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Application of GIS-Technologies for Monitoring the Condition of Hydrological Network

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ABSTRACT

This article discusses major issues and global trends in the organization of hydrological observations. An approach to optimization of the hydrological network based on the use of geographic information systems (GIS) as a tool for processing, analysis and mapping of the hydrological data is offered. The calculation of the criteria of the number of hydrological stations for the European territory of Russia is made, and the main hydrological characteristics of the region are mapped. The results are analysed and the prospects for further research are outlined.

Key Words: Hydrological Stations; GIS; Environmental Management; Hydrology Optimization; Thematic Electronic Maps.

INTRODUCTION

The role and effect of hydrologic observation network operation for investigation of flow formation processes, and the level of knowledge about reasons of water regime changes depend on completeness and reliability of hydrometeorologic observation data which allow analysus of hydro-physical processes in various spatial-temporal scales. Observation data are necessary for numerical models of flow characteristics forecasting with a high resolution. Justification of criteria for optimum location of hydrologic network becomes especially relevant in the light of global climatic changes, and consequently, more frequent natural disasters. The world accounts for over 120 types of natural phenomena causing human losses and bringing a significant economic damage. A special group among them is disastrous hydrologic phenomena. According to a conference in Yokohama (Osipov 1995), floods only account for 32% of the total number of natural disasters. Together with the growth of material and human losses as a result of negative impact of waters, we observe an increase in the scarcity of water resources that are necessary for production of food, power, provision of population with high quality potable water, preservation of vulnerable ecological systems. According to UNESCO (2011), "water crisis" observed in many countries over the last decades is attributable not only to climatic changes, but also to irrational economic activity on water catchment. The main source of information about dangerous hydrologic phenomena is the state hydrologic observation network. The number of river flow observation points in Russia in 1990s, after the dissolution of Soviet Union and lack of financing by Hydrometeorologic Service, decreased by almost 30% (Frolov, n.d.). With the network reduction being caused by serious political and economic events in Russia, the tendency of decreasing of hydrologic points in developed countries is astonishing. For example, in the USA, over 2200 water monitoring posts ceased operation during the period 1980 to 2005, although the total number of acting posts remained quite stable and equaled about 7000 (USGS 2007). In this case, the problem is not simply in the disappearance of posts, but in the loss of the posts that used to register data for at least 30 years. These stations are especially needed for carrying out of precise analysis of flood water and dry weather flow frequency, and also for the assessment of hydrologic characteristics and trends in the conditions of climate change (Lins 2008). Another example of the network reduction that has a negative effect on investigation of climatic trends is Panarctic region, where the number of hydrologic posts recently dropped down to the level of early 1960s. In Ontario (Canada), 67% of river water monitoring posts were closed down during the period 1986 to 1999 (Shiklomanov et al. 2002). The information received on the basis of clearly arranged monitoring programmes is the main pre-requisite for precise assessment of conditions of water resources and scope of water problems. In keeping with this approach, I observe an evident necessity of developing criteria for defining the quantity of hydrologic posts in a given region for the purpose of reliable analysis and forecast of hydrologic processes in global, regional and local scales.

This paper provides an approach to optimization of hydrologic network on the basis of using of geo-information systems (GIS) as a tool for processing, analysis, and mapping of hydrologic data. Here, I will discuss the monitoring of hydrologic network providing data about water flow over a long period of time and reflecting common zonal hydrologic regularities.

METHODOLGY

The criterion for assessment is the methodology of justification of efficient location of hydrologic network suggested by Karasev (1968). The final aim of this method is to define optimum water catchment area closed by a reference hydrologic post (Fopt) by the following formula:

$$Frepr < Fgrad \leq Fopt \leq Fcor \quad (1)$$

where F_{grad} = changes in flow rate attributed to geographic zonality of climatic factors and defined by the formula:

$$F_{grad} \geq \left[8\sigma_0^{\,2} / (gradY)^2\right] Y_{av}^{\,2} \quad (2)$$

where σ_0 = error of definition of flow characteristics based on hydrometric data; *gradY* = gradient of flow module; *Yav.* = average value of flow module for the territory under study.

F_{cor} = correlation criterion or maximum area of water catchment regulated by a monitoring hydrologic post, where a positive correlation of flow is possible, which is derived using the formula:

$$F_{cor} \leq \sigma_0^{\,4} / (a^2 c_v^{\,4}) \quad (3)$$

where a = the value opposite to radius of spatial correlation of hydrologic characteristics; Cv = annual flow variation index.

F_{repr} – representative criterion or marginally small area of water catchment, which shall fall under one stream flow post in order that the information received from it reflects common zonal regularities of the flow, and not local peculiarities.

The optimum composition of monitoring hydrologic network for a given river basin is assessed by dividing the total area of such river basin by the area of optimum water catchment:

$$N_{opt} = F/F_{opt} \quad (4)$$

Clear scientific justification of the methodology together with the use of geo-information systems allows assessing the value of optimization criteria with a high degree of accuracy and reliability. The necessity for using GIS-technologies in this respect is attributed also to the large area of the region under study and the volume of data to be processed.

Baseline information for the estimates comprised of data on flow module rate (*ml*) and variation coefficient (*Cv*) with discreetness 1° on latitude and longitude for the territory of the European part of Russia. A linear profile of hydrographic system of the European part of Russia was developed in ARCVIEW GIS software, data on type and water content of river objects were entered to the attributive table, length of both main rivers and their feeders was calculated (Figure 1).

GRID-profile with 13 km interpolation span and fixed radius was developed based on flow module. Deterministic method of weighted distances (IDW) was chosen as the method of interpolation, and the field of the characteristics under study was classified by the degree of escalation (Mitchell 1999). In a similar way a raster-vector image was achieved also for variation coefficient (Figure 2).

The final stage of the work was hydrologic zoning of the territory under study and estimating of both main hydrologic characteristics and hydrologic network optimization criteria themselves. On the territory of the European part of Russia, the biggest river basins have been delineated and subdivided into regions depending on their attachment to a specific hydrologic zone. River systems are divided into groups depending on their length (Figure 3).

Landfill areas have been defined, average regional static characteristics have been estimated with the help of Spatial Analyst module. On the basis of this work, hydrologic network optimization criteria have been estimated for 13 regions. The transition from linear measurements to area-based ones was accomplished using empiric formulae:

$$L = 2\sqrt{F}\ ; \ \ l = 0.5L \qquad (5)$$

where F is basin area; L is distance between centers of adjoining basins.

Also, the following assumptions have been made n the estimates: error of flow rate definition $\sigma = 0.05$, radius of annual flow correlation 1600 km. The optimum water catchment area closed by a hydrologic post is chosen based on the equation (1) taking into account the differentiation of optimum areas depending on the order of hydrologic characteristics distribution moment.

RESULTS

Analysis of the estimated results brings about the following conclusions:

- Gradient criteria necessary to get representative information about spatial-time changes of the first moment of annual flow distribution (*Fgrad*) do not differ much within one hydrologic zone, but show a clear tendency of a decrease in north-south direction (Table 1).
- Correlation criterion reaches minimum values in semi-desert regions of don and volga rivers, maximum values fall at Pechora region (tundra).
- *Fgrad* and *Fcor* are not maintained for zones of maximum instability of water regime (semi-desert and desert regions of Don and Volga rivers), as they are kept within the range of 200 to 600 km^2, which does not help achieving zonal values of flow. Therefore, *Fopt* was taken as equal to *Frepr* for these regions.
- Estimated number of hydrologic posts in zones with inert hydrologic regime (kama/forest, pechora/ forest) underperforms as compared to the actual number existing to date. At the same time, the number of existing hydrologic points in zones of unstable flow regime (steppe part of Volga and Don river basins) is surely not sufficient for describing of flow formation processes

Thus, using GIS-technologies in the optimization of monitoring objects in the sphere of natural resource management allows not only representing massive data in the form of thematic electronic maps, but also makes it possible to analyze distribution, correlations and tendencies of spatial-time characteristics of the territories under study. However, in the process of work we faced some difficulties related to allocation of hydrological regions for further use of optimization criteria. A general rule of thumb states that only in case of homogeneous (in terms of conditions of flow formation) hydrologic regions it is possible to get specific results. Therefore, at

Table 1. Values of optimum areas and estimated number of flow posts

River basin / hydrologic zone	Basin area, km^2	*Fgrad*t.km^2	*Fcor*, t.km^2	*Fopt*, km^2	***Nopt.***	***Nf***
Don /semi-desert	180,392	14.24	31.36	3000	60	60
Don / steppe	378,000	299.85	122.39	1500	252	203
Kama / forest	250,000	259.78	9130.56	4695	27	60
Oka / forest	120,000	1257.62	2265.30	1761	53	27
Oka / steppe	125,000	936.39	1789.53	1362	70	56
Onega / forest	41,400	2466.94	1488.32	1977.63	17	11
Pechora / tundra	80,789	1694.61	100243	5096	1	-
Pechora / forest	259,000	1204	45685.2	23444	6	39
Western Dvina/forest	81,000	1745.93	1956.97	1851	41	63
Western Dvina / forest	357,000	1340.67	6955.74	4148	51	97
Volga / forest	479,000	1071.50	3106.19	2088.85	154	213
Volga / steppe	741,000	296.30	395.43	1500	494	202
Volga / semi-desert	101,638	49.25	17.64	3000	34	34

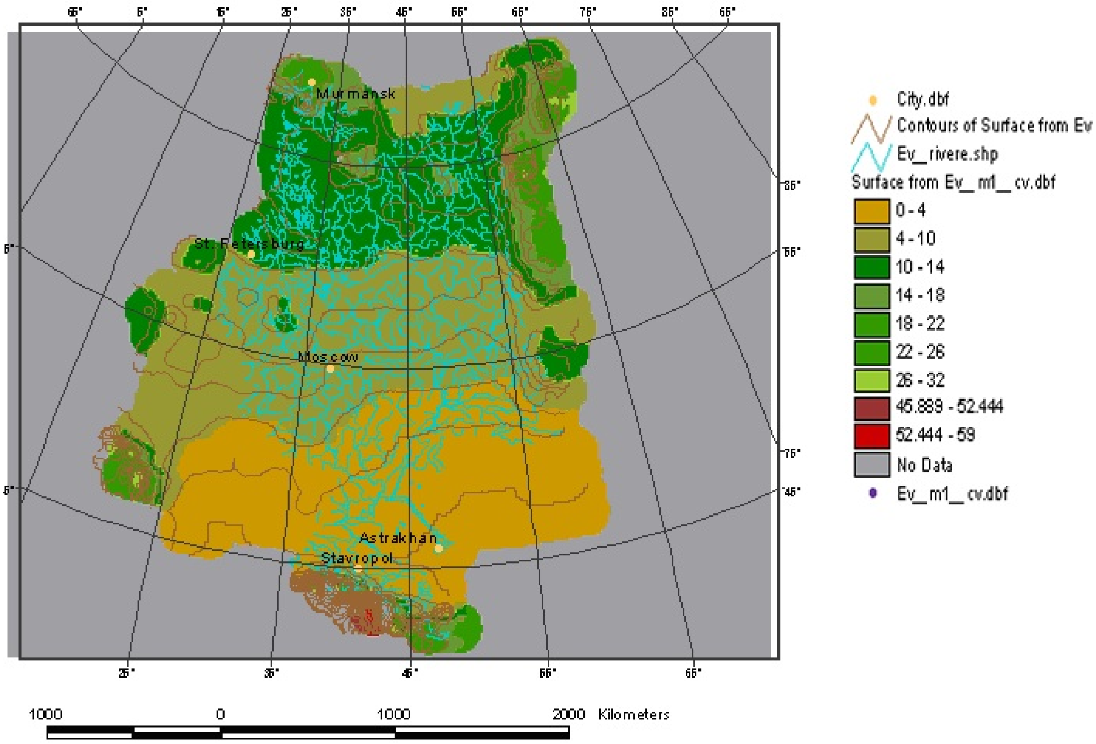

Figure 1 Map of flow module isolines.

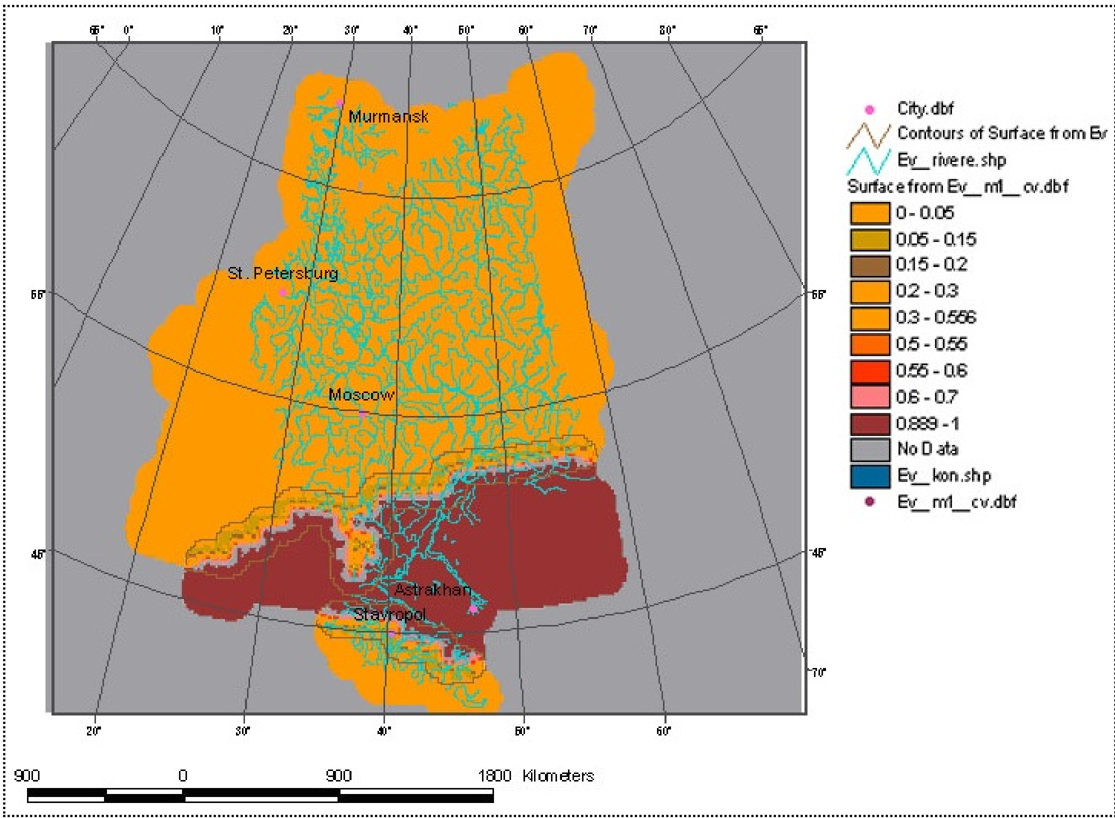

Figure 2. Map of variation coefficient isolines

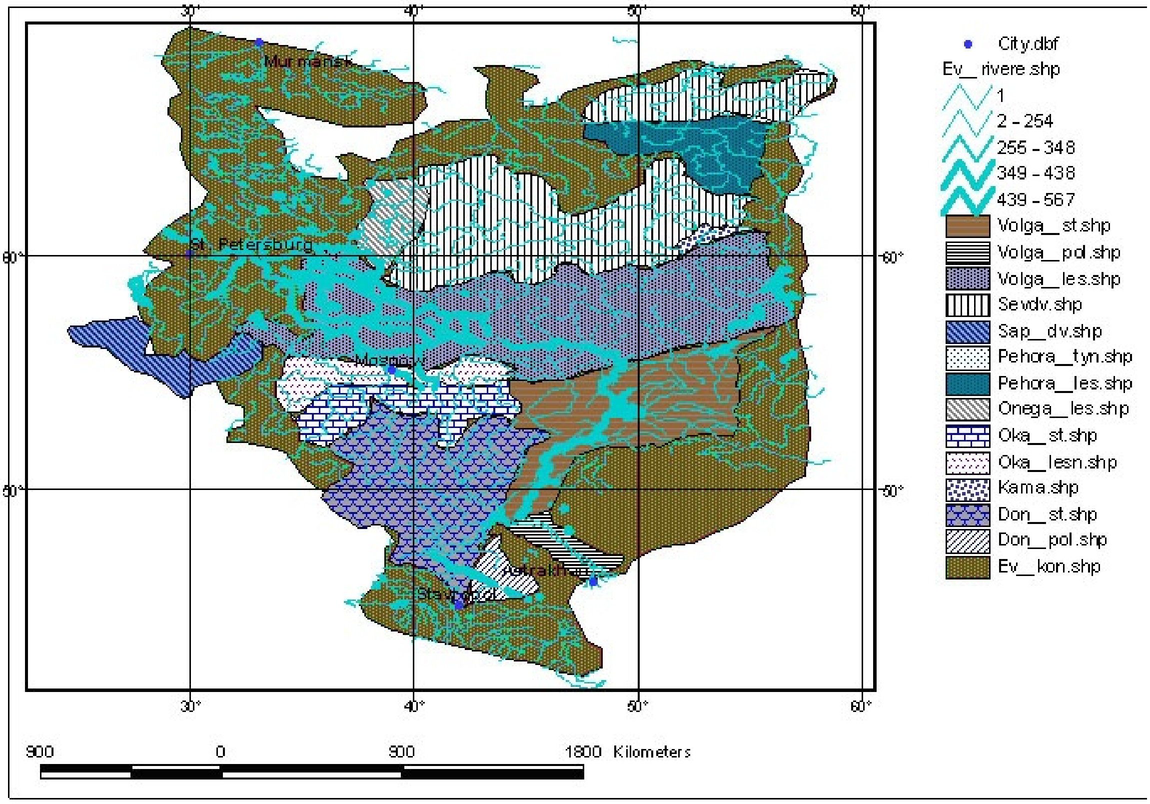

Figure 3. River basins

the next stage of our work we suggest carrying out an initial assessment of homogeneity of hydrologic regions, and only after that – estimating optimization criteria and validating the number of hydrologic posts on the area under study (Pivovarova and Danilov 2012). It is planned to develop a software application that would allow making conclu-sions about homogeneity of a given natural object quickly and with a minimum error probability depending on differentiation of spatial-correlation functions of the characteristics under study.

The results of the present study do not claim any of the recommendations to reduce or increase the population of the hydrological network but the General guidelines and existing trends in the system of organi-zation of complex supervision over a condition of water bodies are marked. The possibility of using GIS-technologies in the methodology of optimization of the hydrological network is tested on the factual material for the purpose of receiving of representative and reliable hydrologic data, and as a result, decreasing uncertainty of hydrologic forecasts, provision of information nece-ssary for planning tasks, making decisions and operative management of water resources.

In conclusion, it is important to note that tools and methods of the research are fully compliant with United Nations' recommendations related to the strategic approach to monitoring and assessment of rivers, lakes and ground waters: "Transformation of data into information stipulates their analysis and interpretation. In particular, complex data management stipulates a reference to simulation models and GIS. It is recommended to use a software customized to specific conditions" (UNECE 2006).

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