Journal of Engineering and Applied Sciences 12 (17): 4495-4499, 2017
ISSN: 1816-949X

Role of Hydrological Monitoring in the Description of the Runoff Formation Processes

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Abstract: This study describes methods of preliminary assessment of the state of meteorological and hydrological exploration of river catchments to develop common approaches to modeling and forecasting of hydrological processes. A brief overview is given of the organization of monitoring systems in different countries. The quantitative assessment is performed of the ground observation coverage over the largest river basins within the European territory of Russia with cartographic visualization in GIS. Recommendations are given on the use of specific hydro-geological models for forecasting for catchments assigned to a particular group according to the state of exploration of runoff formation process.

Key words: Water catchment, GIS, hydrological model, monitoring, hydrological network, meteorological

INTRODUCTION

The procedure for the quantitative and qualitative assessment of the state of hydrological and meteorological exploration (ground observation coverage) of the river water catchment belongs to the category of preparatory procedures necessary for runoff prediction in fully automated mode. It is performed in the very beginning. during preparation of the list of water catchments that will then be included in the database as objects for which the automated forecasting of the runoff is carried out. In addition, the purpose of hydrological and meteorological monitoring is to provide information to support in solution of the largest possible number of tasks of the condition assessment forecast of development and first of all, decision-making in various subject areas related to water resources. However, the development of a fully automated system for control and management of environmental quality is a relatively new problem which has successful solution only in some regions of the world. For example, according to the US Geological Survey, 91 million dollars was allocated for the implementation of a national information program and establishment of a national river monitoring network including more then 12.000 water level and quality monitoring stations at almost all major rivers in the USA. As a result of this research, a unique automated system is operated in the USA allowing collection of reliable information on the amount and quality of river waters for the purpose of operational monitoring and management of the state of the country's water resources.

Most of the hydrometric stations in Canada are located in the Southern half of the country where population and economic pressures are the greatest as a result, the adequacy of the network to describe hydrologic characteristics decreases significantly to the north. The federal Canadian hydrometric network was fully modernized with employment of new field methods and technologies, advanced data management and real-time on-line access to hydrometric information (Bobrovitskaya and Kokorev, 2011). Generally, about 80% of the active hydrometric stations were initially constructed to serve a specific water management purpose, however over time the data from these stations also served other interests. The remaining 20% of the hydrometric stations were strategically located to document hydrological characteristics and processes required to understand the regional hydrology (Yuzyk *et al*., 1995). Currently, there are 2,500 water level and flow stations being operated under the Federal-Provincial and Federal-Territorial CSA; more then 720 are designated as federal stations, about 980 as provincial or territorial stations and 781 as federal provincial or federal-territorial stations. A further 92 stations are fully cost-recovered from other parties and another 302 stations are contributed by other organizations, bringing the total number of active stations

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to ~ 2,870. An additional 5.500 hydrometric stations are no longer active although, their data are stored in the accessible HYDAT database (http://msc.ec.gc.ca/wsc/ hydrometric).

In the EU, the density of monitoring network is traditionally high this is justified, given the physical diversity, anthropogenic factor, population density and land use as well as the types of river and hydrographical conditions (Pivovarova, 2016). On average, there are about 19.000 hydrological stations the average density is one station per 270 km^2. All monitoring stations are managed by the European Environmental Agency (EEA). EEA focuses on the water quality however, the monitoring network also conducts a full range of observations over surface water and groundwater (http://www.eea.europa.eu).

The hydrological network of Russia is one of the oldest and well-developed networks in the world. It has reached the greatest state of development in 1986 when the number of observation points reached 4440 of this number 3926 points were on the rivers and 514-on lakes. By 1999, the network was reduced to 3053 points. Currently, a relative stabilization is noted and even a slight increase in the quantitative composition of the hydrological monitoring network. Currently, 3068 hydrological stations are operating in Russia. On average in the period since 1986, after the disintegration of the former Soviet Union and due to underfunding of the hydro-meteorological services, the hydrological network was reduced by 30.3%. However, in the Far North in Siberia and in the Far East the reduction was more significant (Bobrovitskayaa and Kokrev, 2004). Accordingly, the decrease in the number of observation points leads to the necessity to change the requirements to the composition of hydrological information and modeling of river runoff. In this study, we propose a qualitative and quantitative assessment of the state of water catchments exploration to prepare input data arrays for various kinds of hydrological models.

MATERIALS AND METHODS

Qualitative assessment

The state of meteorological exploration: In the first stage of assessment all water catchments are divided into three groups in terms of coverage by meteorological observations: studied (from the meteorological viewpoint) water catchments are those for which the number of active meteorological monitoring points and stations and the quality of the data (accuracy and spatial-temporal resolution) are sufficient so that only ground observation data on rainfall could be used as the "input" for hydrological model (i.e., without the use of data from other sources such as satellite data, weather radar data or numerical weather models) (Kayastha *et al*., 2013).

Poorly studied (from the meteorological viewpoint) water catchments are those for which the amount of data is not enough to be used as the "input" for hydrological model but is enough for assimilation of output data of the numerical weather models (as well as satellite observations of precipitation in the future today these data come with a considerable delay and cannot be used to forecast dangerous hydrological phenomena). Unstudied (from the meteorological viewpoint) water catchments are those water catchments where no meteorological observations are made.

For the purposes of forecasting the runoff from studied (from the meteorological viewpoint) water catchments the hydrological model can use ground observation data as the "input" when the runoff is forecasted for poorly studied catchments then the model can use the output data of numerical weather models after such data pass the assimilation procedure using the existing ground observation data when forecasting is to be made for unstudied catchments then the output data of numerical weather models can be used validated using the existing ground observation data for adjacent water catchments.

Subdividing of water catchments into groups in terms of meteorological exploration state is performed as follows. First, water catchments for which available data are absent (for whatever reason) shall be classified into the group of unstudied (from the meteorological viewpoint) water catchments. At this stage, all the remaining water catchments shall be conditionally considered as studied for all such water catchments calibration and validation of the hydrological model shall be carried out followed by numerical experiments that shall determine whether there is enough ground observation data for each of them to allow qualitative hydrological forecasting (Kuzmin, 2001). The water catchment is moved to the group of studied ones if data are sufficient or to the group of poorly studied if data are insufficient (in this case ground observation data will be further used only for assimilation of output data of numerical weather models).

State of hydrological exploration: The state of hydrological exploration is defined somewhat differently for this purpose the availability and density of the runoff observations at gaging stations are taken into account including observations at currently closed stations. The point is that in the forecasting such runoff observations (water levels and flows) are normally used only for parameterization (calibration) of hydrological models which is performed using retrospective (historical) data (Johnston and Pilgrim, 1976). Operational runoff observations are used relatively rarely today-mostly for modeling and forecasting of the spread of flooding on major rivers (as the initial and boundary conditions).

In terms of hydrological exploration state, all water catchments are also divided into three groups: studied (from the hydrological viewpoint) water catchments are those where the hydrometric monitoring of the runoff is currently carried out or was carried out in the past and the available data are sufficient for calibration of the hydrological model.

Poorly studied (from the hydrological viewpoint) water catchments are those where the hydrometric monitoring of the runoff is currently carried out or was carried out in the past but the available data are not quite sufficient for calibration of the hydrological model. Poorly studied water catchments are mainly represented by medium and large water catchments located in remote areas of siberia and the far east. Calibration of such water catchments is particularly complex because the only way out is to use a model with “semi-distributed” parameters (in this case medium or large water catchment is divided into partial-studied or unstudied-water catchments followed by determining a set of parameters for each particular water catchment).

Unstudied (from the hydrological viewpoint) water catchments are those where hydrometric monitoring was never carried out. Model parameters for such water catchments are determined based on the study of the so-called transferability the possibility of using the parameters determined based on available observations for other water catchments.

Classification into groups by hydrological exploration state is performed as follows. First, water catchments for which available hydrometric data are absent (for whatever reason) shall be classified into the group of unstudied (from the meteorological viewpoint) water catchments. At this stage, all the remaining water catchments shall be conditionally considered as studied for all such water catchments calibration and validation of the hydrological model shall be carried out followed by numerical experiments that shall determine whether there is enough runoff monitoring data to ensure quality of model calibration and effective (accurate and timely) hydrological forecasting. The water catchment is moved to the group of studied ones if data are sufficient or to the group of poorly studied if data are insufficient.

As a rule, the automated runoff forecasting for poorly studied water catchments is performed using models with “semi-distributed” parameters models with lumped parameters are used for studied and unstudied water catchments. Models with distributed parameters are used very rarely for automated runoff forecasting due to their high resource intensity and lack of detailed data (data for each cell of the computational grid).

RESULTS AND DISCUSSION

Quantitative assessment: The meteorological and hydrological exploration state can be assessed not only qualitatively but also quantitatively. It is appropriate to use the ground observation network density index as the criterion for such assessment. WMO recommendations are available on the minimum number of observation stations: 1 station per 1,000-2,500 km^2 in the plains, 1 station per 300-1000 km^2 in mountainous areas and 1 station per 5,000-20,000 km^2 in arid and polar areas (WMO, 1999). We decided to use the power of GIS technology for the assessment of the hydrological network density in the European territory of Russia and for cartographic visualization. Within this territory we identified the largest river basins and divided them into regions depending on the belonging to a particular hydrological zone (Kuzin, 1960). River systems are divided into groups depending on their length (Fig. 1).

Areas of water catchments were determined and the density of observation points calculated for each hydrological zone (Table 1). As a result of calculations two water catchments were identified in the European territory of Russia which can be classified as poorly studied, namely, pechora/tundra and pechora/forest. Here, we recommend the use of special models for hydrological forecasting. For example, background modeling of runoff in near-real time mode. This is a fully automated procedure that allows calculating and visualizing of the general state of watercourses in relatively large areas, extremely convenient and effective for monitoring of dangerous hydrological phenomena and reduction of the risk of catastrophic floods. Qualitative background forecasts can be used as a signal for using more accurate, complex and demanding (from the viewpoint of labor, CPU resources and required data) forecasting procedures, oriented for example at specific locality for which the risk of flooding is detected in the process of background forecasting.

It should also be noted that the assessment of the state of river catchments exploration. We is needed to develop common approaches to modeling and forecasting of hydrological processes. It is not a secret that each new group of researchers is trying to develop and implement its own model or a set of models when dealing with hydrological modeling tasks for a particular river basin.

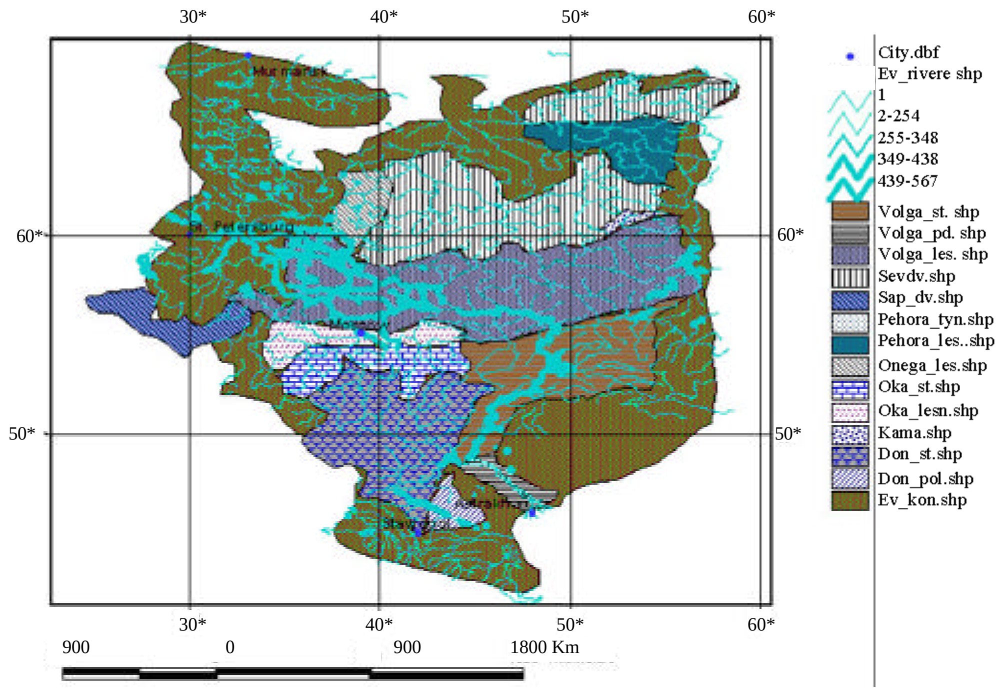

Fig. 1: River basins

Table 1: The density of the hydrological network

River basin/ Hydrologic zone	Basin area (km^2)	Hydrological stations	The density of the hydrological network
Don/semi-desert	180392	60	3006.53
Don/steppe	378000	203	1862.07
Kama/forest	250000	60	4166.67
Oka/forest	120000	27	4444.44
Oka/steppe	125000	56	2232.14
Onega/forest	41400	11	3763.64
Pechora/tundra	80789	-	80789.00
Pechora/forest	259000	39	6641.03
Western dvina/forest	81000	63	1285.71
Western dvina/forest	357000	97	3680.41
Volga/forest	479000	213	2248.83
Volga/steppe	741000	202	3668.32
Volga/semi-desert	101638	34	2989.35

As a result, we have many models for one and the same water body often with not clearly defined or limited access to the data for calibration. As a result, each “new” model will use the same data and therefore have similar drawbacks of previous attempts to modeling (Johnston and Smakhtin, 2014).

CONCLUSION

In conclusion, it should be noted that the subject of our study fully complies with the WMO recommendations for strategic approach to monitoring and assessment of rivers, lakes and groundwater: “Effective resource management requires accurate information as a basis for planning, implementing and monitoring resources” (WMO, 2009). It is becoming increasingly important in the light of global climate change and more frequent natural disasters, consequently, the growing need for operational information on disturbances in the formation of river runoff and the need for forecasting and early prevention of the risk of floods.

ACKNOWLEDGEMENTS

The study is based on research carried out with the financial support of the grant of the Ministry of Education and Science of the Russian Federation (grant ID RFMEFI58316X0059). Russian State Hydrometeorological University.

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