A DISTRIBUTED MODEL OF SNOWMELT PROCESSES (ON EXAMPLE OF VOTKINSKOE RESERVOIR CATCHMENT AREA)

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ABSTRACT

The article analyzes the methods and results of distributed modeling of snowmelt processes on the Votkinskoe reservoir catchment area. The model is based on GIS technologies. For evaluation of the snowmelt intensity, the authors have used the empirical method of calculation of snow cover energy balance, was proposed by P.P. Kuzmin. The validation of simulation results is made according to snow survey data and remote sensing data.

Keywords: snow cover, snowmelt, snow water equivalent, GIS-based modeling, remote sensing data

INTRODUCTION

The catchment area of Votkinsk reservoir is situated in boundary zone between East European plain and Ural mountains. On this territory, the most significant phase of hydrologic regime is spring high water because of snow cover melting which gathered during winter. The volume of snowmelt runoff is more than 60% of annual river flow. In the period of spring high water, the settlements and agricultural lands are regularly flooded [1]. Thereby, monitoring and forecasting of spring flood formation is the very actual problem of this region.

The most important factor in determining the volume of flow and the maximum levels of spring flood is the process of snowmelt. The intensity of snowmelt and water inflow to the catchment areas is determined of complex influence of hydrometeorological conditions, and the properties of land surface and vegetation cover. In this regard, the calculations and forecasts of snowmelt intensity make use of digital elevation models and land cover / land use maps [6-7].

The main objective of this study is the development and validation of spatial model of snowmelt processes in the catchment area of Votkinsk reservoir by using GIS technology. The tested catchment area is 184 km^2. Major part of the investigated catchment is located on the east of East European Plain; about 30% of the territory belongs to the North and Middle Urals mountains. The predominant type of vegetation is secondary dark conifer-leaved boreal forests.

Taking into account the low density of the ground-based observation network, the cell size of the model is assumed to be 3000 m. The snowmelt intensity calculation is performed with a step 12h. The accumulated precipitation and water inflow to the catchment area are calculated with a daily step. The study period covers 2010-2013. It is sufficiently diverse and representative under the terms of the formation and melting of snow cover.

THE INITIAL DATA AND RESEARCH METHODS

As input data in the snowmelt model we have used:

- Digital elevation model Etopo2 (GLOBE);
- the land cover/land use map, created by two space imagery Terra MODIS, summer and winter seasons;
- data on maximum snow water equivalent ;
- the daily observations on the network of weather stations;
- the remote sensing data (Terra/Aqua MODIS and LANDSAT) for model calibration and results validation.

The model output data are snow cover area, snow water equivalent and the meltwater inflow to the catchment area of the rivers (with a daily step). The input data for modeling (digital elevation model and land cover/land use map) of the investigated catchment are shown in Figure 1. Data preparation and calculations were performed by following softwares ArcGis 10.1, Scanex Image Processor 3.6.12 and SAGA 2.0.

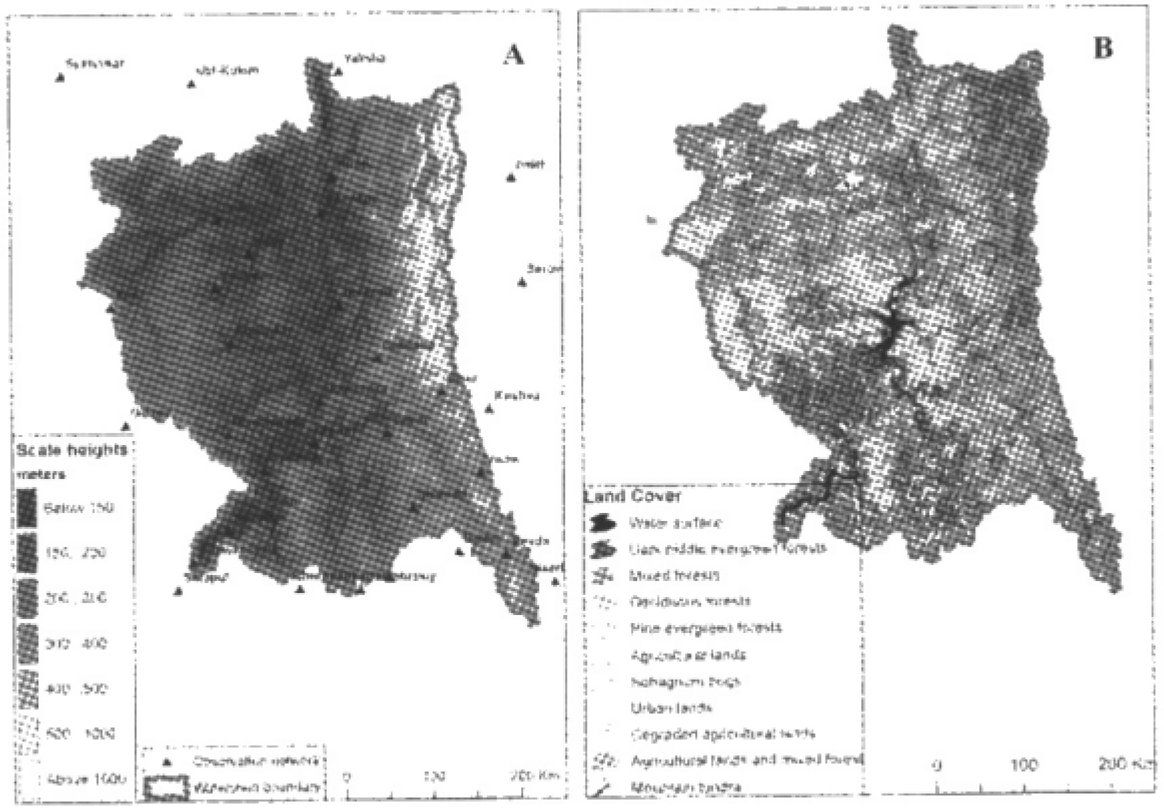

Fig. 1. The input data for modeling: **A** – digital elevation model; **B** – land cover map

Calculation of snowmelt intensity in the catchment areas of rivers is based on a simplified energy balance method was suggested by P.P. Kuzmin [2].This method is also used in the model of the formation and melting of snow cover, was developed by the Institute of Water Problems of Russian Academy of Sciences [6]. This method is based on snow cover energy balance equation on the assumption that the temperature of melting snow is 0°. Heat balance equation, without regard to its minor components, is recorded in the following way

$$W = W_R + W_A + W_E \qquad (1)$$

where W_R – radiation balance, W_A – sensible turbulent heat flux, W_E – latent heat flux for snow evaporation and from water vapor condensation on the snow surface.

The radiation component of snowmelt (M_R) is calculated by the formula:

$$M_R + Q_{sw} - Q_{ls} + Q_{lw} \qquad (2)$$

where Q_{sw} is short-wave radiation balance, Q_{ls} – upward long wave radiation from snow, Q_{lw} – downward long wave radiation. The radiation balance components are calculated as follows (3-5)

$$Q_{sw} = 0{,}125(Q+q)(1-R)(1-0{,}2N_{total}-0{,}47N_{lower}) \qquad (3)$$

$$Q_{ls} = \varepsilon\sigma T_0^4 \qquad (4)$$

$$Q_{lw} = (\varepsilon\sigma T_0^4)(0{,}62+0{,}05e^{0{,}5}(1+0{,}12N_{total}+0{,}12N_{lower}) \qquad (5)$$

where Q+q represents the short-wave direct and diffuse radiation flux (under clear sky conditions) for the day, R denotes albedo of snow cover, N_{total} and N_{lower} – total cloudiness and lower level cloudiness in %, T_0 – air absolute temperature, e – water vapor pressure at a height 2 m, σ signifies the Stefan–Boltzmann constant, ε signifies the effective emissivity of the snowpack taken equal to 0.99 in this study.

The advective component of snowmelt is determined by the turbulent heat exchange heat exchange between snow cover and atmosphere, and latent heat flux from condensation of water vapor on the snow surface:

$$M_A = k(1+0{,}544U_{10})(T_2 - T_0 + 1{,}75(e_2 - e_0)) \qquad (6)$$

where U_{10} represents wind speed at a height 10 m, T_2 and e_2 – air temperature and water vapor pressure at a height 2 m, T_0 signifies temperature of the snow surface, e_0 – the saturated water vapor pressure at a temperature of the snow surface. The coefficient ***k*** before formula (6) depends on the model time step in the case of calculations with steps of 12 hours it is assumed equal to 0,434.

Evaporation from snow cover is calculated by the Kuzmin method [2].

$$E = 0{,}18 + 0{,}098U_{10}(e_2 - e_0) \qquad (7)$$

As input meteorological data for the modeling of snowmelt we have used temperature and humidity, wind speed, total solar radiation, total and lower level cloudiness, liquid and solid precipitation. Recovery of input fields of meteorological parameters for each day of the snowmelt period was performed by GIS technologies. . Furthermore, we have used both actual data of meteorological observation, and data of objective analysis of global weather forecast model GFS/NCEP, as well as mesoscale model WRF/ARW are used to resolve this problem. During interpolation of ground-based observation network data, the authors take into account the dependences of meteorological parameters on the relief and the type of vegetation.

Calculation of total solar radiation (under condition of clear sky) was performed by digital elevation model. The SAGA GIS (System for Automatized Geoscientific

Analysis) was used for the evaluation. To take into account the influence of total and lower level cloudiness, the P.P. Kuzmin method has been used [2]. Total and lower level cloudiness interpolated by using weather station data.

Albedo of snow cover was calculated by empirical dependence on the data of the last snowfall, which suggested by authors of hydrological model DHVSM [7].

$$R=0,9(\lambda)^{N^{0,5}} \tag{8}$$

where 0,9 represents fresh snow albedo, λ signifies the parameter is taken equal 0,85. Snow albedo is highly variable parameter. The reliability of its estimation (under condition of absence of instrumental observations) has significant influence to the accuracy of the snowmelt modeling.

The interpolation of air temperature and humidity was performed on the basis of weather stations observation data, taking into account the vertical gradient of temperature and water vapor pressure. It was calculated by the objective analysis data of GFS/NCEP weather forecasting model.

The estimation of wind speed was performed based on GFS/NCEP model output data, taking into account the terrain height and types of vegetation cover.

The snow surface temperature was assumed $T_0 = 0°$, if the air temperature was above 0°. If $T_2 < 0°$, then $T_0 = \theta_2$.

The saturated water vapor pressure at a temperature of the snow surface $e_0 = 6{,}11$ GPa, if the air temperature was above 0°. If $T_2<0$, then $e_2 = e_0$.

The greatest difficulty is the evaluation of the maximum snow water equivalent and solid/liquid precipitation during snowmelt. These parameters are very high degree of spatial-temporal variability.

The evaluation of precipitation fields during snowmelt were performed on the basis of mesoscale numerical weather forecasting model WRF/ARW. The article [4] is devoted to the assessment of the validity of spring precipitation forecast model [4]. In the absence of model data, the accumulated precipitation was interpolated according to weather stations data, taking into account the altitudinal gradient (10%/100 м). In this case, the phase of precipitation was determined by the empirical formula:

$$N= -0{,}179T_2 - 0{,}034T_{925} - 0{,}078T_{850} + 0{,}372, \tag{9}$$

where N is the percentage of solid precipitation, T_2 represents the air temperature at 2 m, T_{925} and T_{850} – temperature on isobaric surfaces *925* and *850 GPa* accordingly.

The calculation of maximum snow water equivalent is made from snow surveys data. The data of more than 50 weather and hydrological stations were used for it interpolation. Interpolation is performed through the method suggested by V.A. Shutov, separately for forest and field areas [5]. The dependences of snow accumulation on the height of the terrain and vegetation types were taken into account. The typical vertical gradient of snow water equivalent in the Western Urals equals to 10-15% / 100 m . The influence of the vegetation cover is caused by snow interception and subsequent evaporation from the treetops. This process is a great importance in dark coniferous evergreen boreal forests.

Calculated values of snowmelt intensity and snow evaporation were summed for daily intervals. Further calculation of snow cover area, water inflow to the watershed and snow water equivalent was carried out by daily step. Snow cover area was determined by A.G. Kovzel method, based on the model of typical distribution curves of the snow water equivalent for forested and not forested areas. The parameters of the distribution curves of snow water equivalent for the study catchment area are presented in the article [3]. The meltwater inflow to the watersheds was calculated according to known methods, taking into account the water-holding capacity of snow, which is assumed to be equal for forest – 20%, and for no forested areas – 15%. The water inflow to the watersheds consists to two parts: the meltwater inflow from snow cover and solid and liquid precipitation falling on the watershed. In the simulation we also have taken into account the formation and melting of temporary snow cover during the spring season. This process is especially typical for the mountainous parts of the catchment area).

The software module in language C ++ (extension AddIn ArcGis 10.1) was developed to automate the calculations. An example of simulation results (for 2013 spring season) is shown in Figure 2.

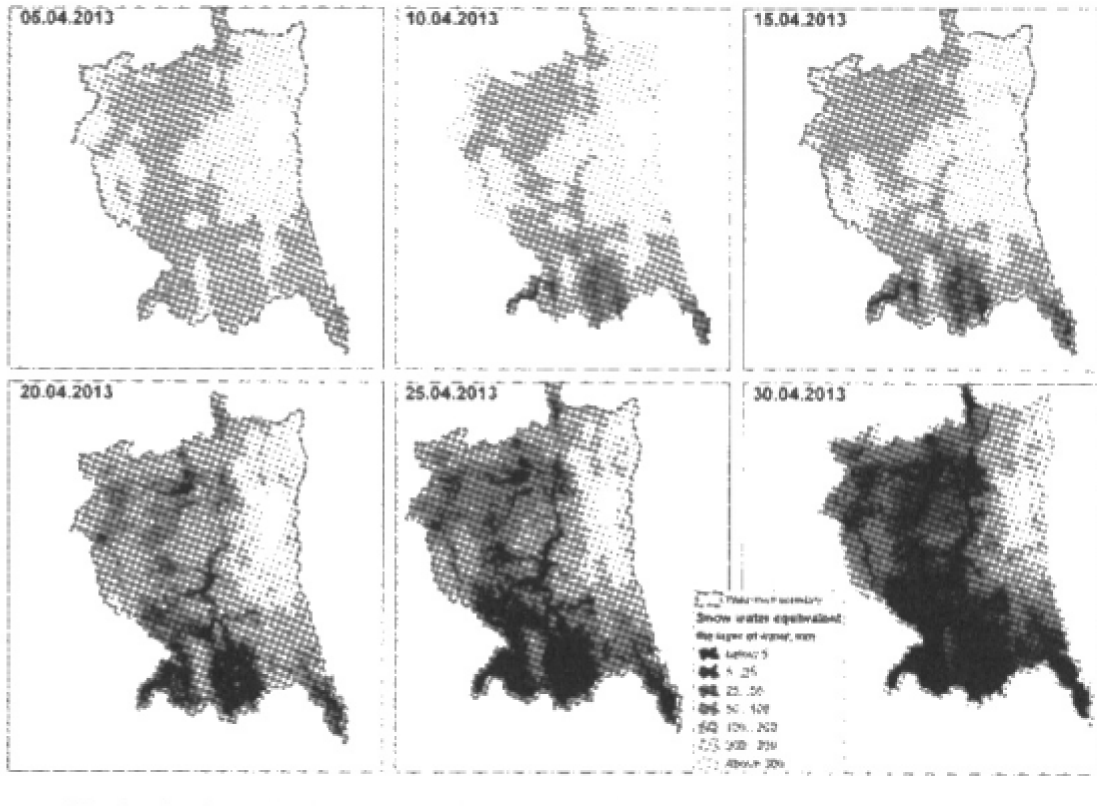

Fig. 2. The dynamics of the snowmelt process of in 2013 spring season (simulation results)

ANALYSIS OF THE SIMULATION RESULTS

Validation of simulation results was performed in two methods:

1. The calculated and actual snow water equivalent were compared using snow survey data.

2. The estimated and actual snow cover area on watersheds was compared using remote sensing data.

Validation of the results according to space monitoring is based on the use of Terra/Aqua MODIS data (product of MOD10). The identification of the snow cover is based on the normalized differential snow index NDSI. The calculation of NDSI is based on visible and short-wave infrared spectral bands of space image. NDSI threshold value was assumed to be 0,35. All image pixels having a value greater than the threshold NDSI were regarded as the snow-capped. This threshold for forested area was assumed to be 50% of the total area, and for not-forested area – 80% of the total area. These ratios were obtained from the comparative analysis of images Terra/Aqua MODIS with higher resolution space images. Thus was compared the actual and estimated snow cover area under condition of absence of cloudiness. The results for 2011 spring season are shown in Table 1.

In most cases, successful overlap of the actual and simulated snow covered area was gained (with the exception of coniferous forests, in which the estimation of snow cover area from satellite data is unreliable). This indicates the objectivity of dependencies of snow water equivalent and other input data from the terrain height and vegetation types, that were used in the model. An example of a comparison of the calculated and actual (determined from Terra MODIS satellite data) snow-covered areas is shown in Figure 3.

Table 1. The comparison of the calculated and satellite derived snow cover area, on the example of 2011 spring season

Observation data		04/16/11	04/17/11	04/27/11	04/28/11	05/01/11	05/05/11
The area, not covered by cloudiness, thousands km^2		38	68,5	106,2	46,3	96,4	183,6
Snow covered area, %	Satelite data	74,0	80,7	37,0	60,0	41,0	10,0
	Simulation results	83,0	91,0	50,0	59,0	45,0	7,4

Validation of simulation results according snow surveys was performed in 2010-2013 spring season. The comparison of actual and estimated snow water equivalent was performed separately for forested and not-forested snow-measuring routes, and points where snow survey was performed in forest as well as in field. The reliability of the results was assessed by standard errors values, which are shown in Table. 2.

The main reasons for deviations from the actual data and simulation results of snow water equivalent are:

- The overestimation of the snowmelt intensity (often in the forest) or its underestimation (usually in the field);
- The errors in the calculation of the maximum snow water equivalent;
- The snow survey data are not representative in comparison with the neighboring area (typical on mountain river catchments),.

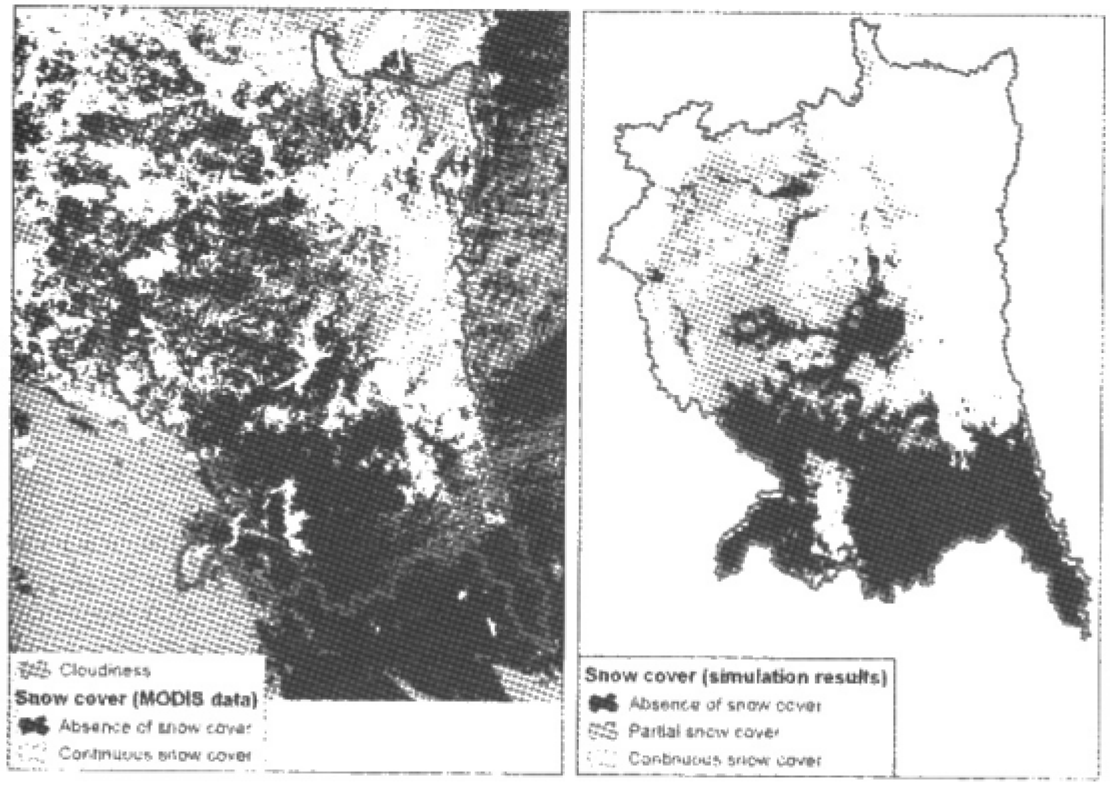

Fig. 3. The comparison of the MODIS data and the simulation results (condition of snow cover, 04/16/2012)

Table 2. The standard errors of the results of calculation of snow water equivalent using P.P. Kuzmin method

Year	Type of snow survey measurements	Standard error of calculation, mm
2010	in the forest	39,4
	on the field	22,8
	Mixed (in the forest and on fields)	27,4
2011	in the forest	43,5
	on the field	27
	Mixed (in the forest and on fields)	33,3
2012	in the forest	28
	on the field	27,8
	Mixed (in the forest and on fields)	26,4
2013	in the forest	47
	on the field	57,1
	Mixed (in the forest and on fields)	41,9

CONCLUSION

Analyzed methodology allows us to evaluate the snow water equivalent, meltwater inflow to the watersheds of rivers and snow cover areas taking into account the mesoscale features of snow cover distribution. Its caused by the nature of land surface and vegetation types.

As a result of comparison of simulated and actual snow cover area on the watersheds it was found out that in most cases the model describes correctly the dynamics of snowmelt, in the plains as well as in the mountains region. While comparing the calculated and actual snow water equivalent, in some cases significant differences were revealed. This errors may be caused with the unreliability of snow survey data during the spring season. The suggested method of snowmelt modeling can be used in the short-term hydrological forecasting, as a component of snowmelt runoff formation model.

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A FIELD STUDY ON OVERNIGHT STAGNATION OF DRINKING WATER IN DOMESTIC DISTRIBUTION SYSTEM

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ABSTRACT

The present study investigates the influence of in-house installation systems to the tap water quality. In the study were collected more than 100 tap water samples from one important city situated in South-East part of Romania with approximately 250,000 inhabitants in order to get an overview of the current contamination level of drinking water (chemical and microbiological) at the consumer's tap.

The quality of drinking water provided by the Water Company was situated in the limits imposed by the National Legislation. The metal concentrations recorded in tap water samples collected with tap flushing procedure were situated under the maximum admissible values, in all cases. The data obtained for 41% of first draw samples (samples collected first in the morning from kitchen without previous flush of the tap) indicated a pollution of drinking water with some metals (Cu, Fe, Ni and Pb) as result of domestic equipment types (pipe, tap, fitting). High concentrations of Cu, Fe and Pb were recorded in households where most of the material used in domestic distribution system was either copper, either cast iron or lead. The study results indicate that in summer period, under the influence of high temperature, the mesophilic bacteria could exceed the admissible values. Biological results showed that in about 55% of the first draw samples, the number of bacteria (at 22°C and 37°C) exceeded the admissible limits, but flushing the tap for more than five minutes lead to improve water quality. Only 14% of the samples remain non-compliance samples.

The conclusion of the study indicates that materials used and stagnation of the water in domestic distribution systems affect the drinking water quality at the consumer's tap.

Keywords: drinking water, stagnation, metals, microbial growth

INTRODUCTION

In most European countries, drinking water quality is routinely monitored in the distribution network but not inside households at the point of consumption, in principal because authorities have limited access to private homes, as well as limited control over household plumbing and operation. Household pipes can, in fact, have a considerable impact on the water quality, which was already shown in several large scale studies addressing heavy metal concentrations in tap water after overnight stagnation [1, 2]. All these studies reported increased concentrations of lead, cadmium, copper and nickel after stagnation in household tap water in Germany and Austria. Pollution with metals