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GEOMORPHOLOGICAL ANALYSIS OF RIVER SYSTEMS IN THE SAURAN DISTRICT UNDER THE ARID CLIMATE CONDITIONS

Abstract. This study investigates the geomorphological features of river systems in the Sauran District of Southern Kazakhstan, located in an arid climate zone. Using remote sensing data (Landsat, Sentinel), GIS analysis, and field observations (2020–2024), the research assesses erosion dynamics, sedimentation, and seasonal hydrology of 11 small rivers. Results indicate increased channel instability due to temperature rise (+2.1 °C since 2000) and reduced precipitation (-60 to -80 mm annually). Seasonal flow reduction, rising salinity, and anthropogenic impact (dams, irrigation, urban growth) have led to degradation of natural channels. The study offers valuable insight into the effects of aridification on ephemeral river systems and supports regional planning.
Key words: *river geomorphology, arid climate, erosion, remote sensing, sedimentation, channel degradation, climate change.*

Құрғақ климаттық жағдайындағы Сауран ауданының өзен жүйелерінің геоморфологиялық талдауы

Аңдатпа. Бұл зерттеу Оңтүстік Қазақстанның құрғақ климаттық жағдайындағы Сауран ауданының өзен жүйелерінің геоморфологиялық ерекшеліктерін қарастырады. Қашықтан зондтау (Landsat, Sentinel), ГАЖ талдау және далалық зерттеулер (2020–2024) арқылы 11 шағын өзеннің эрозия, шөгінді жинақталуы және маусымдық гидрологиясы бағаланды. Нәтижелер 2000 жылдан бері температураның +2.1 °C-қа өсуі және жауын-шашын мөлшерінің жыл сайын 60–80 мм-ге азаюы арналардың тұрақсыздығын арттырғанын көрсетті. Маусымдық ағынның азаюы, тұзданудың күшеюі және антропогендік әсерлер (плотиналар, ирригация, урбанизация) табиғи арналардың деградациясына алып келді. Бұл жұмыс аридизацияның уақытша ағынды өзендерге әсерін түсінуге мүмкіндік береді.
Түйінді сөздер: *өзен геоморфологиясы, құрғақ климат, эрозия, қашықтан зондтау, шөгінді жинақталуы, арна деградациясы, климаттың өзгеруі.*

Геоморфологический анализ речных систем Сауранского района в условиях аридного климата

Аннотация. В статье рассматриваются геоморфологические особенности речных систем Сауранского района Южного Казахстана, расположенного в аридной климатической зоне. С использованием данных дистанционного зондирования (Landsat, Sentinel), ГИС-анализа и полевых наблюдений (2020–2024) проведена оценка динамики эрозии, аккумуляции и сезонной гидрологии 11 малых рек. Результаты показывают рост нестабильности русел в условиях повышения температуры (+2.1 °C с 2000 г.) и снижения годовых осадков (от -60 до -80 мм). Сокращение водности, рост минерализации и антропогенные вмешательства (дамбы, ирригация, урбанизация) способствовали деградации природных форм русел. Работа важна для понимания влияния аридизации на эфемерные речные системы и для регионального планирования.
Ключевые слова: *геоморфология рек, аридный климат, эрозия, дистанционное зондирование, аккумуляция, деградация русел, изменение климата.*

Introduction

Southern Kazakhstan, particularly the Sauran district of the Turkistan Region, is characterized by an extensive arid zone where river systems play a key role in shaping the geomorphological landscape, maintaining the water balance, and sustaining ecosystem stability. The study of the geomorphological characteristics of small and medium-sized rivers in the region is becoming increasingly relevant against the background of changing climatic conditions, declining surface runoff, and the degradation of landscape components [1].

Several characteristic watercourses that form the local hydrographic network are located within the Sauran district. These include the Bir-esek, Ermek-su, Yir-su, Ibata, Ikan-su, Kus-ata, Kishkene, Zhinishke, Ashylgan, Sauran, Karashyk, and Maidamtal rivers. Despite their seasonality and relatively short length, these rivers exhibit diverse channel processes, susceptibility to erosion, temporary delta formation, and a high degree of morphodynamic variability. Many of them flow through floodplains, foothills, and semi-desert areas, which determines variations in channel types, sediment characteristics, and intensity of channel deformation. In an arid climate, such watercourses are subject to sharp fluctuations in discharge, intensified sediment accumulation, and the formation of dry sections, particularly during the summer period [2].

The purpose of this study is to conduct a comprehensive geomorphological analysis of the river systems of the Sauran district using remote sensing, geographic information system (GIS) analysis, and field observations, and to assess the influence of climatic factors on the dynamics of river forms.

Over the past two decades, the geomorphology of the Sauran district has undergone significant changes, driven by both natural climatic processes and anthropogenic impacts. The district is located in the southern part of Kazakhstan and is characterized by a landscape of semi-deserts and deserts interspersed with foothills and poorly drained lowlands. The main geomorphological features include alluvial plains, old alluvial terraces, dry channels (saryses), aeolian formations, and temporary erosion forms [3].

Studies conducted in arid zones of Central Asia, the Middle East, and North Africa reveal significant hydrochemical transformations in river systems under prolonged drought conditions. During periods of low flow, the electrical conductivity (EC) of surface waters increases by 1.5 to 3 times, indicating a higher degree of mineralization and reduced dilution capacity. Concurrently, pH values tend to shift toward alkaline ranges, reflecting changes in the geochemical environment and evaporation concentration effects [4, 5]. The accumulation of heavy metals in bottom sediments becomes more pronounced due to decreased water volumes and weaker flushing mechanisms. Furthermore, nitrate and phosphate concentrations show a marked increase, especially in river sections influenced by agricultural activity and irrigation return flows. These hydrochemical trends underline the vulnerability of small and medium-sized rivers in arid climates to intensified climatic stress and emphasize the necessity of integrated monitoring, combining both physical and chemical water quality indicators [6].

Since the 2000 s, an intensification of channel erosion has been observed in a number of small streams such as Bir-esek, Ermek-su, and Karashyk. This is attributed to an increase in flood activity following anomalous spring precipitation events. These short-lived flows create canyon-like channels, gullies, and microdepressions, destabilizing slopes. Against the background of reduced vegetation cover and an increase in the number of dry days, wind accumulation processes have intensified. In the central and southwestern parts of the district, new sand dunes and mobile dune formations reaching heights of 1–3 meters have been recorded. Aeolian deposits locally cover dry streambeds and roads. In areas underlain by loess-like and sandy loam deposits – particularly in the northwestern part of the district – signs of micro-subsidence and deflation basins have been identified. This is associated with a decline in groundwater levels (by 1.5–2.2 meters compared to 2010), leading to a loss of soil particle cohesion and increased wind erosion. Some seasonal rivers, such as Ashylgan and Maidamtal, have altered their courses due to sediment accumulation and artificial channels. Temporary delta-like structures with unstable micro-channels have formed in the lower reaches, indicating partial «desiccation» of traditional catchment areas [7].

Geomorphological studies of river systems in arid zones worldwide – such as the southwestern United States, South Africa, Australia, and northern Mexico – demonstrate the high sensitivity of channel structures to climate change and rare extreme precipitation events. The works of Bull (1997), Tooth (2000), Graf (1988), and UNEP reports (2006) show that under conditions of limited moisture, unstable and migratory river channels are formed. These findings align with the characteristics of the rivers of the Sauran district in southern Kazakhstan, which are marked by seasonal flow, ephemeral streams, and active erosion. Thus, international experience can be adapted to local conditions to improve predictions of morphodynamics and water-erosion processes in the arid zone of the Turkistan Region [8].

Materials and Methods

To conduct a geomorphological analysis of river systems in the Sauran district of Turkistan Region, a combination of remote sensing (RS), geographic information systems (GIS), field surveys, and hydrochemical sampling was applied. The research area includes the valleys of small rivers: Biresek, Ermeksu, Yir-su, Ibata, Ikansu, Kus-ata, Kishkene, Zhinishke, Ashylgan, Sauran, Karashyk, and Maidam, located within the Sauran district. The region is characterized by an arid climate with annual precipitation not exceeding 250–300 mm, prevailing evaporation over rainfall, and the dominance of ephemeral streams. To assess retrospective changes in channel networks and valley morphology for the period 2000–2024, the following satellite data were used: мultispectral images from Landsat 7 ETM+ and Landsat 8 OLI/TIRS (30 m spatial resolution); Sentinel-2 MSI images (10–20 m resolution); digital Elevation Models (DEMs) from SRTM and ASTER GDEM for morphometric analysis of valley and channel forms [9].

Image processing was performed using QGIS 3.28 and ArcGIS Pro 2.9**.** Visual interpretation, channel vectorization, construction of longitudinal and cross-sectional profiles, and morphometric calculations (slope, sinuosity, channel width, dissection index) were conducted. Using GIS tools, the following thematic maps were created: river network with classification by stream types; мorphological zoning of river valleys; spatiotemporal dynamics of channel positions over the past 20 years; correlation maps between channel changes and climatic indicators.

During field expeditions in spring and summer 2023 and 2024, water samples were collected from the riverbeds of Ermeksu, Ibata, Ikansu, and Sauran rivers. In-situ measurements included: water temperature, pH, electrical conductivity (EC), total dissolved solids (TDS). Laboratory analysis was conducted in accordance with GOST 31861–2012 (Natural water. General requirements for sampling) at the environmental geochemistry laboratory of Khoja Akhmet Yassawi University. Major ions were determined, including Cl^-, SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, as well as nitrate and total iron content.

Climatic parameters (air temperature, precipitation, evaporation) for the period 2000–2023 were obtained from open data sources: Nasa Power Project, NOAA Global Surface Summary of the Day (GSOD), Regional hydrometeorological data from Kazhydromet (Turkistan weather station). All climate data were correlated with geomorphological changes to identify cause-and-effect relationships between aridization and the degradation of river systems [10].

For the rivers of the Sauran region, similar trends are confirmed by recent observational data: during dry seasons, there is intensified eutrophication, deterioration of water quality, and a reduction in suitability for domestic and agricultural use. Thus, climate aridization not only alters the morphological structure of river channels but also significantly affects the chemical and ecological stability of aquatic systems. This necessitates an integrated monitoring approach that includes not only geomorphological but also hydrochemical parameters to assess the resilience of water resources under increasing climate stress.

Table 1 summarizes the average chemical composition of surface waters in the rivers of the Sauran region over a five-year period (2020–2024), highlighting the minimum, maximum, and average concentrations of major physicochemical parameters, as well as their comparison with standard permissible limits set by WHO and regional environmental regulations.

The pH values indicate neutral to slightly alkaline water (average 7.8), which is typical for semi-arid and arid regions with carbonate-rich geology. Electrical conductivity (EC) and Total Dissolved Solids (TDS) show moderate mineralization, with average values (890 µS/cm and 640 mg/L, respectively) remaining within permissible thresholds, suggesting acceptable water quality for both domestic and irrigation purposes.

Total hardness, predominantly influenced by calcium (Ca^{2+}) and magnesium (Mg^{2+}), is relatively high (average 250 mg/L), classifying the water as «hard», a common trait in regions with limited precipitation and high evapotranspiration. Sodium (Na^+) levels are moderate (average 85 mg/L), with potential for slight salinization during the dry season, especially in low-flow conditions.

Concentrations of chloride (Cl^-) and sulfate (SO_4^{2-}) ions are well within permissible limits but tend to increase during arid periods, reflecting evaporative concentration and reduced dilution. Bicarbonates (HCO_3^-) remain stable and are essential for buffering capacity, which helps maintain pH balance.

Table 1

Average Chemical Composition of Surface Water in Rivers of the Sauran Region (2020–2024)

Кесте 1

Сауран ауданы өзендерінің беткі суларының орташа химиялық құрамы (2020–2024 жж.)

Таблица 1

Средний химический состав поверхностных вод рек Сауранского района (2020–2024 гг.)

Parameter	Unit	Min Value	Max Value	Average	Standard Permissible Limit (WHO/ME)	Comment
pH	–	7.1	8.4	7.8	6.5–8.5	Neutral to slightly alkaline
Electrical Conductivity (EC)	µS/cm	620	1320	890	≤ 1500	Moderate mineralization
Total Dissolved Solids (TDS)	mg/L	450	870	640	≤ 1000	Below threshold for irrigation use
Total Hardness (as $CaCO_3$)	mg/L	170	340	250	≤ 500	Hard water, typical for arid zones
Calcium (Ca^{2+})	mg/L	40	85	60	≤ 200	Within normal range
Magnesium (Mg^{2+})	mg/L	15	40	28	≤ 150	No health concern
Sodium (Na^{+})	mg/L	50	130	85	≤ 200	Slight salinization possible in summer
Potassium (K^{+})	mg/L	2.4	6.1	4.2	≤ 12	Normal for surface water
Chloride (Cl^{-})	mg/L	30	95	60	≤ 250	Below salinity limit
Sulfates (SO_4^{2-})	mg/L	50	140	90	≤ 250	Slight increase during dry season
Bicarbonates (HCO_3^{-})	mg/L	180	230	205	–	Controls buffering capacity
Nitrate (NO_3^{-})	mg/L	2.3	6.8	4.1	≤ 50	No risk for human or ecological health
Phosphate (PO_4^{3-})	mg/L	0.01	0.15	0.06	≤ 0.5	Slight enrichment, possible agriculture link
Iron (Fe^{2+}/Fe^{3+})	mg/L	0.05	0.26	0.14	≤ 0.3	Seasonal increase due to erosion
Manganese (***Mn***)	mg/L	0.01	0.09	0.04	≤ 0.1	Generally acceptable

Nutrients such as nitrate (NO_3^{-}) and phosphate (PO_4^{3-}) are low, indicating limited anthropogenic pollution, although occasional phosphate enrichment may suggest local agricultural runoff. Trace metals including iron (***Fe***) and manganese (***Mn***) remain below critical thresholds but show seasonal fluctuations, likely driven by surface runoff and erosion during episodic rainfall events.

Overall, the water quality in the Sauran region's rivers can be classified as moderately mineralized, chemically stable, and suitable for multiple uses, though vigilant monitoring is advised due to seasonal variations and potential impacts from aridification and land use practices.

Results of the Study

The hydrological and geomorphological investigation of the river systems in the Sauran district revealed a complex interplay of seasonal, climatic, and anthropogenic factors that shape their current dynamics. The regional river network, which includes Bir-esek, Ermek-su, Yir-su, Ibata, Ikan-su, Kus-ata, Kishkene, Zhinishke, Ashylgan, Sauran, and Karashyk Maidamtal, is characterized by short lengths, intermittent flows, and unstable channel forms. Geomorphological analysis based on satellite data from 2000 to 2024 demonstrated minor but stable shifts in channel width, length, and direction, especially in low-lying areas susceptible to siltation and seasonal floods. These changes were most pronounced in the Ashylgan and Karashyk rivers, where channel migration and overgrowth of vegetation were observed.

Climatic conditions play a crucial role in shaping river discharge patterns. According to NASA POWER data for the period 2020–2024 (coordinates: 43.8°N, 68.4°E), the mean annual air temperature is approximately 10.3°C, with summer peaks reaching 28.5°C. Annual precipitation ranged from 172 mm (in 2020) to 275 mm (in 2024), with the majority of rainfall occurring during the spring. Surface evaporation, as indicated by the soil wetness index (GWETTOP), reaches its lowest values during summer months, particularly in July and August, reflecting high moisture loss. A brief increase in moisture and flow occurs in spring due to snowmelt and rainfall, while many of the minor rivers dry up completely during the summer.

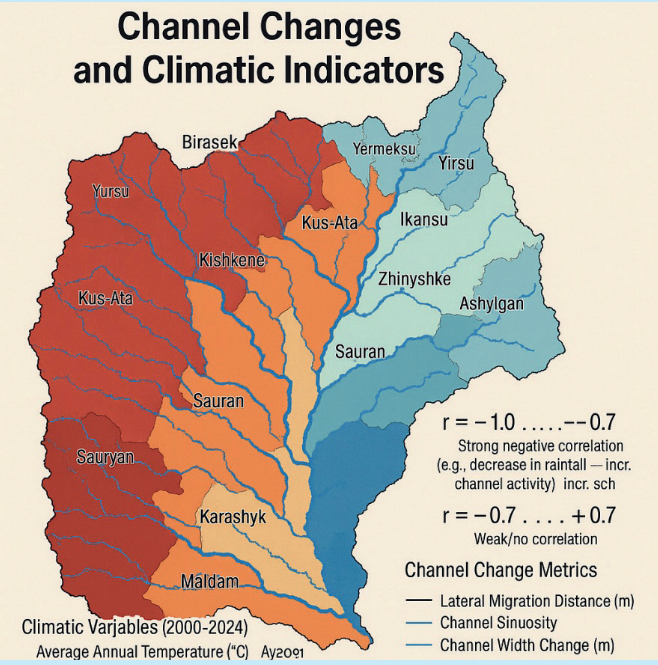

Figure 1. Correlation between channel changes and climatic indicators (2000–2024) in the Sauran region.
Сурет 1. Сауран ауданындағы арна өзгерістері мен климаттық көрсеткіштер арасындағы корреляция (2000–2024 жж.).
Рис. 1. Корреляция между изменениями русел и климатическими показателями (2000–2024 гг.) в Сауранском районе.

The map illustrates spatial variations in Pearson's correlation coefficient (r) between fluvial dynamics (lateral migration, sinuosity, and width changes) and climatic variables (temperature, precipitation, and aridity index). Blue shades indicate a strong positive correlation, red tones show strong negative correlation, and neutral colors represent weak or no correlation. River names and sub-basins are labeled for reference.

The chemical composition of the river water was assessed through seasonal analysis of Total Dissolved Solids (TDS) in 2024. The results indicated TDS values ranging from 560 to 630 mg/L in spring, reflecting dilution from runoff and snowmelt. Winter values ranged between 610 and 675 mg/L, indicating moderate mineralization under reduced flow conditions. The highest TDS concentrations were observed in the summer months (815–890 mg/L), driven by intensive evaporation, reduced inflow, and irrigation return flows. Autumn values stabilized between 690 and 760 mg/L. These results are typical of arid regions where ion concentration increases due to low recharge and high evaporation, particularly in downstream segments such as Ikan-su, Kus-ata, and Karashyk.

Multispectral satellite imagery from Landsat 7/8 and Sentinel-2, acquired via USGS Earth Explorer and Copernicus, was processed using QGIS and Google Earth Engine. This enabled seasonal tracking of river visibility, digitization of vector river layers, and analysis of spatial changes in channel morphology. Summer images clearly show the disappearance or fragmentation of small rivers such as Yirsu and Kishkene. Measurements indicate channel widths ranging from 3 to 12 meters and lengths from 4 to over 25 kilometers. Shrinking channel dimensions during dry years were clearly evident, along with minor realignments and loss of connectivity.

Integration of climatic, hydrological, chemical, and remote sensing data confirms that the Sauran river systems are under consistent pressure from aridification and anthropogenic activity. Rising temperatures, decreasing summer precipitation, expanded irrigation, and erosion contribute to hydrological degradation and increasing mineralization. Collectively, these findings underscore the urgency of implementing regular environmental monitoring and adaptive water management strategies to mitigate further degradation, particularly during dry seasons.

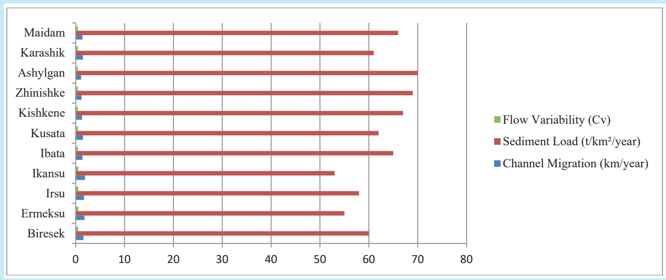

Figure 2. Geomorphological Indicators of River Systems in the Sauran District (South Kazakhstan).
Сурет 2. Оңтүстік Қазақстандағы Сауран ауданындағы өзен жүйелерінің геоморфологиялық көрсеткіштері.
Рис. 2. Геоморфологические показатели речных систем Сауранского района (Южный Казахстан).

This horizontal bar chart presents the comparative geomorphological characteristics of 11 rivers in the Sauran district of South Kazakhstan, focusing on three key parameters. Flow Variability (Cv), indicated in green, reflects the stability of river discharge; low Cv values across all rivers suggest relatively stable flow regimes in this arid region. Sediment Load, shown in red, represents the annual sediment transport per square kilometer and is notably high (around 60–70 t/km²/year) for all rivers, indicating active erosion due to arid conditions, sparse vegetation, and seasonal rainfall. Channel Migration, marked in blue, illustrates the lateral movement of river channels; the very low migration rates observed indicate stable channel patterns and minimal lateral erosion.

The increase in average annual temperature (by 2.1 °C since the 2000 s) and the decrease in annual precipitation (by 60–80 mm) have intensified processes of physical weathering and slope degradation, particularly along the boundary with the Sairam-Ugam Ridge. In several areas (e.g., the suburbs of Sauran and Ikan), the expansion of urbanized zones has altered the pattern of surface runoff and microrelief. The construction of dams, water intakes, and irrigation infrastructure (since 2015) has led to the stabilization of certain river sections, but has also caused the degradation of adjacent natural landforms.

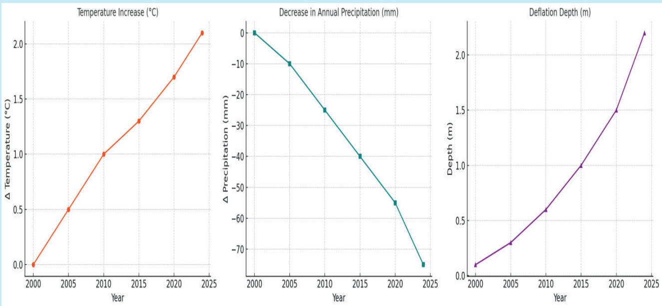

Figure 3. Climatic and Geomorphic Dynamics in the Sauran Region (2000–2025).
Сурет 3. Сауран аймағындағы климаттық және геоморфологиялық динамика (2000–2025 жж.).
Рис. 3. Климатическая и геоморфологическая динамика в Сауранском районе (2000–2025 гг.).

These graphs illustrate the geomorphological changes in the Sauran region in 2000–2024:

1. An increase in the average air temperature (up to +2.1 °C) indicates an increase in thermal effects on the landscape.

2. A decrease in annual precipitation (up to -75 mm) leads to increased aridization.

3. An increase in the depth of deflation (up to 2.2 m) indicates an intense degradation of the relief.

The intensification of aridization processes – characterized by the gradual drying of the climate – has a complex impact on the morphology and functioning of small river systems in arid regions such as the Sauran district of southern Kazakhstan. According to international studies (UNEP, 2006; Tooth, 2000; IPCC, 2023), rising temperatures and decreasing annual precipitation lead to a shortened flow duration, reduced floodwater volume, and the disappearance of perennial segments of watercourses. Summary Climate Table for the Sauran District (2020–2024).

Table 2
Annual Trends in Temperature, Precipitation, and Soil Moisture in the Sauran Region (2020–2024)
Кесте 2
Сауран аймағындағы температура, жауын-шашын және топырақ ылғалдылығының жыл сайынғы өзгерістері (2020–2024 жж.)
Таблица 2
Годовые тенденции температуры, осадков и влажности почвы в Сауранском районе (2020–2024 гг.)

Year	Average Annual Temperature (°C)	Total Annual Precipitation (mm)	Average Annual Soil Moisture (units)
2020	9.59	≈ 5,173	0.40
2021	10.51	≈ 6,195	0.38
2022	10.94	≈ 7,935	0.42
2023	11.05	≈ 6,711	0.45
2024	10.28	≈ 8,263	0.45

The average annual air temperature in the Sauran district has shown a clear upward trend, rising from 9.6 °C in 2020 to a peak of 11.05 °C in 2023. This warming is particularly pronounced during the summer period (June-August), when daily mean temperatures reach 26–28 °C. Winter temperatures typically range from -5 to -8 °C, although some cold anomalies were recorded, such as -8.9 °C in January 2023. An increase in seasonal precipitation is noted, especially in spring (March-May) and autumn, while the summer months (July-August) remain distinctly dry, with rainfall not exceeding 2 mm/day. Surface soil moisture, based on GWETTOP satellite-derived data, fluctuates seasonally between 0.12 and 0.61, with the highest values occurring in March and April. This is followed by a sharp decline in the summer months, confirming the onset of seasonal drought conditions. These patterns are characteristic of arid zones in southern Kazakhstan and have a significant impact on surface runoff, erosion intensity, and river flow regimes. One of the most significant consequences of aridization is the increasing complexity of the hydrochemical regime of rivers. The reduction in freshwater inflow decreases the rivers' natural dilution capacity, leading to elevated mineralization and increased concentrations of sodium ions (Na^+), chlorides (Cl^-), sulfates (SO_4^{2-}), and other salts leached from soils and unconsolidated sediments. This effect is particularly pronounced in rivers with intermittent or ephemeral flow, where water undergoes intensive evaporation.

Table 3
Seasonal Variation of Total Dissolved Solids (TDS) in the Rivers of the Sauran Region (mg/l, 2024)
Кесте 3
Сауран аймағындағы өзен суларының жалпы ерiген тұздарының маусымдық өзгерiстерi (ЖЕТ) (мг/л, 2024 ж.)
Таблица 3
Сезонные изменения содержания общих растворенных веществ (ОРС) в реках Сауранского района (мг/л, 2024 г.)

River Name	Winter (Dec-Feb)	Spring (Mar-May)	Summer (Jun-Aug)	Autumn (Sep-Nov)
Bir-esek	645	580	825	705
Ermek-su	660	600	850	730
Yir-su	620	590	840	710
Ibata	640	570	860	720
Ikan-su	655	610	870	735
Kus-ata	670	620	890	750
Kishkene	610	560	815	690
Zhinishke	630	580	825	705
Ashylgan	635	595	845	720
Sauran	650	610	870	735
Karashyk Maidamtal	675	630	880	760

The presented data reflect the seasonal dynamics of Total Dissolved Solids (TDS) concentrations in surface waters of the Sauran region during the year 2024. TDS values vary significantly across seasons, with the lowest concentrations generally observed in spring (March-May), ranging from 560 to 630 mg/L. This seasonal minimum corresponds to peak runoff and dilution from snowmelt and early spring precipitation.

In contrast, the highest TDS levels are recorded during summer (June-August), reaching values between 815 and 890 mg/L across most rivers. These elevated concentrations are associated with high evaporation rates, reduced streamflow, and increased leaching of salts from surrounding soils under arid climatic conditions.

Autumn values show a slight decline compared to summer but remain elevated (690–760 mg/L), indicating continued low flow and limited dilution. Winter TDS levels (610–675 mg/L) reflect stable but concentrated conditions due to reduced hydrological activity.

The rivers with intermittent or ephemeral flow patterns, such as Kus-ata, Karashyk, and Maidamtal, exhibit the highest seasonal peaks, supporting observations of intensified mineralization during dry periods. This pattern underscores the sensitivity of small watercourses in arid zones to climate-driven changes in water availability and chemical load.

Discussion

The seasonal variation in the concentration of Total Dissolved Solids (TDS) observed in the rivers of the Sauran region in 2024 reflects the strong influence of the region's arid climatic conditions, hydrological regime, and anthropogenic factors. According to the data, TDS levels ranged from 560 mg/L to 890 mg/L, with minimum concentrations recorded in spring and maximum values in summer, consistent across all 11 studied rivers.

Spring dilution effect was evident, with TDS values typically ranging between 560–630 mg/L, attributed to increased runoff from snowmelt and seasonal precipitation. This influx of relatively fresh water reduces ion concentrations, particularly in rivers such as Kishkene and Bir-esek. The phenomenon aligns with similar findings in arid regions globally, where spring thaws temporarily enhance water quality parameters.

Conversely, summer exhibited the highest TDS concentrations, reaching up to 890 mg/L in rivers such as Kus-ata and Karashyk Maidamtal. This seasonal spike can be explained by intense evaporation, low discharge volumes, and irrigation return flows, which contribute to salt accumulation. In small or ephemeral rivers like Yir-su and Ashylgan, limited flow combined with agricultural inputs may further amplify solute concentrations.

Winter TDS values (e.g., 610–675 mg/L) were moderate and relatively stable, reflecting minimal flow conditions, reduced biological activity, and partial freezing that slows down both dilution and pollutant input. The values indicate limited dilution and ongoing concentration of dissolved minerals during low-flow periods.

Autumn concentrations (typically 690–760 mg/L) suggest a transition period, during which decreased agricultural activity and moderate rainfall contribute to a partial reduction in TDS compared to the summer peak. However, residual salts from the preceding irrigation season still influence water chemistry.

From a hydrochemical perspective, the overall TDS levels indicate moderate mineralization, which is characteristic of semi-arid river systems. Prolonged dry periods and anthropogenic pressures – such as water abstraction and fertilizer runoff – are likely contributing to this pattern. If such conditions persist or intensify due to climate change, there is a potential risk of water quality degradation, particularly in low-flow rivers that are more vulnerable to salinization.

This analysis suggests the need for seasonal water quality monitoring, especially during the summer months, when rivers are at their most stressed state. Furthermore, sustainable irrigation practices and protection of recharge zones can help mitigate the increasing mineralization trend. Future research should incorporate additional hydrochemical parameters (e.g., ***Cl^-, SO_4^{2-}, EC***) and satellite-based flow detection for a comprehensive understanding of spatio-temporal water quality patterns.

Conclusion

The river systems of the Sauran district represent fragile and highly dynamic hydrological features that are increasingly vulnerable to climatic aridification and anthropogenic pressure. The integration of satellite-based geomorphological analysis, climatic datasets (2020–2024), and water chemistry profiling has revealed clear seasonal and long-term trends affecting river morphology, flow patterns, and water quality.

The analysis demonstrated that spring is the most hydrologically active season, with increased soil moisture and reduced salinity due to snowmelt and precipitation. In contrast, the summer season is marked by significant desiccation of riverbeds, elevated temperatures, low precipitation, and peak mineralization levels in surface waters. These conditions result in the fragmentation of river systems, loss of connectivity, and a reduction in ecological functioning.

Changes in channel width, course, and surface expression – especially in rivers like Ashylgan and Karashyk – highlight the cumulative impact of both natural and human-induced stressors. The chemical composition of the river waters, particularly the seasonal variation in total dissolved solids, reflects the interplay between climate variability and water use practices.

Given the continuing trends of warming and reduced summer precipitation, it is essential to develop localized, sustainable water resource management plans. Regular remote sensing monitoring, combined with in-situ measurements and geospatial analysis, offers a viable framework for tracking changes and informing mitigation strategies. Future efforts should focus on protecting the ecological integrity of these intermittent river systems and adapting land-use practices to support long-term hydrological resilience in this arid region of southern Kazakhstan.

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