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Natural factors of formation and development of geosystems in the Qaratal River basin, Kazakhstan

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ABSTRACT
Given the effects of hydrology on geomorphology and changes in the land body by water flow and the creation of runoff flow, as well as the effect of the shape of basin, the type of basin in terms of geology, the slope of basin, etc., research on this matter becomes important. Damage to agricultural lands, lands, and facilities located on the banks of rivers and streams by running waters and floods can be prevented by careful study, infrastructure and well-documented planning. Given that the Qartal River basin in Kazakhstan is spread over a wide area, the study of the geomorphology of its basin is of particular importance. Therefore, this research aims to identify the factors effective in the formation and development of geosystems in this basin. First, geological, morphometric, and hydrological discussions have been conducted for the basin. In this study, hydrometric climatological data of physical and hydrological characteristics for the basin were analyzed, and it was determined that the aforementioned factors have complex relationships with each other and that the most important factor affecting the behavior of the river was climatic factors, especially the amount and type of rainfall. In this study, the potentials of the basin in terms of climate and water supply were identified and determined, which can be further exploited with careful management and planning.

Keywords: Geosystem, Qartal River, Hydrometry, Water quality.
Article type: Research Article.

INTRODUCTION
From a systems perspective, geosystems are dynamic ones with complex nonlinear behavior. The nonlinear responses of these open systems in non-equilibrium conditions create unstable structures and patterns at equilibrium thresholds. The study of order and repetition in many natural phenomena, such as cloud shapes, mountain ranges, watercourse networks, drainage patterns, and vegetation, has led to the creation of mathematical relationships between these repeating patterns in the form of the concept of fractal geometry. The word fractal is derived from the Latin word fractious (Nikora 1991), meaning a broken and crushed stone. It has been developed as a sub-branch of complex analysis to overcome the weaknesses of Euclidean in the expression and modeling of natural phenomena. The fractal nature of drainage networks was one of the first examples of fractal behavior

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presented by Kusák (2014). Fractal geometry represents a repeating pattern in objects and images; that is, if any image or shape with this property is divided into smaller parts (based on the fractal scale), each of these smaller parts is a reduced copy of the original shape, which in a systems perspective is considered a form of critical self-organization. The goal of fractal geometry is to calculate and find this geometric dimension to predict the behavior of nature and the dynamics of the patterns in it. River networks, as a geosystem identity, are one of nature's most prominent fractal patterns. These patterns significantly create tree-like structures that allow sediment and runoff to be transported to the most stable part of a watershed system (basin outlet) to create balance in the river system, and they exhibit fractal behaviors in this process. Based on the thermodynamics law, the chaotic behavior of water flow in upstream of watersheds is influenced via independent (initial roughness, geology, climate, and time) and dependent parameters of the geosystem (Mofidi *et al.* 2023) such as morphometry, domain morphology, sedimentary material morphology, drainage network morphology, bed material and other dependent characteristics, organizes watercourse patterns on the basin bed to enhance an equilibrium point with minimum energy (basin output) by releasing energy and increasing thermodynamic entropy, and will affect drainage density depending on its energy level. The geometric characteristics of a watercourse network following the process of branching can be easily described by the step-by-step growth of a fractal tree (Kim & Jung 2014). This pattern starts with a single branching procedure named the fractal initiator (Martinez *et al.* 2022; Fig. 1) and, through replication based on the initial pattern, creates the whole pattern of a river shape in a watershed annually.

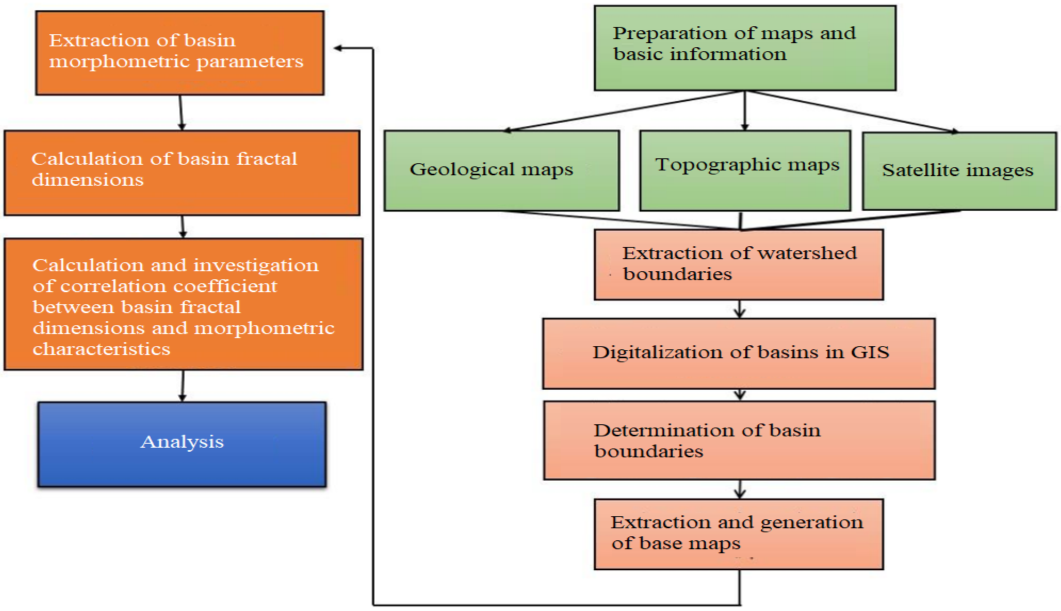


Fig. 1. Research steps.

Today, population growth and human need for water, health development, agricultural industry, etc., have made rivers and watersheds more important. The creation of cities and towns or any facility on the edge of these basins must be based entirely on hydrological and geomorphological studies, and in any urban and regional planning that is carried out, the river's boundaries should not be violated, and sufficient care should be taken in the basin bed for further exploitation. This has led to the mutual relationships of hydrology and geomorphology and the performance of their mutual effects, which cause phenomena that require research to understand these relationships in the river basin. Throughout human history, communities and rivers have been closely linked, with human civilization emerging from the riverbanks (Semenov 2008). River water flow's quantitative and qualitative state is very vulnerable to land use changes (Miklós *et al.* 2019). Anthropogenic interventions affect the natural arrangement of transport and sedimentation processes from semi-arid mountain basins to the downstream. Urbanization exposes the natural and urban basins to rapid land use changes (Vladimirov *et al.* 2019). Therefore, the importance of land use as an environmental variable has raised its changes as an important issue in environmental change and sustainable development (Bayandinova *et al.* 2018). Various studies have been conducted on fractals, self-regulation (Frolov & Cherkashin 2019), and chaos in coastal and stream geomorphology (Kabdrakhmanova *et al.* 2019; Mirzaev 2019; Tarikhazer 2020; Abdullayev *et al.* 2024; Alhammadi *et al.* 2024). In the study of Mahmood & Gloaguen (2012), the fractal dimension in Argentina's Bahia

Blanca tidal channel uses fractal geometry and two methods of proximity and counting boxes. Their results showed that most of the channels in the region have self-repeating properties, but three of the channels studied lack fractal dimension. In the study performed by Wang *et al.* (2020) the fractal dimensions of drainage networks, after applying different fractal models, concluded that the DLA model is the best for studying the fractal dimensions of drainage networks. Hallet (1990) also studied the fractal behavior of stream landforms such as waterfalls and ridges using a simple and simulated model. In the study of Shen *et al.* (2011), the fractal characteristics of the main channel of the Yellow River in China are related to the tectonic evolution of the studied area. In this study, by studying the Qartal River basin, theoretical objectives, including understanding the interrelationships of geomorphology and hydrology in its basin are achieved, based on which, the effective environmental factors and the formation of the relevant basin can be theoretically identified and studied.

MATERIALS AND METHODS

Qartal River starts from the Chinese mountains and flows 400 km westward into Lake Balkhash. This river has strategic environmental importance for its catchment area due to its length and as the easternmost river in Kazakhstan. Due to the region's cold climate, the river freezes entirely for three months in the winter season. It has a strategic position in its catchment area due to irrigation for agriculture and domestic and industrial uses. The studied basin of Qartal River includes two mountainous parts (beside the Chinese border) and the plain area in Lake Balkhash. In this study, daily and annual discharge data from stations in two regions, instantaneous peak discharge from two stations (during the years 2005-2024, daily and annual precipitation decades from the stations in the mentioned period, recorded precipitation and runoff events in two basins and aerial photographs were used.

Fig. 2. Geographical schematic of Qartal River.

The SCS-CN method was proposed by the US Natural Resources Conservation Service (NRCS), and its salient features include simplicity, future predictability, stability, and modeling of watershed runoff characteristics, as well as its robustness due to its dependence on two parameters: the curve number (CN) and the initial loss (λ). This method produces suitable moisture estimates for many agricultural and urban basins of different sizes and climates. In this study, the model calibration method based on observational data was used to estimate the parameters of this method, which include the curve number (CN) and the initial loss ratio (λ). The initial loss ratio of precipitation is usually considered to be 20% of the surface retention of the basin (Tucker & Slingerland 1997).

RESULTS

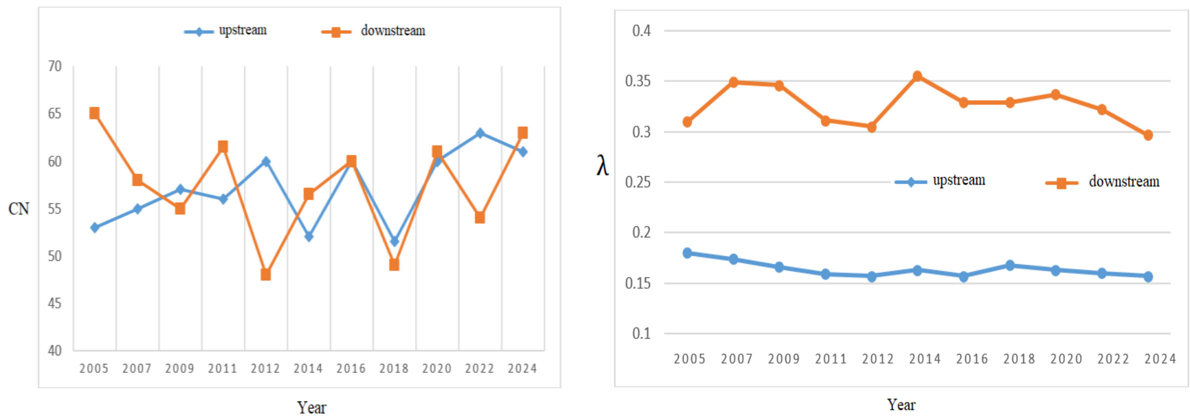
The land use changes of the Qartal River basin in 2005, 2014, and 2023 are shown in Table 1. According to this table, during the three periods, the area of urban surfaces with low runoff production (such as houses and villa complexes), such as low-density, semi-dense, and high-density vegetation cover, and barren lands have been decreasing. However, the area of urban surfaces with medium runoff production has increased in 2014 compared to 2005. However, in 2023, its amount has decreased, indicating that areas with medium runoff levels have become surfaces with high runoff due to the conversion of former villa buildings into apartments, rooftops, and highways in the new period. Also, the area of barren lands in 2005 was higher compared to 2014 and 2023, and in the last two decades, its use has been converted into the urban construction sector. It can be stated that the amount of urban land use has increased, and according to the findings of land use change, the amount of barren land was higher in 2005. Vegetation has decreased over time, and urban surfaces with high runoff production in 2023, with an area of 11.32 km^2, have created a significant difference compared to 2005, with an area of 3.45 km^2.

Table 1. Comparison of the rate and percentage of land use changes in the Qartal basin in 2005, 2014, and 2023.

Land use	2005	2014	2023
	Area (km^2)	**Area (km^2)**	**Area (km^2)**
Barren	21.23	19.33	19.01
Rocky surfaces	12.34	12.30	11.45
Dense vegetation cover	5.02	4.11	3.45
Semi-dense vegetation cover	1.73	1.04	0.71
Light vegetation cover	12.56	12.89	12.45
Urban surfaces with high runoff production	3.45	9.03	11.32
Urban surfaces with moderate runoff production	2.97	3.66	3.57
Urban surfaces with low runoff production	6.11	4.01	3.69
Weighted average CN	83.56	87.67	89.92
Surface retention coefficient	125.89	106.78	103.45
Annual precipitation	345.67	500.45	309.56
Runoff height	230.12	390.56	211.45

Time trend of parameter change

Anthropogenic activities and land use changes in the western region of Qartal River have severely affected the hydrological cycle and runoff production from 2005 to 2023. So, the decreasing trends of the runoff coefficient, the ratio of primary losses (λ) and surface retention (S) are evidents in the first station in the downstream part of the basin. The value of the runoff coefficient in this basin has varied from 70.1 in 2005 to 7.8 in 2023. Therefore, the surface retention ratio, which has decreased from 125.89 in 2005 to 106.78 in 2014 and 103.45 in 2023, has exhibited a decreasing trend, which is actually due to the elevation in impervious surfaces and the drop in the turbidity storage. In contrast, the change in the surface retention coefficient in the basin's upstream has been remarkably insignificant. According to the SCS method used to estimate runoff height (Bo *et al.* 2011), the runoff height upraised in 2014 compared to 2005 but declined in 2023 due to the drop in precipitation. In the upstream part and its basin area, there was no possibility of construction and land use change due to the height and high slope of the region. For this reason, the CN level, surface retention coefficient, and λ did not change there (Fig. 3). The CN and λ values at the upstream station fluctuated less than at the downstream one. The CN level at the first station varied between 53 and 62, and the λ value from 0.15 to 0.173, while these values for the downstream station fluctuated between 48 and 64 and 0.13 to 0.195, respectively (Fig. 3).



CN λ

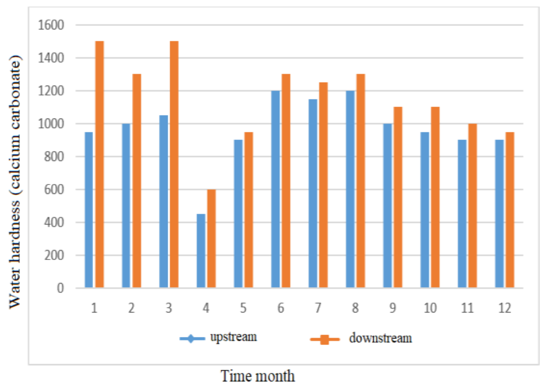
A **B**

Fig. 3. Annual trend of changes in parameters of two down and upstream; A: CN; B: λ.

Examining the relationship between the values of the curve number and rainfall depth, as well as the ratio of calibrated initial losses and rainfall depth at the two studied stations, shows that the coefficient of explanation of these relationships at the downstream station was 0.94 and 0.93, respectively, while this value at the upstream station was 0.91 and 0.89, which was lower than that at the former (Fig. 3). In most basins, there is usually a systematic correlation between the calculated CN and rainfall depth, such that the calculated CN is close to a constant number with the elevating rainfall depth, which is attributed to the specific characteristics of the basin (Nikolopoulos *et al.* 2011). The reason for the low coefficient at the upstream station is associated with the land use changes, which have led to an elevation in impervious surfaces and a drop in puddle storage and, as a result, have disrupted the relationship between rainfall-runoff at this station. In heterogeneous basins or those that undergo the land use changes, assuming a single value for the mentioned parameters is associated with a high error (Hou *et al.* 2024) and consequently leads to unreliable estimates because these parameters display very high temporal and spatial variations. Therefore, using these relations to derive CN and λ leads to more accurate results. Many previous studies have proven that the value of λ should be 0.05, according to which runoff amount has been measured in 327 basins in the United States (Kelly *et al.* 2017). Some studies have also shown that the values considered for λ should be between 0.01 and 0.05, which can provide more realistic results in all regions. According to these relations, the value of λ = 0.2S can only be used for precipitations more significant than 100 mm in the studied basin, and the equation changes in different precipitations. Therefore, contrary to the assumption and due to the temporal changes in precipitation and hydrological conditions effective in runoff production, CN values for urban basins can exhibit a wide range.

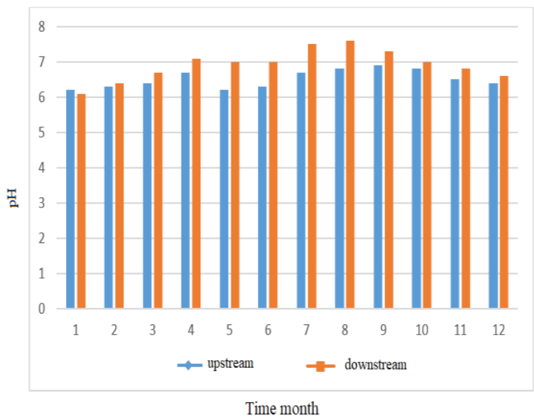
Surface water quality parameters

In this study, to identify the water type, hydrochemical facies, and geochemical evolution path in the two studied basins, water quality variables, hardness, and acidity are presented in Fig. 4. The values of acidity and dissolved solids at the first station (entrance to the plain) were high, which could possibly be due to the reduction in flow volume, evaporation, and geological formations of the region. In the case of using water for aquatic ecosystems, the parameters pH, dissolved oxygen, chemical and biological oxygen demand, total dissolved solids, chloride, and nitrate nitrogen have been employed, while in the case of drinking purposes, the parameters pH, total dissolved solids, nitrate (in terms of nitrogen), phosphate, sulfate, dissolved oxygen, chemical and biological oxygen demand, chloride, sodium, calcium, magnesium, and total hardness have been used (Patil *et al.* 2012). Notably, the standard for wastewater and return water in green space irrigation is used for agricultural purposes. In the case of drinking purposes, the standard for drinking water and for aquatic ecosystems, provided by Patil *et al.* (2012) is used.



Water hardness (calcium carbonate)

A



pH

B

Fig. 4. Water quality; A: Water hardness; B: pH.

CONCLUSION

Urbanization brings environmental challenges at local, regional, and broader scales that directly impact hydrological systems' physical and biochemical characteristics. In this study, the Qaratal River basin was studied as one of the principal rivers of Kazakhstan. In the formation and evolution of watercourse networks in a watershed, known as a geosystemic identity, the emergence of tree-branch patterns is the result of nonlinear responses of sediment and runoff flows to the intrinsic and extrinsic characteristics of the basin, which are manifested in the form of density and number of tributaries and their branching rate in a watershed system. In the Qaratal River basin, urban development has led to an elevation in impervious surfaces, a drop in infiltration, and, consequently, a decrease in surface retention. Therefore, an upraise in impervious surfaces has led to an increase in CN and, consequently, an elevation in runoff volume and a decline in λ. These changes have disrupted the relationship between natural factors in the formation and development of geosystems in the Qaratal River basin.

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