Performance assessment of groundwater drainage basin in small-sized mountain rivers based on DTM

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Abstract. The paper describes the performance assessment methods for groundwater drainage basin based on the analysis of morphometric indices of small-sized mountain river drainage basins. DTM was applied to analyze morphometric indices of drainage basins.

1. Introduction

Performance assessment of groundwater drainage basin is commonly used to solving the problems associated with mineral resource management: water supply provision due to groundwater utilization, water inflow calculations in mining, water-base ecological problem- solving. Existing drainage assessment methods are predominately based on either hydrometric data analysis obtained from systematic observations (methods based on the separation of runoff hydrographs) or synchronous measurements of river drainage conducted during independent groundwater regimes, i.e. when the river drainage develops due to separation of groundwater flow [4]. Obtaining such data within field experiments requires significant material expenses. However, theoretical approach in estimating the groundwater drainage values has been attracting the attention of numerous scientists [[3], [5]]. In this respect, the methods assessing groundwater drainage is based on mapping involving minimum volume of field experimental data. Today this is of specific interest.

The investigated area is located in northern Kuznetsk Alatau. The authors proposed a method in studying the mountain groundwater drainage basins within this area. Such areas are considered to be a problematic site due to poor hydrogeological exploration.

Solution of this problem involves factual material harvesting, performance assessment of groundwater drainage, analysis identifying their environmental factors and morphometric dependency via DTM.

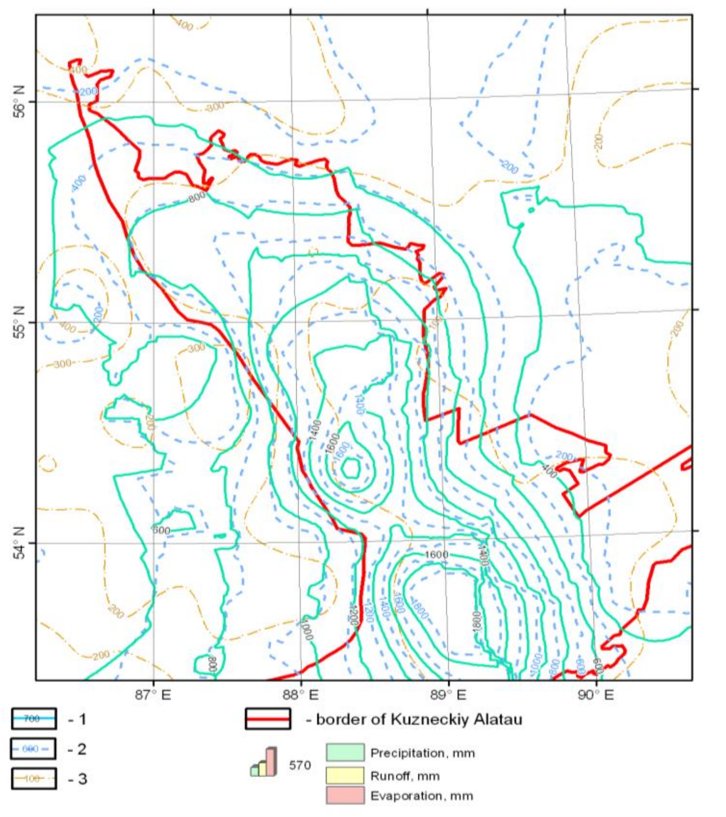
2. Materials and methods

Factual data, being background experimental data, includes meteorological data and information on average monthly river discharge from 10 hydrometric stations (Roshydromet) within an observation period (1030-2014), as well as terrain altitude survey data produced within the framework of SRTM program [6].

The investigation involves two basic trends- hydrological and morphometric, which, in its turn, embraces data analysis phase and presentation of obtained results.

Hydrogeological investigation included spatial water balance assessment (spatial variability of rainfall and evaporation), as well as assessing drainage via the method of separation of runoff hydrographs.

The location of hydrometric stations and basic water balance elements are depicted in Figure 1. The water balance assessment of major drainage basins within this area was based on the rainfall-evaporation data from Roshydromet.



1 – precipitation; 2 – runoff; 3 – evaporation.
Figure 1. Map of water balance elements.

Rainfall supplying groundwater recharge is one of the basic factors in generating groundwater runoff and their variability within the investigated area ranges from 400 to 1800mm/year. The rainfall variability within this area is distinguished by pronounced vertical zonation, characterizing regularly upbuilding of layers with increasing absolute relief elevation. Low rainfall occurs in areas with absolute elevation of more than 700m. Atmosphere circulation influences the distribution of rainfall throughout the territory. Local distribution of rainfall volume is predominately determined by the landscape features. Slope exposure is of significant importance in this process, especially in the winter months.

Evaporation plays a prominent role in the water balance of this area. Based on Roshydrometa observation network data it has been established that the investigation area has one and the same specific feature typical for all mountain areas-regular evaporation discharge distribution pattern i.e. decreasing discharge to height. It varies from 200-300mm/year in basins and foothills to 50-100mm/year in investigated mountain area; whereas the most significant evaporation discharge decrease (averagely, up to 100mm/year) is observed in the height interval from 200-300 to 1000m.

Separation of runoff hydrograph method for rivers is based on the classical approach proposed by B.I. Kulelin [4]. Separation of runoff hydrograph differentiates surface and underground gathering zones. However, based on the different research data [3], the groundwater recharge in significantly large rivers embraces ground and deep water zones (where ground water runoff increases due to the inflow of deep groundwater). Practically, this method is implemented by Visual Basic for Application. A more detailed description of runoff rate assessment can be found in previous research papers [1].

Morphometric survey based on DTM data includes data acquisition and further analysis of relevant characteristic features of river networks and drainage basins. Obtained numerical morphometric parameter values are applied in identifying the characteristic groundwater runoff- numerical relief characteristic relation.

GIS Ilwis [10] was applied in the investigated area. The results involved morphometric parameter values of rivers and drainage basins, including 12 thousand river drainage divide ratios within the investigated area. Based on this data it was possible to conduct an integrated analysis of the morphometric river network parameter values, plotting datum surface and other morphometric survey.

Data analysis implementation of river valleys and river drainage basins and determination of their morphometric parameters was performed via GIS ArcGIS 9.3 and Ilwis 3.5 on digital topographic base and comparable to map scale 1:50000.

Morphometric drainage basin parameters were obtained by standard hydrological analysis methods of DTM within the framework of Ilwis. The following morphometric parameters were obtained- area size and perimeter, minimum and maximum relief elevation within drainage basin, above and average basin altitude, as well as length of major streams and their slope. All in all, more than 2500 small river drainage basins located within 10 base drainage basins were described. Detailed morphometric survey was described in [2]. The final investigation stage (after analyzing climatic, morphometic and hydrogeologic data) included statistical analysis to identify the significant factors determining the formation of groundwater runoff within the investigated area.

Based on the multiple linear regression (MLR) method a simulation model was designed which numerically describes the relation of the modification of groundwater runoff rate to total relevant governing factors.

3. Results and Discussion

The major morphometric factors determining the hydrogeological features of the investigated area are the geomorphological conditions and hyposographical location of river drainage basins. The most distinctive one is the total and surface runoff rate – hyposographical elevation of drainage basin relation. Hydrogeologically, the role of rivers in the investigated area is only the draining of different igneous, sedimentary and metamorphic rocks of various ages.

Numerous domestic and foreign scientist have also described similar approaches in identifying the interrelation between drainage basin parameters with river runoff parameters [7, 8, 9]. We as authors, propose a more detailed and integrated approach in assessing the factors determining the formation of groundwater runoff.

Interrelated bound between the relief parameters and modification of flow has been determined by correlation analysis (Table 1). All modification parameters of flow show a positive relation to datum surface slope, while negative – drainage basin area.

Table 1. Pair correlation coefficients: modification of flow to morphometric drainage basin parameters.

Drainage module	Area	Perimeter	Drain length	Relief elevation			Draining zone capacity	Slope
				Minimum	Maximum	Average		
$M_{\mathbf{riv.}}$	**–0.61**	–0.50	–0.46	**–0.75**	–0.23	**–0.52**	–0.06	**0.65**
$M_{\mathbf{surf}}$	**–0.60**	–0.49	–0.46	**–0.79**	–0.26	**–0.58**	–0.08	**0.61**
$M_{\mathbf{und.}}$	**–0.58**	–0.49	–0.45	**–0.52**	–0.07	–0.23	0.06	**0.76**
$M_{\mathbf{deep\ und.}}$	**–0.53**	–0.47	–0.48	–0.41	–0.16	–0.20	–0.07	**0.71**

Modification of groundwater runoff rate shows the most close relation to the slopes (pair correlation coefficients 0.71–0.76).

$M_{\mathbf{riv.}}$–river runoff module; $M_{\mathbf{surf}}$ - surface river runoff component module; $M_{\mathbf{und.}}$– underground river runoff component module; $M_{\mathbf{deep\ und.}}$ – deep fraction in underground river runoff component module. Significant correlation coefficients were identified for 0.10 significance level.

Parameters characterizing the formation of underground run-off with the involvement of multiple linear regression (MLR) method could be combined into one equation. A series of similar regression equations, describing the underground run-off dependency in different draining levels to governing morphometric parameters was obtained on the basis of data from detailed investigated areas (Tsentralninsk granitoid massif). An extended equation, including both morphometric features of the area and climatic and hydrogeological factors was applied in the case of Kuznetsk Altai:

$M = -2.24 - 3.26PDOL + 0.000113DLP - 0.00128S - 0.00804H_{max} - 0.00721dH + 34.0UKL + 0.00582Os$, where PDOL – valley sequence; DLP – drain length m.; Hmin – height of emerging spring, m; Hmax – height of accumulation area, m; dH – thickness of draining zone, m; HIR – width of stream, m; UKL – slope; S – area of drainage basin, km²; Os – rainfall mm., at $R2=0.71$; $N=46$

Based on obtained dependency detailed areal assessment of subsurface water flow rate was conducted within the limits of elementary drainage basins by morphometric parameter substitution. In this case groundwater run-off level for investigated areas could be assessed, as well those hydrometric stations which have not been included.

Based on the generalization of obtained values, numerical run-off parameters were calculated, which could characterize the water exchange intensity at different draining levels of groundwater by relevant river ordering. Based on obtained data of subsurface water flow rate by IDW method and ArcGIS the following map was plotted, reflecting the distribution of subsurface water flow rate (Figure 2).

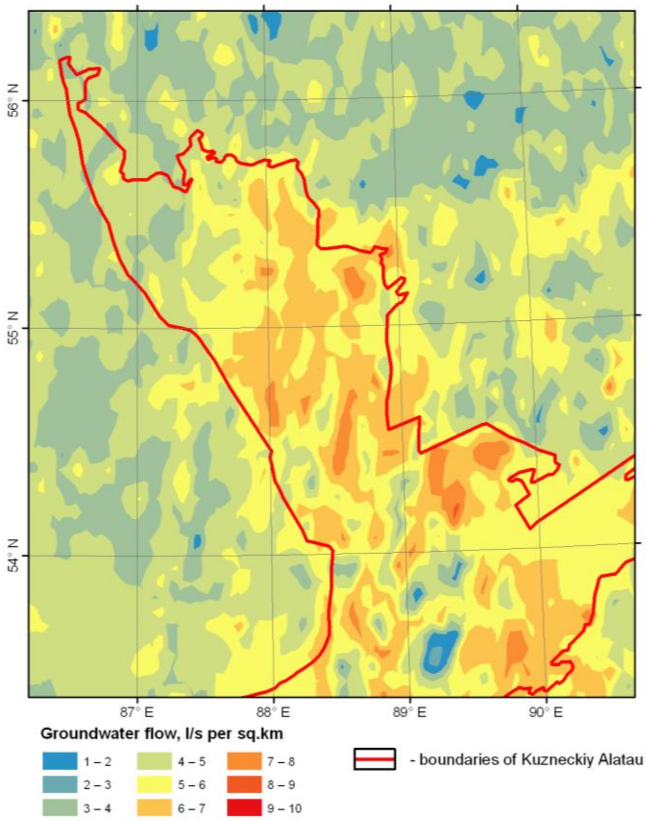


Figure 2. Map of subsurface water flow rate.

Obtained results show the changes of subsurface water flow rate to drain depth: from valley of 2nd ordering to valley of 6th ordering the water exchange slows down characterizing decreasing run-off rate from 12 liter/sec.·km^2 to 5-6 liter/sec.·km^2 within the most elevated areas of investigated territory.

4. Conclusions

The main investigation results are the integrated methodological approaches in obtaining numerical parameters of groundwater run-off for small-sized river drainage basins of mountain regions. The investigation methods are based on an integrated approach applied in classical, hydrological and hydrogeological surveys in combination with up-dated processing equipment and analysis of spatial geodata. As a result of data processing map documents were compiled providing a detailed description of the spatial distribution of different morphometric parameters within the investigated area and further analysis of the quantitative distribution of groundwater resources.

The proposed method could be the base for detailed investigation of the quality and quantity parameters of water resources in mountain regions. This, in its turn, could optimize water resources management and water consumption, predict the possible quality changes of water resources after different technogenic effects and further hydrogeochemical exoloration of mineral deposits. Investigation results are illustrated as map material.

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