitoring of the hydrological situation in debris flow-prone river basins, continuous monitoring of environmental safety, forecasting of debris flow phenomena and theoretical calculation of hydraulic characteristics of the expected flow and decision-making to prevent hazards.

References

[1] П.Н. Вабищевич, Численные методы решения задач со свободной границей, Изд. Московского университета, (1987) 164 p. [In Russian: P.N. Vabishchevich, Numerical methods for solving free-boundary problems, Moscow University Press, Moscow].

[2] О.Г. Натишвили, В.И. Тевзадзе, Волны в селях, Тбилиси, (2011) 162 p. [In Russian: O.G. Natishvili, V.I. Tevzadze, Waves in Debris Flows, Tbilisi].

[3] T. Takahashi, Debris flow, IAHR Monograph Series, Netherlands, Balkema Publishers, (1991).

[4] P. Zhu, Z. He, Y. Wang et al., A study of typical mountain hazards along Sichuan-Tibet highway, Chengdu Science and Technology University Publishing House, (1999).

[5] D. Rickenmann & C. Chen (eds), Debris flow hazards mitigation: Mechanics, prediction, and assessment, Rotterdam, Millpress, Vol.1 & Vol.2 (2003) 1325 p.

[6] О.Г. Натишвили, В.И. Тевзадзе, Основы динамики селей, Изд. "Мецниереба", Тбилиси, (2007) 214 p. [In Russian: O.G. Natishvili, V.I. Tevzadze, Fundamentals of debris flow dynamics, Metsniereba Publishing House, Tbilisi].
[7] М. Шаюсупов, Движение многофазных потоков с переменным расходом в руслах, Ташкент, Фан, (1981). [In Russian: M. Shayusupov, Movement of multiphase flows with variable flow rates in channels, Tashkent, Fan].