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THE INFLUENCE OF LAND COVER AND GEOLOGICAL STRUCTURE ON THE NATURAL REGULATION OF RIVER RUNOFF

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Background. In arid and semi-arid regions like the Karabakh region of Azerbaijan, the efficient management of scarce water resources is critically dependent on the natural regulation of river runoff. This process, which ensures a more balanced intra-annual distribution of water, is traditionally understood to be influenced by climate and surface cover. However, the specific role of underlying geological structures has often been assessed only indirectly, presenting a significant research challenge. This study investigates the impact of both geological formations and surface cover characteristics on the natural runoff regulation of rivers from 1999 to 2024, a period marked by climatic changes and significant landscape alterations.

Methods. An integrated approach combining hydrometeorological data, remote sensing, and GIS technologies was employed. The study utilized long-term climate data (precipitation, temperature, etc.), satellite imagery (Landsat), and a digital elevation model. Key methodologies included the application of the NRCS-CN (Natural Resources Conservation Service Curve Number) method and the calculation of a "natural regulation ratio" (NRR), defined as the ratio of baseflow (Q_b) to surface runoff (Q_s). Hydrologic Soil Groups (HSGs) and various indices (NDVI for vegetation cover, BSI for bare soil) were analyzed to characterize land use/land cover (LULC) and its changes. The analysis focused on comparing river basins with similar climatic and morphometric characteristics but differing geologies.

Results. The study confirmed that geological structure is a key factor in the rivers feeding. Rivers flowing through the highly water permeable, fractured volcanic rocks of the Karabakh Plateau exhibited high NRR values (often above 1.0), with baseflow (groundwater flow shares) exceeding 50 %. In contrast, rivers in the south, underlain by impermeable rocks, showed very low NRR, with surface runoff dominating (70–90 % of rivers total flow). Overall, the regional average NRR was 0.97, indicating a near-equal balance between surface and subsurface flow sources. However, a negative trend was observed: over the 25-year period, landscape changes driven by aridification and reduced vegetation cover led to surface consolidation. This caused a 11.4 % decrease in initial abstraction parameter (flow-forming potential of precipitation) and a 4.79 % decline in the regional NRR, signaling a reduction in natural regulatory capacity.

Conclusions. The findings conclusively demonstrate that the geological foundation is a decisive controller on the natural regulation of river flow in arid regions. The presence of fractured, permeable rocks facilitates high infiltration and substantial subsurface flow, creating a natural reservoir that ensures water availability during dry periods. Consequently, assessing the geological context is essential for effective water resource management planning. The identified decline in the natural regulation ratio underscores the vulnerability of these water systems to ongoing climate change and land degradation. For rivers with inherently low regulation, artificial measures like reservoir construction remain necessary. This study provides a critical framework for prioritizing water management strategies based on a basin's specific hydro-geological characteristics.

Keywords: geological structure, land cover, river runoff regulation, baseflow, infiltration rate, initial abstraction.

Background

Global climate change and anthropogenic pressures are leading to a progressive decline in the world's freshwater resources (Mishra, 2023; Sivakumar, 2011). This necessitates more efficient utilization and continuous assessment of these vital supplies. A more acute reduction in river water resources is observed in arid and semi-arid regions (Wang et al., 2024), including the Republic of Azerbaijan, where river flow constitutes the primary source of water reserves. In arid regions, the scarcity of water is compounded by the intra-annual uneven distribution of river discharge, which creates additional challenges (El Kenawy, 2024). For instance, during the spring months when rivers experience their highest discharge, water demand is relatively low, and a significant volume of water often flows unused without being stored. Conversely, the peak water demand occurs during the summer irrigation season.

However, during this critical period, water scarcity emerges in the majority of rivers, with many even drying up completely (Ministry of Ecology of Azerbaijan, 2021). Therefore, the regulation of river flow is of paramount importance for the integrated management of water resources (Ciampittiello, Marchetto, & Boggero, 2024).

The regulation of river flow, meaning the relatively even distribution of discharge throughout the year, is a very important factor for the efficient use of their resources (Nilsson et al., 2005). In Azerbaijan, the most extensive consumer sector for river water is agriculture. Approximately 70–75 % of river water is used for irrigation farming. However, during the intensive irrigation period (June–August), only a small portion (15–21 %) of the annual flow of most rivers occurs. In the spring months, a much larger share of the flow, often 25–45 %, is utilized. Another negative trend observed over the last 20 years is the overall

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decrease in precipitation and runoff during the warm months (spring–summer) by up to 2.5–4 % relative to the annual indicator (Makhmudov et al., 2024).

Consequently, a significant disparity arises between river discharge and water demand during the consumption period in arid regions. This necessitates additional interventions to regulate river flow. The most viable approach for managing river water is the artificial regulation of flow through the construction of on-stream or off-stream reservoirs (Tonkin, & Death, 2014). However, the construction of reservoirs not only requires substantial financial investment but can also lead to land submergence, salinization, and other ecogeographical issues. Therefore, the parallel assessment of the natural regulation of river flow is a highly important procedure from both ecological and economic perspectives.

The primary indicator of natural river flow regulation is a high proportion of groundwater in their recharge (Wang et al., 2015). In rivers predominantly fed by surface waters (rain and snow), the intra-annual distribution of flow exhibits considerable variation. During spring and autumn, when water demand is low, 60–70 % of the river's annual discharge can occur. Furthermore, this flow is primarily formed from surface (rain and snowmelt) sources. Conversely, a higher share of groundwater contribution leads to a more naturally balanced distribution of flow throughout the year. The role of groundwater in river discharge is manifested primarily in its natural regulatory function, whereby it acts as a source of sustenance for the river during dry periods. This creates favorable conditions for the utilization of water resources in arid agricultural regions where water demand is high.

Our research has determined that the geological structure of a territory is a fundamental factor in the natural regulation of river flow. Rivers within basins dominated by fractured and porous rocks exhibit a high degree of natural regulation. Conversely, the impermeability of the surface cover plays a negative role in flow regulation. Specifically, in areas with rich vegetation, the high water retention capacity activates infiltration processes, thereby increasing the natural regulation of the flow. In contrast, climate aridification reduces vegetation density and accelerates land degradation, which in turn increases surface impermeability. Against a backdrop of declining precipitation, this conditions the conversion of rainfall primarily into surface runoff. Consequently, a weakening of infiltration and the natural regulation process is observed.

The assessment of natural flow regulation holds significant economic and ecogeographical importance. It can yield effective results not only for the efficient use of river water resources but also for the preservation of ecological flow, agroclimatology, the determination of irrigation norms, the construction of reservoirs, and other related fields. Monitoring of main environmental components affecting rivers groundwater feeding in the Karabakh region of Azerbaijan allows assessing changes in the volume of water resources and contributes to the prevention of emergencies. The results obtained are also effective in terms of more efficient use of water resources, especially in terms of meeting the needs of irrigated agriculture, which is the main area of water consumption in the Karabakh region.

Methods

The research methodology accounted for the influence of the primary components shaping the land (soil) cover in the study area. Input data were collected from satellite imagery, a digital elevation model (DEM), and hydrometeorological observation data spanning the period 1999–2024. For areas lacking direct observation stations,

climate and river flow data were reconstructed using interpolation, inverse distance weighting, and spatial analogy techniques (Makhmudov, & Teymurov, 2024).

The hypsometric characteristics of the territory – including elevation, slope degree, and aspect – were analyzed using the DEM. Morphometric indicators, such as river lengths, basin areas, flow direction, horizontal and vertical surface fragmentation, and river network density, were derived using the Surface, Density, and Hydrology toolkits within ArcGIS software.

Fragments of Landsat-7 and Landsat-8 multispectral satellite imagery were used to classify different landscape types, soil-vegetation cover, and moisture conditions. Vegetation indices (NDVI, SAVI) and the built-up index (NDBI) were applied to the predominant land use and land cover (LULC) types within the river basin to determine vegetation cover density (Rianti, & Sari, 2024).

Soil cover analysis was conducted by integrating normalized difference soil indices, specifically the Bare Soil Index (BSI) and a normalized difference index for soil erosion (NDBal). These indices are critical for determining the level of soil degradation (Mammadov et al., 2025; Nguyen et al., 2021).

Furthermore, The National Atlas of the Republic of Azerbaijan was referenced for data on the soil's granular composition and the geological structure of the study area (National Atlas of the Republic of Azerbaijan, 2014).

To assess the heat-moisture regime of the area, several indices were analyzed, including the Normalized Difference Water Index (NDWI), the Normalized Difference Moisture Index (NDMI), the Normalized Difference Drought Index (NDDI), and Land Surface Temperature (LST).

The research methodology incorporated the scientific and theoretical foundations of several leading global hydro-pedological methods for studying land cover. Specifically, the Ponce-Shetty, Lvovich, SCS-CN, and Rational methods were employed (Gnann, Woods, & Howden, 2019; Hawkins et al., 2020; Lvovich, 1974; Wang, Liu, & Yang, 2012).

The Rational Method and the NRCS-CN (Natural Resources Conservation Service Curve Number) method are considered among the most popular and effective approaches for assessing soil-water relationships in a given area (Makhmudov et al., 2025).

The Rational Method is widely used to estimate the rate of precipitation conversion into surface runoff. Rational (surface) runoff coefficients are variable quantities, influenced by a range of runoff-forming factors. Key determinants often include precipitation intensity, basin area and slope, various landscape types, and soil infiltration coefficients.

The NRCS-CN method is a fundamental model applied to estimate both surface runoff and infiltration levels. The methodology incorporates several critical parameters for analyzing the influence of an area's geological structure on runoff formation. These include initial abstraction, soil moisture content, maximum soil retention, Hydrologic Soil Groups (HSGs), and other components.

1) Maximum Soil Retention (S , mm) represents the soil's maximum water retention capacity under specific physio-geographical conditions. The relationship between this parameter, precipitation (P , mm), and surface runoff (Q , mm) is expressed as:

$$S = 5 \times [P + 2Q - (4Q^2 + 5PQ)^{1/2}] \quad (1)$$

2) Initial Abstraction (I_a , mm) is the portion of rainfall lost before runoff begins, primarily to soil wetting. In other words, it is the volume of water from a rainfall event consumed by losses such as infiltration, evaporation, interception by

vegetation, and depression storage, which does not contribute to surface flow (Teymurov, 2022). This parameter is functionally related to the maximum retention (S) by:

$$I_a = \lambda S \quad (2)$$

Here, λ is an abstraction coefficient, a variable quantity that is inversely proportional to the antecedent moisture condition.

3) Actual Soil Moisture Content (F , mm) is the actual volume of water stored in the soil under current conditions. It is calculated using the water balance equation:

$$F = P - Q - I_a \quad (3)$$

4) Hydrologic Soil Groups (HSGs) are a classification system that indicates a soil's potential to generate surface runoff based on its infiltration capacity and granular composition. According to the USDA-NRCS classification, soils are categorized into four main groups (A, B, C, D). There is a clear tendency for infiltration rates to decrease and surface runoff potential to increase from group A (lowest runoff potential) to group D (highest runoff potential) (Nielsen, & Hjelmfelt, 1998; Ross et al., 2018).

The study of HSGs within the process of assessing infiltration and flow regulation allows for obtaining more effective and accurate results.

For the delineation of HSGs, the **Soil Texture Triangle** is applied, defining twelve distinct soil codes based on mechanical composition: sand (S), loamy sand (LS), sandy loam (SL), loam (L), silty loam (SiL), silty (Si), sandy clay loam (SCL), clay loam (CL), silty clay loam (SiCL), sandy clay (SC), silty clay (SiC), and clay (C).

Given that infiltration is primarily governed by the relative proportions of sand and clay, their percentages serve as the key transitional criteria between these soil codes and the broader HSGs. The classification is as follows: **Group A:** Sand > 50 %, Clay: 0–10 %; **Group B:** Sand: 20–50 %, Clay: 10–20 %; **Group C:** Sand: 40–60 %, Clay: 20–40 %; **Group D:** Sand: 20–30 %, Clay: 40–60 % (Dewangan et al., 2023).

Table 1 (USDA, & NRCS, 2009) presents key hydrogeological characteristics for the different soil mechanical composition codes according to this classification system.

Another important aspect included in the USDA soil classification is the estimation of the infiltration capacity of soils based on their granular texture, different slope degree, and moisture content (Table 2).

Table 1
Hydrogeological characteristics of hydrologic soil groups (HSGs) (USDA-NRCS classification)

HSGs	Soil codes	Porosity, %	Infiltration level	
			mm/hr	Rate
A	S, LS, SL	43.7–45.3	> 7.62	Very high
B	SiL, L	46.3–50.1	3.81–7.62	High
C	Si, SCL	39.8–48.2	1.27–3.81	Moderate
D	SiCL, CL, SC, SiC, C	43.0–47.9	0.00–1.27	Low

Table 2
Changes in infiltration capacity depending on the granulometric composition of soils

Soil texture types	Percent of slope				
	0–4 %	5–8 %	8–12 %	12–16 %	Over 16 %
	Infiltration rate, inches/hour				
Coarse Sand	1.25	1.00	0.75	0.50	0.31
Medium Sand	1.06	0.85	0.64	0.42	0.27
Fine Sand	0.94	0.75	0.56	0.38	0.24
Loamy Sand	0.88	0.70	0.53	0.35	0.22
Sandy Loam	0.75	0.60	0.45	0.30	0.19
Fine Sandy Loam	0.63	0.50	0.38	0.25	0.16
Loam	0.54	0.43	0.33	0.22	0.14
Silt Loam	0.50	0.40	0.30	0.20	0.13
Silt	0.44	0.35	0.26	0.18	0.11
Sandy Clay	0.31	0.25	0.19	0.12	0.08
Clay Loam	0.25	0.20	0.15	0.10	0.06
Silty Clay	0.19	0.15	0.11	0.08	0.05
Clay	0.13	0.10	0.08	0.05	0.03

Results

Investigating the influence of an area's geological structure on runoff formation is considered one of the most challenging research areas compared to other factors. In traditional studies, the impact of geological structure on the water balance was assessed only indirectly (Rustamov, & Kashkay, 1978). The most original research method for studying this influence involved comparing rivers with

minimal differences in their formative climatic and other physio-geographical factors, as well as the morphometric indicators of their basins, but with significant differences in their flow quantities. A comparison of the flow quantities of two river basins (the Zabukh and Shamkir rivers) located in the Karabakh region, which have approximately similar physio-geographical and morphometric characteristics, was conducted and is presented in Table 3.

Table 3
Comparison of selected physio-geographical and morphometric indicators of the Zabukh and Shamkir Rivers

Rivers	Basin area, km ²	Mean Elevation, m	Precipitation, mm	Evaporation, mm	Forest Cover Coefficient, %	Slope, %
Zabukh	896	1970	670	376	28	47
Shamkir	922	1897	650	374	25	48

As evident from the table, the quantitative indicators of the most important factors influencing runoff formation are similar for both rivers. However, their flow quantities and the proportions of surface and subsurface flow components differ significantly.

The average annual runoff layer was 348 mm for the Zabukh River and 294 mm for the Shamkir River. The extensive distribution of fractured volcanic rocks within the Zabukh River basin has created a substantial disparity in the ratio of its surface-to-subsurface flow components, favoring the latter. Specifically, the subsurface flow contribution was 53 % in the Zabukh River, compared to only 42 % in the Shamkir River. Consequently, the infiltration rate was approximately 45 L/day in the former, compared to just 36 L/day in the latter.

Modern hydrological approaches, combined with the capabilities of remote sensing and GIS technologies, have enabled a more in-depth study of an area's geological and geomorphological structure. The geological structure of a territory is of great importance for the more efficient utilization of water resources, particularly from the perspective of river feeding sources.

The influence of the geological structure and surface cover on river flow was assessed using the Karabakh region as a case study. This region is distinguished by its complex geological and geomorphological structure, even within Azerbaijan. The total area of the study region is 13,736 km². For the analysis, the geospatial coverage was defined by fragments of Landsat satellite images with path/rows 188–032 and 168–033 (Fig. 1).



Fig. 1. Location of the study area within the Republic of Azerbaijan and on satellite image fragments

The research process was carried out according to the following sequence:

- Climate data (precipitation, temperature, humidity coefficient, etc.) for the study area for the period 1999–2024 were collected from hydrometeorological observation stations.
- The hypsometric and morphometric components of the study area were assessed.
- Monitoring of changes in Land Use/Land Cover (LULC) types, soil, and vegetation cover was conducted using remote sensing data and GIS technologies.
- The spatial distribution of runoff across the basin was calculated by applying runoff and infiltration coefficients.
- The spatial distribution and temporal variability of components determining the area's moisture content and infiltration levels were identified for the study period.
- Data for all components across the river basin were integrated into a GIS database, and inter-component relationships were analyzed.

- The proportions of surface and subsurface flow contributions to the rivers were estimated using ArcGIS computational, comparative, and statistical software tools.

The processing phase encompassed every distinct combination of these components. Consequently, the moisture levels were refined according to various component scenarios. The variability of runoff and infiltration coefficients from precipitation for different moisture levels (humid, dry, and average multi-annual periods) within selected LULC types is presented in Table 4.

The validation of the assessment has also proven successful. For over 30 river basins with diverse physiogeographical conditions in the Karabakh region, the error between the actual and the newly calculated surface and subsurface flow components was within 10 % in 84 of cases, and between 10–18 % in the remaining instances. This indicates a high reliability of the obtained results. The results we obtained using remote sensing methods and GIS technologies were also compared with the results of previous studies conducted in similar areas using traditional methods and were completely justified (Imanov, & Alakbarov, 2014; Aliyev, 2000).

Table 4

Distribution of runoff and infiltration coefficients from precipitation under three moisture conditions
(I: humid period, II: dry period, III: average multi-annual period)

LULC	HSG	Situation	Surface runoff coefficient	Infiltration coefficient
Forests and gardens	A	I	0.11	0.55
		II	0.10	0.39
		III	0.085	0.295
	B	I	0.14	0.51
		II	0.13	0.34
		III	0.10	0.26
	C	I	0.16	0.47
		II	0.14	0.31
		III	0.115	0.215
	D	I	0.20	0.41
		II	0.17	0.27
		III	0.125	0.185
Cultivated areas	A	I	0.18	0.46
		II	0.17	0.33
		III	0.145	0.255
	B	I	0.22	0.38
		II	0.20	0.27
		III	0.15	0.22
	C	I	0.27	0.28
		II	0.24	0.21
		III	0.165	0.175
	D	I	0.32	0.25
		II	0.27	0.17
		III	0.175	0.125
Semi-deserts and dry steppes	A	I	0.67	0.10
		II	0.16	0.06
		III	0.075	0.075
	B	I	0.68	0.08
		II	0.185	0.045
		III	0.0825	0.0325
	C	I	0.70	0.06
		II	0.205	0.035
		III	0.09	0.11
	D	I	0.72	0.05
		II	0.22	0.03
		III	0.086	0.011

When mapping the main components influencing groundwater flow, an entirely new approach was applied for interpolating and extrapolating hydrometeorological data. In ArcGIS, the maps of key components were reclassified, integrated through overlay analysis, and compared with runoff indicators. The combination of components via overlay and the assessment of their interactions represent an innovative methodological contribution to geoinformation mapping. Figures 2 and 3 display the most critical factors determining infiltration intensity and subsurface flow

formation in the Karabakh region. Fig. 2 illustrates the river network and land cover (LULC) characteristics of the study area, whereas Fig. 3 highlights the principal climatic and hydrogeological drivers affecting both surface and subsurface river flow.

The trends in soil and vegetation cover, landscape changes, water resources, and the key climatic factors influencing them within the Karabakh territory from 2000 to 2023 are presented in Table 5.

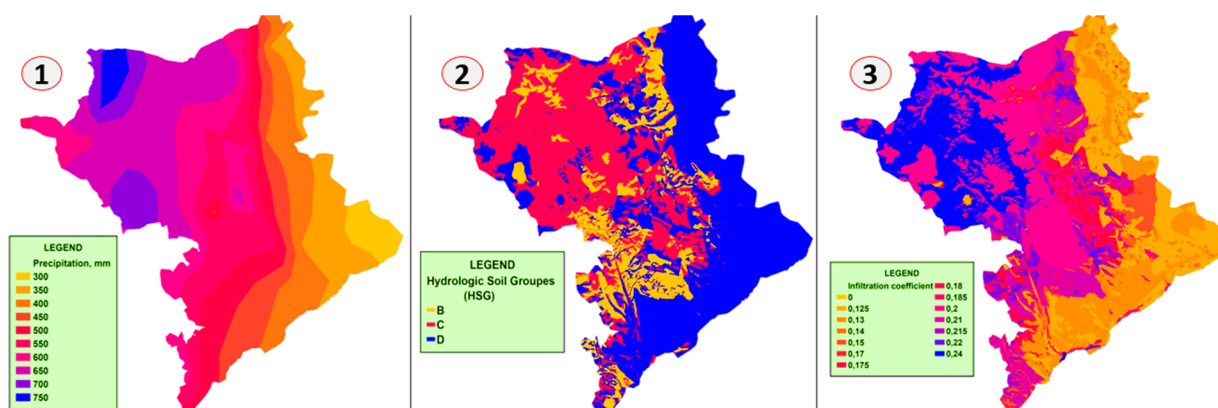


Fig. 2. Key climatic and hydrogeological components influencing subsurface flow formation in the rivers:
1 – Precipitation; 2 – Hydrologic soil groups (HSG); 3 – Infiltration coefficient

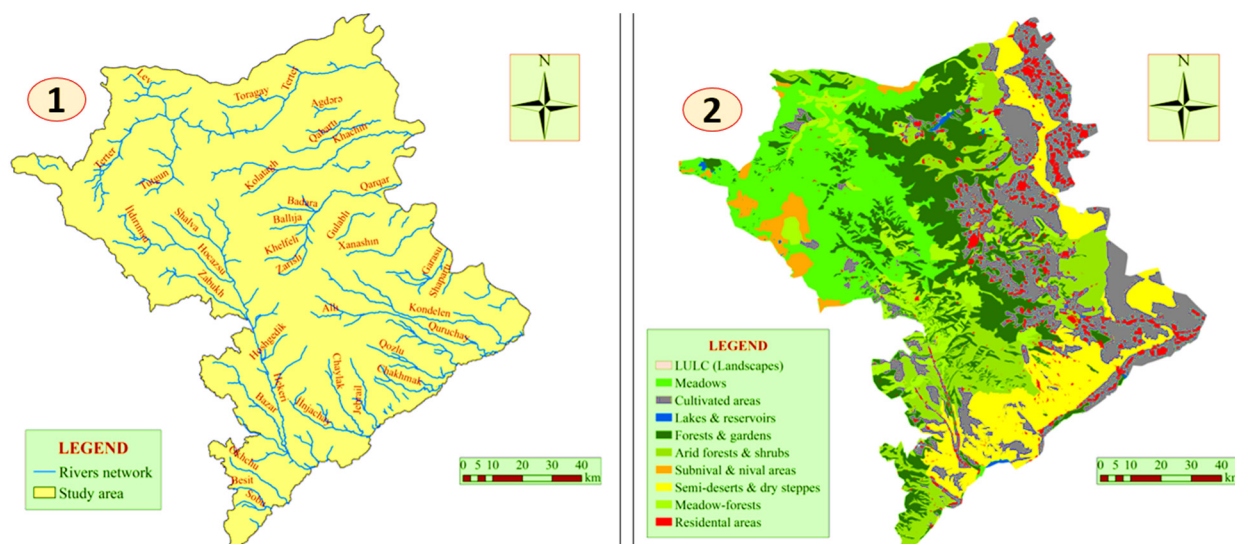


Fig. 3. Rivers network (1) and LULC (2) components of the Karabakh region

Table 5

Changes of hydrometeorological and land cover components in 1999–2024

Study subjects	1999	2024	Difference, %
Air temperature, °C	8.26	9.03	+8.53
Atmospheric precipitation, mm	579.3	528.7	–7.08
Potential evapotranspiration, mm	778.4	849.5	+8.46
Actual evaporation, mm	420.5	382.0	–9.16
Air humidity coefficient	0.744	0.622	–16.4
Factual soil moisture, mm	196.3	171.9	–12.4
Initial abstraction	268.9	304.1	+11.6
Maximum soil water retention, mm	1043.2	1119.7	+6.83
Area of dense vegetation cover, km ²	2251.3	1919.1	–14.8
Areas with poor infiltration capacity (HSG "D"), km ²	6119.4	6623.3	+7.61
Areas with high surface runoff, km ²	1850.2	1453.7	–21.4
Surface runoff coefficient	0.1322	0.1215	–8.13
Infiltration coefficient	0.1351	0.1182	–12.5
Ratio of infiltration to surface runoff	1.022	0.973	–4.79

The changes observed in both climate and surface cover from 1999 to 2024 have been unfavorable for the natural regulation of river flow. Negative shifts in climatic parameters have further consolidated the surface layer, adversely affecting soil moisture and infiltration processes. During this period, the actual water retention capacity of the soils decreased by 12.4 %, while the maximum retention potential increased by 6.83 %. Furthermore, a decrease of 11.6 % was observed in the initial abstraction parameter, which is critical for determining the runoff and infiltration potential of the area.

Landscape types and vegetation density also significantly influence infiltration and the natural regulation of rivers. Landscapes with dense vegetation cover, such as forests and meadows, slow down the conversion of precipitation into surface runoff through root systems and enhance infiltration. Conversely, in areas deprived of or poor in vegetation – such as deserts, semi-deserts, dry steppes, nival and subnival zones, and badlands - the impermeability of the surface weakens the infiltration process (Antoneli, Thomaz, & Bednarz, 2019; Zhu et al., 2022).

Between 1999 and 2024, significant landscape transformations occurred in the Karabakh region under the influence of climate change and human activity. This is particularly evident in the reduction of areas with dense vegetation cover, such as subalpine and alpine meadows, which decreased by 13.4 %, and forests, which saw a 15.5 % reduction. Conversely, areas characterized by semi-desert and dry steppe landscapes increased by 12.4 %, while

unproductive lands and badlands expanded by 13.3 %. Overall, these land use and land cover (LULC) changes have led to a further consolidation of the region's surface layer and a weakening of its infiltration capacity. In this process, the military landscapes (belligerative) created as a result of the prolonged conflict have also had a notable impact.

The distribution of the ratio between surface and subsurface flow for the rivers in the Karabakh region over the average multi-annual period covering 1999–2024 is presented in Table 6.

In most rivers, the surface flow component typically predominates over the subsurface contribution. The ratio of subsurface flow to surface flow ($k=Q_u/Q_s$) is considered an indicator of a river's natural regulation. The higher this value, the more naturally regulated the flow is considered. A natural regulation index of $k \geq 1.0$ indicates highly regulated flow, a value between 0.5–1.0 indicates moderate regulation, and a value of ≤ 0.5 indicates poorly regulated flow.

As can be seen from Table 6, the subsurface flow contribution in most of the largest and most abundant rivers of the Karabakh region (e.g., Tartar, Hakari, Bazar) and their tributaries (e.g., Tutgun, Turagay, Zabukh) is either greater than or approximately equal to the surface flow contribution. This is related to the fact that the formation areas of these rivers are largely situated within the Karabakh volcanic plateau, which is predominantly composed of fractured rocks (Mukhtarov et al., 2015).

Table 6

The level of surface and underground feeding of major Karabakh rivers (with %)

Rivers	Catchment area, km ²	Precipitation, mm	Runoff coefficient	Surface runoff, Qs, mm	Baseflow, Qu, mm	Ratio Qu/Qs
Tartar	2650	623.4	0.4135	46.0	54.0	1.174
Levchay	367	764.5	0.5932	50.4	49.6	0.984
Tutgun	522	617.1	0.4426	46.2	53.8	1.165
Turagay	172	728.7	0.6751	44.3	55.7	1.257
Khachin	657	547.2	0.2918	54.1	45.9	0.848
Qarqar	1490	413.1	0.1925	70.0	30.0	0.429
Kondelen	536	432.6	0.1107	71.6	28.4	0.397
Quruchay	512	478.6	0.1928	62.6	37.4	0.597
Bazar	2711	587.3	0.3418	47.3	52.7	1.114
Hekeri	2570	602.2	0.3223	42.2	57.8	1.369
Zabukh	527	689.3	0.4471	47.4	52.6	1.109
Okhchu	1175	594.7	0.2443	50.7	49.3	0.972
Besit	354	536.2	0.1745	48.3	51.7	1.071
Bartaz	33.5	471.8	0.1332	56.3	43.7	0.776
Injachay	351	453.3	0.0814	74.9	25.1	0.335
Chaylak	190	461.1	0.1036	75.7	24.3	0.321
Chakmakh	110	376.3	0.0462	70.0	30.0	0.428
Jebrail	78.3	403.6	0.0579	86.4	13.6	0.157
Qozlu	99.8	382.7	0.0843	77.3	22.7	0.297
Chereken	134	352.1	0.0628	71.5	28.5	0.398
Garasu	168	326.4	0.0389	80.6	19.4	0.241
Khanashin	234	411.2	0.0743	80.2	19.8	0.247
Qabarti	96.8	544.3	0.1808	60.1	39.9	0.663
Karabakh	13736	541.5	0.2633	50.7	49.3	0.972

The high porosity of the widespread rocks in this area increases the proportion of precipitation allocated to infiltration. This water subsequently contributes to the river's total discharge, facilitating natural regulation. A significant portion of rivers with a natural regulation index above 0.4 are also located in areas dominated by rocks with high water-conducting properties.

In contrast, rivers flowing through the southern and southwestern parts of the Karabakh region (e.g., Injachay, Chaylag, Chakhmaq, Jabrayil) generally exhibit very low *k*-values. The headwaters of these rivers are situated significantly downstream from the fractured rocks of the volcanic plateau. Their basins lie in an arid climate zone where 65–85 % of precipitation is lost to evaporation. Due to

the prevalence of impermeable and non-porous rocks, the remaining precipitation (20–30 %) contributes primarily to surface runoff. In these rivers, surface runoff often constitutes 70–80 %, and sometimes up to 90 %, of the total discharge. The poor regulation of flow, coupled with the fact that many of these rivers dry up in summer, creates additional challenges for utilizing their water resources. Consequently, artificial regulation of river flow is prioritized here, typically achieved through the construction of on-stream or off-stream reservoirs.

Figure 4 provides an example of three rivers in the Karabakh region (Turagay, Levchay, and Khanashin) that exhibit distinct differences in their subsurface flow contributions.

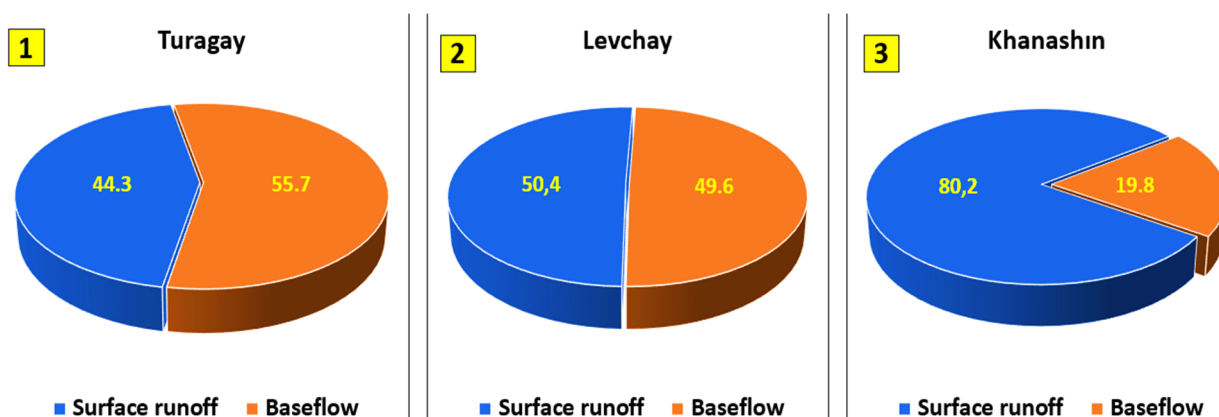


Fig. 4. Distribution of surface and subsurface flow for selected characteristic rivers

As illustrated in Figure 3, the subsurface flow contribution to the Turagay River's discharge is higher than its surface flow component. This is primarily related to the dominance of fractured volcanic rocks within its basin. While the Levchay River basin is situated at a high elevation, leading to a significant contribution from snow and rain, it also features extensively distributed, highly permeable rocks

that promote substantial infiltration. Consequently, the contributions of surface and subsurface flow to the Levchay's discharge are approximately equal. In contrast, the Khanashin River, representing rivers that flow primarily through low-lying plains, exhibits virtually no natural regulation. As shown, surface runoff constitutes over 80 % of its total discharge.

Discussion and conclusions

The research has established that the geological structure of a territory plays a crucial role in river flow composition. Specifically, rivers' draining areas with highly permeable rocks exhibit a greater subsurface flow component. This, in turn, creates favorable conditions for the natural regulation of river discharge. Significant variations in flow sources are observed among rivers across different parts of the Karabakh region. Despite this, the overall natural regulation index for the study area was calculated at 0.97. This indicates that surface and subsurface contributions to the total flow of the region's rivers are approximately equal. Rivers originating from the Karabakh volcanic plateau, where fractured rocks are widespread, demonstrate a high degree of natural flow regulation. In the majority of these rivers, the subsurface flow contribution exceeds the surface flow.

In addition to geological structure, the character of the surface cover also significantly influences the natural regulation of river flow. In areas with impermeable surfaces, the rate of precipitation spreading over the basin increases, consequently weakening flow regulation. During the study period (1999–2024), a trend of climatic aridification and vegetation thinning has led to a further consolidation of the surface cover in the Karabakh region. As a result, the initial abstraction (the potential for precipitation to generate runoff) decreased by 11.4 %, and the natural regulation index (the ratio of infiltration to surface runoff) declined by 4.79 %.

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References

- Aliyev, F. Sh. (2000). *Groundwaters of the Republic of Azerbaijan, resource use and geoeological problems* [in Azerbaijani]. [Əliyev, F. Ş. (2000). *Azərbaycan Respublikasının yeraltı suları, onlardan istifadə və geoeoloji problemlər*].
- Antonelli, V., Thomaz, E. L., & Bednarz, J. A. (2019). The Faxinal System: Forest fragmentation and soil degradation on the communal grazing land. *Singapore Journal of Tropical Geography*, 40(1), 34–49. <https://doi.org/10.1111/sjtg.12258>
- Ciampittiello, M., Marchetto, A., & Boggero, A. (2024). Water resources management under climate change: A review. *Sustainability*, 16(9), Article 3590. <https://doi.org/10.3390/su16093590>
- Dewangan, S. K., Shrivastava, S. K., Soni, A. K., Yadav, R., Singh, D., Sharma, G. K., ... & Sahu, K. (2023). Using the soil texture triangle to evaluate the effect of soil texture on water flow: A review. *International Journal for Research in Applied Science & Engineering Technology (IJRASET)*, 11(6), 389–390.
- El Kenawy, A. M. (2024). Hydroclimatic extremes in arid and semi-arid regions: Status, challenges, and future outlook. In *Hydroclimatic Extremes in the Middle East and North Africa* (pp. 1–22). Elsevier.
- Gnann, S. J., Woods, R. A., & Howden, N. J. (2019). Is there a baseflow Budyko curve? *Water Resources Research*, 55(4), 2838–2855. <https://doi.org/10.1029/2018WR024464>
- Hawkins, R. H., Moglen, G. E., Ward, T. J., & Woodward, D. E. (2020). Updating the curve number: Task group report. In *Watershed Management Conference 2020* (pp. 131–140). American Society of Civil Engineers.
- Imanov, F. A., & Alakbarov, A. B. (2014). The interaction of surface and groundwater in the context of the underground organization of surface flow in the territory of Azerbaijan. *Materials of Caspian Conference on Water Technologies* (pp. 69–74). Azerbaijan [in Azerbaijani]. [Imanov, F. Ə., & Ələkbərov, A. B. (2014). Azərbaycan ərazisində yerüstü axımın yeraltı təşkil şəraitində yerüstü və yeraltı suların qarşılıqlı əlaqəsi. *Xəzər Su Texnologiyaları Konfransının materialları*].
- Lvovich, M. I. (1974). *World water resources and their future* (Translation of the original Russian edition by American Geophysical Union, 1979) [in Russian]. [Львович, М. И. (1974). *Мировые водные ресурсы и их будущее*. Мысль].

Makhmudov, R., & Teymurov, M. (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.

Makhmudov, R., Aliyev, V., Teymurov, M., & Gafarov, E. (2024). Regional climate changes in Azerbaijan and assessment of their impact on water resources with a new method. *Reliability: Theory & Applications*, 19(SI 6 (81)), 830–837.

Makhmudov, R., Teymurov, M., Agayev, Z., & Jabrayilov, E. (2025). Assessment of water resources in Nakhchivanchay River Basin using runoff coefficients method. *Proceedings of the Bulgarian Academy of Sciences*, 78(9), 1312–1318.

Mammadov, G. S., Teymurov, M. A., Mammadov, Z. R., Yusifova, M. M., Osmanova, S. A., Gasimov, A. M., ... & Salimova, S. J. (2025). Climate change effects on soil fertility and moisture in the Nakhchivanchay River Basin, Azerbaijan. *International Journal of Agriculture and Biosciences*, 14(5). <https://doi.org/10.47278/journal.ijab/2025.152>

Mishra, R. K. (2023). Fresh water availability and its global challenge. *British Journal of Multidisciplinary and Advanced Studies*, 4(3), 1–78.

Mukhtarov, A. Sh., Kadirov, F. A., Feyzullayev, A. A., Huseynov, D. A., Aliyev, Ch. S., et al. (2015). *Geology of Azerbaijan* (A. A. Alizadeh, Ed.; Vol. 2). Elm Publishing House [in Azerbaijani]. [Azərbaycanın geologiyası (Akad. A. A. Əlizadə, red.; Cild 2). "Elm" nəşriyyatı]. <https://www.researchgate.net/publication/312176204>

National Atlas of the Republic of Azerbaijan. (2014). *State Land and Cartography Committee of the Republic of Azerbaijan*. Baku Cartographic Factory.

Nguyen, C. T., Chidthaisong, A., Kieu Diem, P., & Huo, L. Z. (2021). A modified bare soil index to identify bare land features during agricultural fallow periods in Southeast Asia using Landsat 8. *Land*, 10(3), Article 231. <https://doi.org/10.3390/land10030231>

Nielsen, R., & Hjelmfelt, A., Jr. (1998). Hydrologic soil group assignment. *International Water Resources Engineering Conference, ASCE*, 2, 1297–1302.

Nilsson, C., Reidy, C. A., Dynesius, M., & Revenga, C. (2005). Fragmentation and flow regulation of the world's large river systems. *Science*, 308(5720), 405–408. <https://doi.org/10.1126/science.1107887>

Rianti, D. I., & Sari, D. N. (2024). Analysis of changes in vegetation density Index in Surakarta City 2018-2022 using LANDSAT-8 OLI/TIRS satellite imagery. *IOP Conference Series: Earth and Environmental Science*, 1357(1), Article 012033. <https://doi.org/10.1088/1755-1315/1357/1/012033>

Ross, C. W., Prihodko, L., Anchang, J., Kumar, S., Ji, W., & Hanan, N. P. (2018). HYSGs250m, global gridded hydrologic soil groups for curve-number-based runoff modeling. *Scientific Data*, 5, Article 180091. <https://doi.org/10.1038/sdata.2018.91>

Rustamov, S. G., & Kashkay, R. M. (1978). *Water balance of the Azerbaijan SSR*. Elm Publishing House.

Sivakumar, B. (2011). Global climate change and its impacts on water resources planning and management: Assessment and challenges. *Stochastic Environmental Research and Risk Assessment*, 25(4), 583–600. <https://doi.org/10.1007/s00477-010-0423-y>

Teymurov, M. A. (2022). The value of initial abstraction and estimation of runoff-forming rainfall rate at a specific geographical location. *Science, Education and Innovation in the Context of Modern Problems*, 5(4), 123–136.

Tonkin, J. D., & Death, R. G. (2014). The combined effects of flow regulation and an artificial flow release on a regulated river. *River Research and Applications*, 30(3), 329–337.

USDA & NRCS (United States Department of Agriculture & Natural Resources Conservation Service). (2009). *Hydrologic soil-cover complexes* (National Engineering Handbook, Part 630, Hydrology, Chapter 9). https://irrigationtoolbox.com/NEH/Part630_Hydrology/H_210_630_09.pdf

Wang, H., Jiang, X. W., Wan, L., Han, G., & Guo, H. (2015). Hydrogeochemical characterization of groundwater flow systems in the discharge area of a river basin. *Journal of Hydrology*, 527, 433–441. <https://doi.org/10.1016/j.jhydrol.2015.04.063>

Wang, X., Liu, T., & Yang, W. (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.

Wang, J., Cui, C., Jia, Z., Liu, M., Pang, S., & Zhai, K. (2024). Analysis of the responses of surface water resources to climate change in arid and semi-arid area. *Agricultural Water Management*, 295, Article 108751. <https://doi.org/10.1016/j.agwat.2024.108751>

Zhu, G., Yong, L., Zhao, X., Liu, Y., Zhang, Z., Xu, Y., ... & Wang, L. (2022). Evaporation, infiltration and storage of soil water in different vegetation zones in the Qilian Mountains: A stable isotope perspective. *Hydrology and Earth System Sciences*, 26(14), 3771–3784. <https://doi.org/10.5194/hess-26-3771-2022>

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ВПЛИВ ПОКРИВУ ЗЕМЛІ ТА ГЕОЛОГІЧНОЇ СТРУКТУРИ НА ПРИРОДНЕ РЕГУЛЮВАННЯ РІЧКОВОГО СТОКУ

Вступ. У посушливих та напівпосушливих регіонах, таких як Карабаський регіон Азербайджану, ефективне управління дефіцитними водними ресурсами критично залежить від природного регулювання річкового стоку. Цей процес, який забезпечує більш збалансований внутрішньорічний розподіл води, традиційно вважався таким, на який впливають клімат і поверхневий покрив. Однак специфічна роль геологічних структур, що лежать в основі, часто оцінювалася лише опосередковано, що становить значний виклик для дослідження. Це дослідження аналізує вплив як геологічних формацій, так і характеристик поверхневого покриття на природне регулювання річкового стоку з 1999 по 2024 роки – період, позначений кліматичними змінами та значними змінами ландшафту.

Методи. Було використано комплексний підхід, що поєднує гідрометеорологічні дані, дані дистанційного зондування Землі та ГІС-технології. Дослідження ґрунтувалося на довгострокових кліматичних даних (опаді, температура), супутникових знімках (Landsat) та цифровій моделі рельєфу. Ключовими методиками були застосування методу NRCS-CN (Natural Resources Conservation Service Curve Number) та розрахунок коефіцієнта природного регулювання (NRR), визначеного як співвідношення підземного базового стоку (Q_b) до поверхневого стоку (Q_s). Гідрологічні групи ґрунтів (HSGs) та різні індекси (NDVI для рослинності, BSI для оголеного ґрунту) аналізувалися для характеристики видів земного покриття та їх змін. Аналіз зосереджувався на порівнянні річкових басейнів із схожими кліматичними та морфометричними характеристиками, але різною геологією.

Результати. Дослідження підтвердило, що геологічна структура є першочерговим чинником. Річки, що дрениують тріщинуваті вулканічні породи Карабаського плато, демонстрували високі значення NRR (часто понад 1,0), причому внесок підземного стоку сягав 53 %, а швидкість інфільтрації становила ~45 л/добу. На противагу цьому, річки на півдні, що лежать на водонепроникних породах, показали дуже низький NRR, із переважанням поверхневого стоку (70–90 % загального стоку). Загалом середньорегіональний показник NRR становив 0,97, що вказує на майже рівновагу між поверхневими та підземними джерелами стоку. Однак спостерігалася негативна тенденція: протягом 25-річного періоду зміни ландшафту, спричинені аридифікацією та зменшенням рослинного покриття, призвели до консолідації поверхні. Це спричинило зменшення потенціалу початкової абстракції на 11,4 % та зниження регіонального NRR на 4,79 %, що свідчить про зменшення природної регулювальної здатності.

Висновки. Результати остаточно демонструють, що геологічна основа є вирішальним чинником природного регулювання річкового стоку в аридних регіонах. Наявність тріщинуватих, проникних порід сприяє високій інфільтрації та значному підземному стоку, створюючи природне сховище, яке забезпечує наявність води в посушливі періоди. Отже, оцінка геологічного контексту є необхідною для ефективного планування водних ресурсів. Виявлене зниження коефіцієнта природного регулювання підкреслює вразливість цих водних систем до тривалих змін клімату та деградації земель. Для річок із вроджено низьким регулюванням штучні заходи, такі як будівництво водосховищ, залишаються необхідними. Це дослідження надає критично важливу основу для пріоритизації стратегій управління водними ресурсами на основі специфічних гідрогеологічних характеристик басейну.

Ключові слова: геологічна структура, покрив землі, регулювання річкового стоку, базовий стік, швидкість інфільтрації, початкова абстракція.

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