

ASSESSMENT OF WATER RESOURCES IN
NAKHCHIVANCHAY RIVER BASIN USING RUNOFF
COEFFICIENTS METHOD

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Abstract

The article proposes a new method for assessing the water resources of river basins. The essence of the proposed assessment with Runoff Coefficients Method (RCM) is the principle of estimating river water resources using runoff coefficients that take into account the influence of complex runoff-forming factors. Runoff coefficients are values that reflect the level of atmospheric precipitation formation into surface runoff under specific physical-geographical conditions. The main goal of applying new method was to transform the inter-component natural regularities into a quantitative form and use this approach to estimate the water resources of the territory. Research using the RCM method is carried out based on the principle of “maximum information, minimum dependence”. Thus, the assessment of water resources is fulfilled more efficiently and reliably by taking into account the data of most factors affecting the rivers runoff formation to the maximum extent, through the application of space information and fast GIS technologies. At the same time, dependence on observation data, spatial-temporal limitations, and difficulties associated with physical contact with the area are minimized. Advantages of the RCM can be used to solve most water-related problems. The water resources of the Nakhchivanchay river, given as an example in the article, were estimated at $6.805 \text{ m}^3/\text{s}$ (214.36 million m^3) using RCM. There was a very small difference between the actual gauged data of the river and the volume assessed by the new method (233.8 million m^3) and it amounted to only 8.31%.

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Key words: water resources, hydrological units, runoff coefficients method, rational method, SCS-CN method, analogue terrains method

Introduction. Water resources assessment has always been one of the scientific problems that has been the focus of hydrological research [1]. Their depletion is not only accompanied by a slowdown in sustainable economic development and reforms, but also threatens the existence of humanity as a whole [2]. Therefore, monitoring changes in natural complexes, including water resource volumes, against the background of global changes should become a priority area of modern hydrological science. However, the pace of scientific research development on water resources often lags behind the dynamic development of scientific-technical innovations and the economy. The main reasons for this are the lack of dense hydrometeorological observed stations and research methods that adequately respond to reforms. It is impossible to fully assess the water resources of river basins as a whole based on existing observation data. On the other hand, the establishment of a new network of numerous hydrometeorological stations can lead to additional financial costs, loss of time, and even greater delays compared to reforms. In order to overcome the existing shortcomings, research methods that serve the principle of more modern and operational assessment are currently being applied in the field of water resources assessment around the world [3–5].

Taking into account the trend observed in world science and the serious need for continuous assessment of water resources, we have proposed a novel hydrological method (RCM-Runoff Coefficients Method).

The main objective of this article is to highlight the scientific advantages and significance of the RCM method. The application of this method can yield highly effective results in addressing various water-related issues, particularly in the integrated management of water resources and in assessing river runoff based on the "basin principle". Moreover, the RCM method enables a more operational and reliable assessment of water resources, even in the absence of observational data and without spatial or temporal limitations. This capability is of critical importance today, given its vital socio-economic relevance.

Materials and methods. Nakhchivanchay is the largest river located in the Nakhchivan Autonomous Republic of Azerbaijan. This river, distinguished by its diverse physical-geographical conditions, is 81 km long and has a basin area of 1624.1 km² (Fig. 1).

Satellite images, digital elevation model (DEM) and hydrometeorological observation data from 1999–2024 were used as input research materials. Fragments of Landsat-7 ETM+ and Landsat-8 OLI/TIRS multispectral satellite images were applied to obtain various landscape types (LULC), soil cover, vegetation density and moisture conditions of the territory. Considering the content of the study, priority was given to indices for vegetation (NDVI), bare soil (BSI), residential areas (NDBI), water (NDWI), and moisture (NDMI)).



Fig. 1. View of the study area over the Republic of Azerbaijan

The hypsometric indicators of the area (elevation, slope degree, aspect, etc.) were studied using a digital elevation model (DEM). The restoration of hydrometeorological data in areas where observations were not made was carried out using modern Interpolation and Analogue terrains methods, and Counter-approach technology [6, 7].

The essence of the RCM-based assessment we propose lies in evaluating water resources using runoff coefficients that account for the combined influence of complex runoff-forming factors. In the research process, we have accepted runoff coefficients as a hydrological unit (hydrological code). The use of such hydrological units for assessment has a long-standing tradition in hydrological science.

The principle of hydrological coding is based on the fact that as a result of a comprehensive analysis of the territory, hydrological units are determined, and these criteria are considered acceptable for other regions with similar natural conditions where there is no observational data. So far, a number of hydrological units have been used (rational coefficients, curve numbers, hydrological soil codes, etc.). In this regard, the Rational method, the SCS-CN method and the hydrological units applied in them (rational coefficients and curve numbers) are the most actively used criteria.

When determining rational coefficients, various LULC (landscapes), slope degree and Hydrological soil groups (HSGs) were taken into account.

The Rational Method is expressed by the following equation [8]:

$$(1) \quad Q = k \times ciA,$$

where: Q is the river discharge (m^3/s), i is the precipitation amount (mm), A is the catchment area (km^2), c is the runoff (rational) coefficient, k is the conversion factor used to express the result in m^3/s from the original units ($k = 0.0000314$).

LULC (Land-use & Land cover) is the sum of natural and anthropogenic landscapes characterizing the general view of the surface cover of the territory.

Hydrologic Soil Groups (HSGs) is a classification division that indicates ability of soils to generate surface runoff and infiltration, depending on their granulometric composition. According to the USDA and NRCS classification 4 HSGs (A, B, C, D) are distinguished [9].

The most widely used hydrological units in hydrology are the runoff curve numbers (CN) [10,11].

Hydrological units were originally applied to estimate runoff volume in local areas and only during rainfall events. However, these methods are now being used in a wider range of applications, through internal modification and synthesis with other methods, beyond their original scope [12–14].

Results and discussion. The rainfall-flow mechanism, formation of the rivers runoff is a very complex process and there are many factors affecting it. Studies show that including more factors in the assessment process further increases the accuracy of the results obtained. Therefore, the study process took into account the influence of most of the components that shape river flow. Our main goal was to estimate the water resources by converting natural regularities between components into quantitative form. Each component that makes up the river basin has a unique role in the runoff formation. We have divided the runoff-forming factors into relatively stable (slow-changing) and fast-changing components. Slow-changing components include the hypsometric and geomorphological components (average elevation and slope degree, aspects, basin area, rivers length, horizontal and vertical fragmentation of basin surface, river network density, etc.). The active and decisive influence on rivers water resources is exerted by fast-changing factors. These include climate and humidity indicators (temperature, precipitation, evaporation, humidity coefficient, actual soil moisture and maximum soil water retention, etc.), landscape types (LULC), plant and soil cover, soils granular composition and HSG.

In order to estimate the runoff coefficients, first, observation data of hydrometeorological stations are collected. Information about other components is determined using space information and DEM model of the area. The moisture level is assessed by the humidity coefficient. Low (≤ 0.3), medium (0.3–0.8), and high (≥ 0.8) humidity coefficient indicators are determined. The collected data on runoff, climate and other physical-geographical components are entered into the ArcGIS database, combined and reclassified. Each different combination of runoff-forming components results in a quantitatively different runoff coefficient. As an example, Table 1 shows the changes in annual runoff coefficients for combinations of important runoff factors and corresponding to their different classifications for areas located within some selected LULC types.

The assessment process was carried out on up to 120 river basins of Azerbaijan, with different physical-geographical conditions and sizes. The approbation of the RCM method has been highly justified. The error between actual observation data and runoff coefficients found through the RCM was up to 10% in 94 cases,

T a b l e 1

Changes of runoff coefficients under impacts of various runoff-forming factors

Moisture level	Hydrological soil groups (HSGs)					
	HSG “B”			HSG “C”		
	Slope degree, %					
	≤ 6	6–15	≥ 15	≤ 6	6–15	≥ 15
	Subalpine and alpine meadows					
high	0.39	0.45	0.50	0.46	0.52	0.56
average	0.34	0.38	0.43	0.43	0.45	0.48
low	0.14	0.17	0.21	0.16	0.20	0.26
	Cultivated areas					
high	0.13	0.15	0.18	0.16	0.19	0.24
average	0.05	0.065	0.10	0.055	0.08	0.11
low	0.02	0.04	0.065	0.03	0.055	0.075
	Residential areas (settlement 65%)					
high	0.44	0.47	0.52	0.46	0.51	0.55
average	0.28	0.36	0.41	0.32	0.39	0.45
low	0.19	0.23	0.28	0.22	0.26	0.32

and in the remaining cases in the range of 10–15%.

As an example, the process of assessing water resources of the Nakhchivanchay river basin using the RCM is given below. Study period covers the years 1999–2024. Mapping of some runoff factors using ArcGIS based on hydrometeorological data and satellite images is shown in Fig. 2.

The average indicators of the most important factors determining climate and humidity regime gave the following results: temperature – 10.52 °C, precipitation – 467.1 mm, potential evaporation – 837.5 mm, actual evaporation – 333.6, humidity coefficient – 0.56, runoff layer – 133.5 mm, actual soil moisture – 223.6 mm, maximum water retention – 732.4 mm.

As we have mentioned, it is possible to estimate water resources for any area without spatial-temporal limitations using the RCM. Table 2 reflects the process of assessing water resources for the Nakhchivanchay river basin in areas where various landscape (LULC) types are distributed. The calculations were made separately for areas where each LULC type is distributed, and by summing them, the total water resources of the river basin were determined.

Conclusion. The RCM proposed in the article includes most of the advantages provided in modern hydrological methods. The assessment with the new method is distinguished by its high accuracy, as it is carried out using modern scientific approaches, reliable data (space information) and GIS technologies. The volume of water resources assessed by the RCM of the Nakhchivanchay river basin,

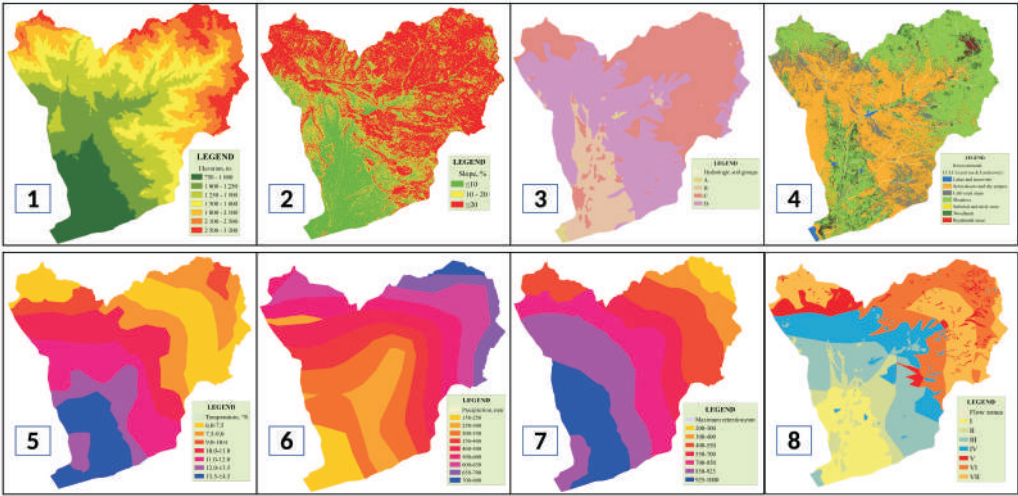


Fig. 2. Maps of runoff coefficients and some runoff-forming factors:
1 – Elevation; 2 – Slope; 3 – HSGs; 4 – LULC (Landscapes); 5 – Temperature; 6 – Precipitation;
7 – Maximum retention; 8 – Flow zones

T a b l e 2

Assessment progress of water resources of the Nakhchivanchay basin

LULC	Area, A , km^2	Runoff coefficients, c	Precipitation, i , mm	Water discharge, Q , m^3/s
Meadows	503.1	0.5302	502.4	4.208
Cultivated areas	318.2	0.0759	318.5	0.241
Woodlands	88.83	0.3392	583.9	0.552
Semi-deserts & dry steppes	612.9	0.1740	346.2	1.159
Water bodies	8.71	0.1903	472.1	0.0245
Subnival & nival areas	35.23	0.6809	637.6	0.480
Residential areas	57.17	0.1874	419.7	0.141
Nakhchivanchay basin	1624.1	0.2857	467.1	6.805

which is the study area, also proves this. Thus, average annual flow coefficient of the rivers in the basin for the period up to 2024 was $c = 0.2857$. River water discharge (Q) estimated by the Rational formula (1) was $6.805 \text{ m}^3/\text{s}$.

REFERENCES

[1] VÖRÖSMARTY C. J., P. B. MCINTYRE, M. O. GESSNER et al. (2010) Global threats to human water security and river biodiversity, *Nature*, **467**(7315), 555–561.

- [2] GLEICK P. H. (2014) Water, drought, climate change, and conflict in Syria, *Weather, climate, and society*, **6**(3), 331–340.
- [3] CHIN D. A. (2023) The Curve Number Method in the 21st Century, *Journal of Irrigation and Drainage Engineering*, **149**(6), <https://doi.org/10.1061/JIDEDH.IRENG-10108>.
- [4] MAKHMUDOV R., V. ALIYEV, M. TEYMUROV, E. GAFAROV (2023) Assessment of the water balance of the territory and rivers water resources using a new operational-interactive method, *Reliability: Theory & Applications*, **18**(SI 5 (75)), 500–509.
- [5] JABRAYILOV E. A. (2022) Monitoring of fragile ecosystems with spectral indices using Sentinel-2A MSI data in Shahdagh National Park, *Geography Environment Sustainability*, **15**(1), 70–77.
- [6] MAKHMUDOV R., M. TEYMUROV (2024) Importance of using GIS software in the process of application of Analogue terrains and Counter-approach technologies in water resources assessment, *Advanced Remote Sensing*, **4**(1), 36–45.
- [7] LEMMA T. M., G. D. GESSESSE, A. K. KASSA, D. C. EDOSSA (2018) Effect of spatial scale on runoff coefficient: Evidence from the Ethiopian highlands, *International Soil and Water Conservation Research*, **6**(4), 289–296.
- [8] BURRA S., V. KANNALA, S. MENON (2021) Runoff estimation by using rational method: A review, *International Journal of Applied and Natural Sciences (IJANS)*, **10**(1), 33–36.
- [9] USDA & NRCS (United States Department of Agriculture & Natural Resources Conservation Service) (2009) Part 630, Hydrology, Hydrologic Soil Groups.
- [10] MOGLEN G. E., H. M. SADEQ, L. H. HUGHES et al. (2022) NRCS curve number method: comparison of methods for estimating the curve number from rainfall-runoff data, *Journal of Hydrologic Engineering*, **27**(10), [https://doi.org/10.1061/\(ASCE\)HE.1943-5584.0002210](https://doi.org/10.1061/(ASCE)HE.1943-5584.0002210).
- [11] ZHANG W. Y. (2019) Application of NRCS-CN method for estimation of watershed runoff and disaster risk, *Geomatics, Natural Hazards and Risk*, **10**(1), 2220–2238.
- [12] LI B., T. SUN, F. TIAN et al. (2024) Hybrid hydrological modeling for large alpine basins: a semi-distributed approach, *Hydrol. Earth Syst. Sci.*, **28**(20), 4521–4538.
- [13] WANG X., T. LIU, W. YANG (2012) Development of a robust runoff-prediction model by fusing the rational equation and a modified SCS-CN method, *Hydrological Sciences Journal*, **57**(6), 1118–1140.
- [14] MAO W., J. YANG, Y. ZHU et al. (2018) An efficient soil water balance model based on hybrid numerical and statistical methods, *Journal of Hydrology*, **559**, 721–735.

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