



Riverbank Erosion Using GIS and Remote Sensing Along the Greater Zab River in Iraq

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Article information

Received: 22- Nov -2024

Revised: 18- Feb -2025

Accepted: 17- May -2025

Available online: 01- Apr -2026

Keywords:

Environmental Degradation,
River Erosion and Deposition,
GIS,
Remote Sensing.

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ABSTRACT

Studying the relationships between rivers and human activity is now crucial due to the significance of rivers for their morphology. The purpose of this study is to identify the historical human impacts on the Greater Zab River's (GZR) morphology. To detect the GZR bank line and flow path and estimate the rate of erosion and sedimentation along the riverbank for the period from 1952 to 2023, a time series of satellite images and a single toposheet have been analyzed utilizing Arc GIS 10.8 software. The results reveal that between the 1950s and the 2020s, the GZR underwent significant narrowing, shortening, and embankment due to various human influences, climate changes, and geomorphological conditions as well. Sand mining, bank erosion and accumulation, together with Land Use/Land Cover (LULC) changes, are the main sources of the GZR's depletion and violent alteration of its propagation. The investigation also reveals that throughout the previous 7 decades, an area of around 9.38 km² was eroded, with the highest erosion rate during the decade (1984 to 1993). The GZR was generally wider in 1952 than it would be in 2023 in the two periods' shifting regions. Throughout the years, it is also possible to observe a frequent change in the river courses. The conclusion of this study highlights the value of using a geospatial approach to effectively analyze riverbank erosion in alluvial channels.

DOI: [10.33899/injes.v26i2.60901](https://doi.org/10.33899/injes.v26i2.60901), ©Authors, 2026, College of Science, University of Mosul.

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تآكل ضفاف نهر الزاب الكبير باستخدام نظم المعلومات الجغرافية والاستشعار عن بعد في العراق

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المخلص	معلومات الارشفة
إن دراسة العلاقات بين الأنهار والنشاط البشري أمر بالغ الأهمية الآن نظرًا لأهمية الأنهار في مورفولوجيا الأنهار. وكان الغرض من هذه الدراسة هو تحديد التأثيرات البشرية التاريخية على مورفولوجيا نهر الزاب الكبير (GZR). لتحديد خط ضفة نهر الزاب الكبير ومسار تدفقه وتقدير معدل التعرية والترسيب على طول ضفة النهر للفترة من 1952 إلى 2023، تم تحليل سلسلة زمنية من صور الأقمار الصناعية وطبقة طبوغرافية واحدة باستخدام برنامج Arc GIS 10.8. كشفت النتائج أنه بين الخمسينيات والعشرينيات من القرن العشرين، خضع نهر الزاب الكبير لتضييق وتقصير وسد كبير بسبب التأثيرات البشرية المختلفة بالإضافة إلى التغيرات المناخية والظروف الجيومورفولوجية. كان تعدين الرمال وتآكل الضفة وتراكمها وتغيرات غطاء استخدام الأراضي (LULC) هي المصادر الرئيسية لاستنزاف نهر الزاب الكبير، مما أدى إلى تغيير مساره بشكل كبير. كشف البحث أيضًا عن تآكل مساحة تبلغ حوالي 9.38 كيلومتر مربع خلال العقود السبعة الماضية، حيث شهد العقد من عام 1984 إلى عام 1993 أعلى معدل تآكل. كان عرض نهر الزاب الكبير أوسع بشكل عام في عام 1952 مما سيكون عليه في عام 2023 في المناطق المتغيرة للفترتين. وعلى مر السنين، من الممكن أيضًا ملاحظة تغير متكرر في مجاري الأنهار. وتُبرز خلاصة هذه الدراسة أهمية استخدام نهج جغرافي مكاني لتحليل تآكل ضفاف الأنهار في القنوات الرسوبية بفعالية.	<p>تاريخ الاستلام: 22- نوفمبر - 2024</p> <p>تاريخ المراجعة: 18- فبراير - 2025</p> <p>تاريخ القبول: 17- مايو - 2025</p> <p>تاريخ النشر الإلكتروني: 01- ابريل - 2026</p> <p>الكلمات المفتاحية:</p> <p>التدهور البيئي، وتآكل الأنهار والترسيب، نظم المعلومات الجغرافية، الاستشعار عن بعد،</p> <p>المراسلة: الاسم: راحيل حمد</p> <p>Email: rahel.hamad@soran.edu.iq</p>

DOI: [10.33899/injes.v26i2.60901](https://doi.org/10.33899/injes.v26i2.60901), ©Authors, 2026, College of Science, University of Mosul.

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Introduction

Globally, freshwater rivers' biodiversity is threatened by increasing river fragmentation. Several natural and man-made factors split rivers (Fuller et al., 2015). Among the important factors are riverbank erosion and sand mining. It can take many different forms, such as flooding, landslides, and soil erosion, all of which have an impact on the environment of the river basin region, either directly or indirectly (Billah et al., 2023). Pollution, providing drinking water, river channelization, and damming, as well, are all causing rivers to suffer more and more (Schmutz and Sendzimir, 2018). To bridge the gap between cultural and scientific perspectives on rivers, it is important to understand how human actions, especially historical actions that have long since ceased, continue to affect river ecosystems (Wohl, 2019).

Rivers, a very powerful force, have been shaped over millions of years. Each river can reveal its history by examining its features and the characteristics of the sediments that form its bed. Alluvial channels experience a lot of erosion and deposition. One challenge that alluvial rivers face is their morphological patterns, which affect rivers worldwide. Both human and natural forces have contributed to the development of these patterns. The dynamically flowing river means that it is constantly moving, causing numerous issues for the people living nearby. Human activities such as farming, habitat destruction, and deforestation can greatly accelerate

erosion rates, increasing them by a factor of 10 to 100 compared to natural geological processes on rates, increasing them by a factor of 10 to 100 compared to natural geologic processes (Kang and Kanniah, 2022).

Geographic Information Systems (GIS) and Remote Sensing (RS) are vital tools for detecting changes along riverbank erosion. Results from trend analysis and change detection can be used to make predictions (Hassan, 2015).

Materials and Methods

Case study's description

The Greater Zab River is shared by Turkey and Iraq. It flows across northern Iraq, and it originates in the Ararat Mountains of Turkey and travels 372 km to join the Tigris River south of Mosul City (Aziz and Omar, 2019). Generally, there are three courses (reaches) in the Greater Zab River. The first course comes from a mountain course in Iraq, where the water moves at a greater speed because of the steep gradient and the valley's restricted flow. The region of importance (area of interest and second course) is in the middle section, which begins at Bekhme Gorge (Fig. 1). The lower flow of the river, which is the third section, has a gradual slope and is nearly level. In the current study, approximately 104 km long has been selected for the middle reaches of the GZR, which is one of the major tributaries of the Tigris River in Iraq, over the past seven decades.

River terraces, which are made of conglomerate, siltstone, sandstone, rock fragments, silty, and clayey soil, cover the majority of the studied area. Moreover, the GZR flows mostly over clastic rocks that include several Quaternary sediment types, including deposits from floodplains and river terraces. Therefore, the formation of alluvial fans, mass movements, and structural shapes is the reason for the changing river patterns (Sissakian and Al-Ansari, 2019).

The dense bankside vegetation offers habitat for terrestrial animals as well as food and shade for river-dwelling species (Addy et al., 2016). Rivers that are shaded by riparian shrubs and trees provide vital habitat for instream fauna, primarily fish. Some of the most important ecosystems in nature are riparian zones (Plate 1), that is important for providing habitat for animals that live in and around the river, and it moderates and **cool** the temperature of the entire ecosystem, and they are fully dependent on the river's flow regime to survive (Sreebha, 2008).

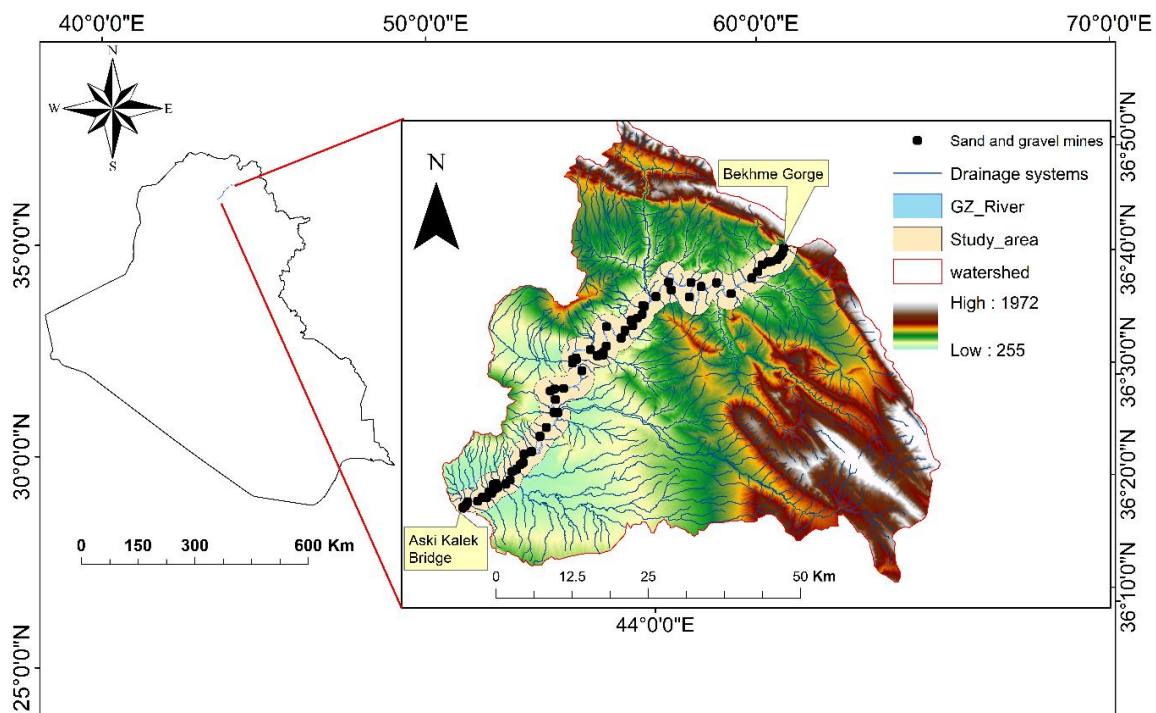


Fig. 1. Locations of GZR, drainage network systems, DEM values, and sand and gravel mines within the study area.



Plate 1. Surrounding riparian vegetation buffer at GZR (Photo by R. Hamad, 2023).

Tree roots and woody debris in the stream enhance its physical habitat diversity, stabilize sediments, and improve the water quality. Woody debris slows the flow of the water, forming eddies and pools where fish can rest, hide from scavengers, and avoid direct sunlight (Addy et al., 2016) (Plate 2).



Plate 2. Spatial structure of the environment that allows species to live and reproduce at GZR (Photo by R. Hamad, 2023).

The main causes of bank erosion and accumulation are channel expansion, elongation of meander bends, lateral channel movements, and meander cutoff (Plate 3).



Plate 3. Erosion of banks and expansion of the aggregation channel at GZR (Photo by R. Hamad, 2023).

The mid bar is depicted in Plate (4), which developed as the stream's secondary flow swept and rolled sand, gravel, and small stones laterally across the stream's bed, and up the point bar's shallow and sloping floor (Semwal and Dutt Chauniyal, 2019).

Another feature exposed in the area of interest was Riffles and pools, which develop when shallow water moves quickly over gravel or cobbles, breaking up the water's surface (Addy et al., 2016). The channel splits into two branches due to abrupt changes in gradient caused by riffle formation, and silt is dumped in the pool along the channel close to the bifurcation. There was a lengthy tail of gravel between the two dividing channels (Plate 5). Moreover, island bars frequently grow at riffle places and then emerge above the water as the water level drops (Semwal and Dutt Chauniyal, 2019).



Plate 4. Point bar at GZR (Photo by R. Hamad, 2023).



Plate 5. Riffles at GZR (Photo by R. Hamad, 2023).



Plate 6. Splitting of GZR as a result of the excavation of sand and gravel (Photo by R. Hamad, 2023).

The geometry of rivers is dynamic and reacts to both natural and artificially induced activity. Sand mining can change the shape of rivers (Plate 6). Both the length and the width are subject to change (Smith and Winkley, 1996). Thus, human activities are more powerful than natural events such as floods, droughts, and landslides in causing changes in the river pattern (Hossain et al., 2013).

The Greater Zab River between Bekhme Gorge and Aski Kalek Bridge is the subject of the study area, where it flows from the northeast to the southwest. The Google Earth Engine recorded a mean monthly maximum temperature of about 27.66 °C and a mean monthly minimum of 13.80 °C from 1980 to 2022. The altitude of the study area (a one-kilometer buffered zone) varies from 1972 meters above sea level in the highlands to 255 meters above sea level in the lowlands.

The total annual precipitation (1980–2022) is drawn as a graph based on the data downloaded from the Google Earth Engine (GEE). The years 1987, 1993, and 2019 had the highest totals of precipitation (911.6, 907.2, and 879.8 mm), respectively. On the other hand, the minimum total precipitation in 2021, 2008, and 1989 was (355.3, 401.0, and 405.6 mm), respectively (Fig. 2).

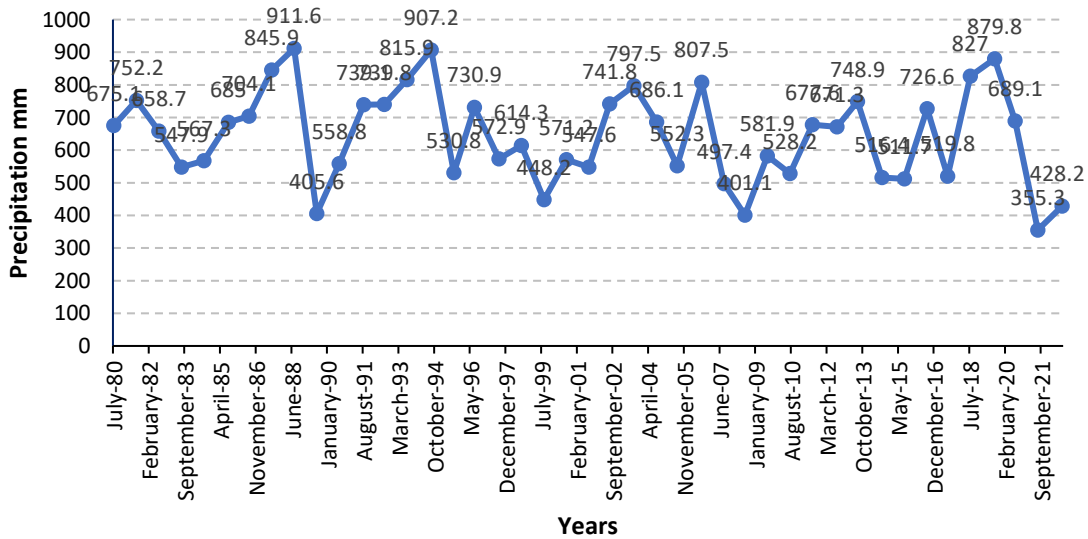


Fig. 2. Total precipitation (in mm) in any place within the research area (downloaded from the Google Earth Engine platform).

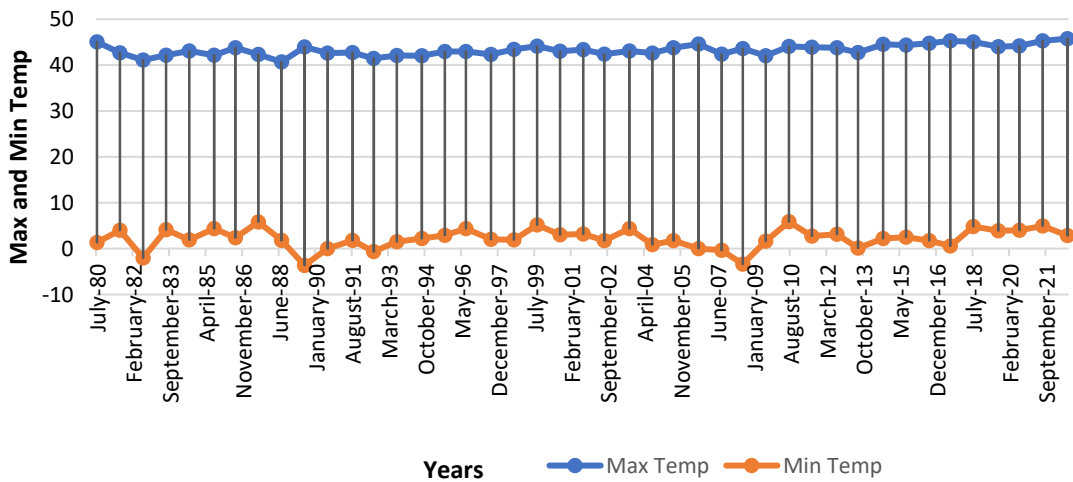


Fig. 3. Highest and lowest temperatures (in °C) for each winter and summer season for any place within the research area.

The research area's maximum and minimum temperatures for the same period, however, are shown in Figure 3. The highest recorded temperature was 45 °C in 1980, while the lowest recorded temperature was -3.6°C in 1989.

Geological setting of the study area

Several exposed formations are intersected by the GZR such as Pila Spi Formation (well-bedded, hard pale grey limestone, dolomite and rare marl) starting at the Bekhme Gorge, then followed by: Fatha Formation (alternation of green marl, reddish brown claystone, limestone, and gypsum), Injana Formation (alternation of sandstone, siltstone, and claystone, all reddish brown in color), Mukdadiya Formation (alternation of sandstone, siltstone and claystone; all grey in color), and Bai Hassan Formation (coarse conglomerate and reddish-brown claystone with rare sandstone) in addition to alluvial fan sediments (both are well developed old and recent alluvial fans) and river terraces, which are very similar to the deposits of Bai Hassan Formation (based on Elias and Sissakian, 2022) (Fig. 4).

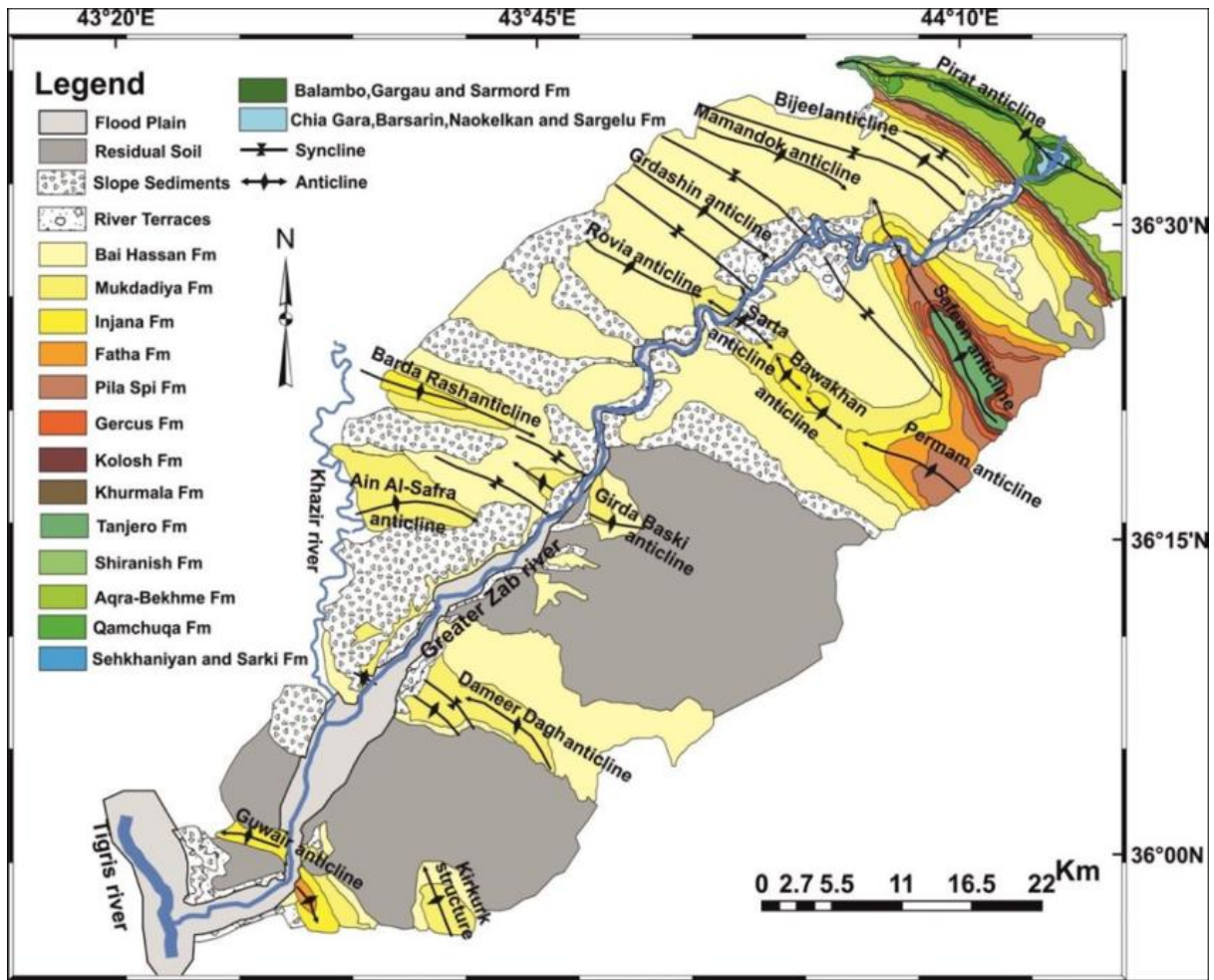


Fig. 4. Geological map of the studied area (after Elias and Sissakian, 2022).

Data Set and Method

The analysis of bank erosion and bank aggregation in a temporal context is the major goal of the study. One Landsat scene from USGS Earth Explorer, Landsat images contained enough information to cover the whole area, and UTM Zone 38N encompasses the research area. Six satellite images with dates ranging from 1973 to 2023 and one topographic map for the year 1952 from Hunts Company are used to evaluate changes in the study area (Table 1).

Table 1: Satellite images and topographic maps with their acquisitions and resolutions.

	Sensor	Band numbers	Date of acquisition	Spatial resolution [m]
Hunting Aero-surveys	-	Topographic Map	1952 Survey of Iraq	1:20,000
Landsat1	MSS	1,2,3	July 13, 1973	79
Landsat5	MSS	1,2,3,4	June 15, 1984	30
Landsat5	MSS	1,2,3,4	July 26, 1993	30
Landsat5	TM	1,2,3,4,5,6,7	September 24, 2003	30
Landsat8	OLI_TIRS	1,2,3,4,5,6,7	July 17, 2013	30
Landsat8	OLI_TIRS	1,2,3,4,5,6,7	July 29, 2023	30

In the dry season (June to September), multi-temporal Landsat images were collected with optical sensors. Only satellite images taken during the dry season were chosen because during this time of year, vegetation cover and other ground conditions, especially the water level, are relatively stable from year to year. This is crucial for determining how the GZR changes over time in terms of erosion and aggregation.

To distinguish between the soil, vegetation, and water body in the study area and to compare the riverbank line of several images, the Normalized Difference Water Index (NDWI) is utilized in this investigation. Water bodies have values greater than 0.5 (McFeeters, 2013). The NDWI map is created using the following equation:

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$$

When predicting the bank line relocation of any river system, coarser resolution photos typically lead to higher mistakes, and vice versa. Therefore, the Landsat-MSS image with a 79x79 m resolution fails to show bank erosion and aggregation in several areas along the studied river. Although Landsat-TM images at 30-m resolution are frequently more beneficial than Landsat-MSS 79-m resolution images for mapping uniform close-to-urban land covers, they occasionally may be less effective in uneven urban regions (Hossain et al., 2013). The MSS images with a 79-meter resolution had been resampled to a 30-m resolution.

In the current work, variations in erosion deposition by a decade are examined for the period intervals (1952–1973, 1973–1984, 1984–1993; 1993–2003; 2003–2013; and 2013–2023). This study uses spatial and temporal analysis to evaluate changes and geo-visualize variations in the GZR. Processing and studying geographical data in a GIS environment has been done, as has using the Random Forest for image classification technique in the R statistical program. Furthermore, Arc GIS version 10.8 is utilized to calculate river movement and bank erosion.

Moreover, between 1952 and 2023, the amount of lost land and newly generated land was measured individually for the two different banks. Where the most recent bank line crossed the prior line, erosion is present, and where it left the line, aggregation is present. The amount of erosion and aggregation is properly calculated. Finally, a scheme of erosion and aggregation is drawn, and thence, the movement is found.

Results

Classification Maps and Accuracy Assessment

Random forest classification is used to categorize the images into several land cover classes to examine how land use and land cover have changed over time. The versatility, feature importance evaluation, decreased overfitting risk, and hyperparameter modification of random forest make it one of the most used machine learning techniques (Halabaku and Bytyçi, 2024). Since there were no built-up areas in the study area in 1972, the image from that year is divided into four classes, as opposed to the 2023 image, which is divided into five categories: cultivated land, built-up areas, barren soil, rocky lands, and rivers. Actual and periodic percentage of changes in land cover across the various periods between 1973 and 2023 were examined as seen in Figures 5 and 6, respectively.

The combined data derived from the analysis of satellite images are presented in maps. In contrast to image 1973, which had an accuracy assessment of 0.96 and a kappa coefficient of 0.94, image 2023 had a kappa coefficient of 0.91 and an accuracy assessment of 0.93.

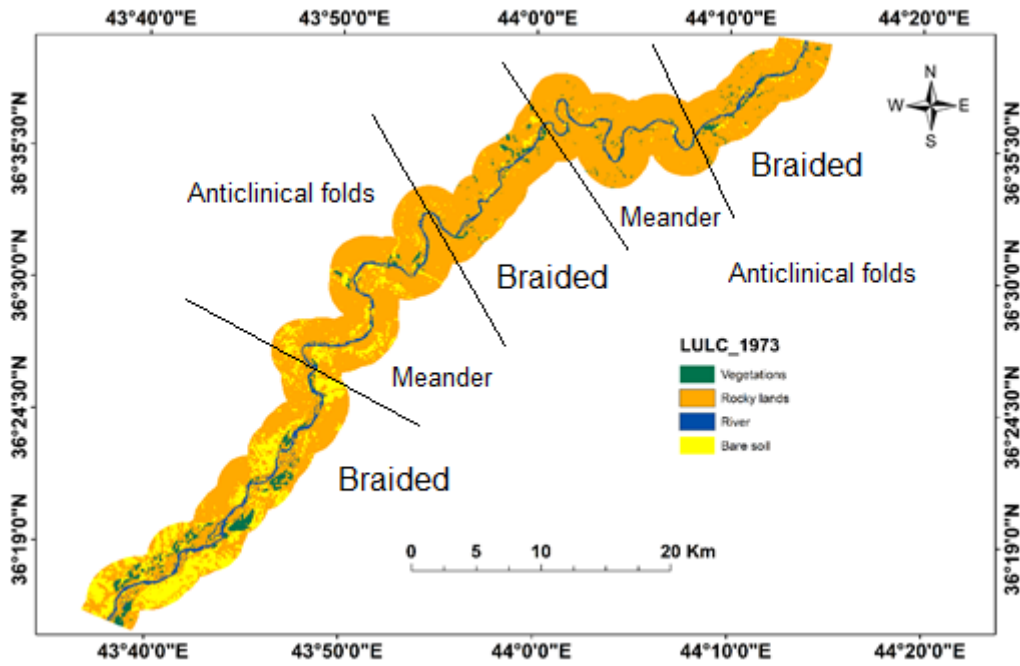


Fig. 5. Random Forest classification of GZR in 1973.

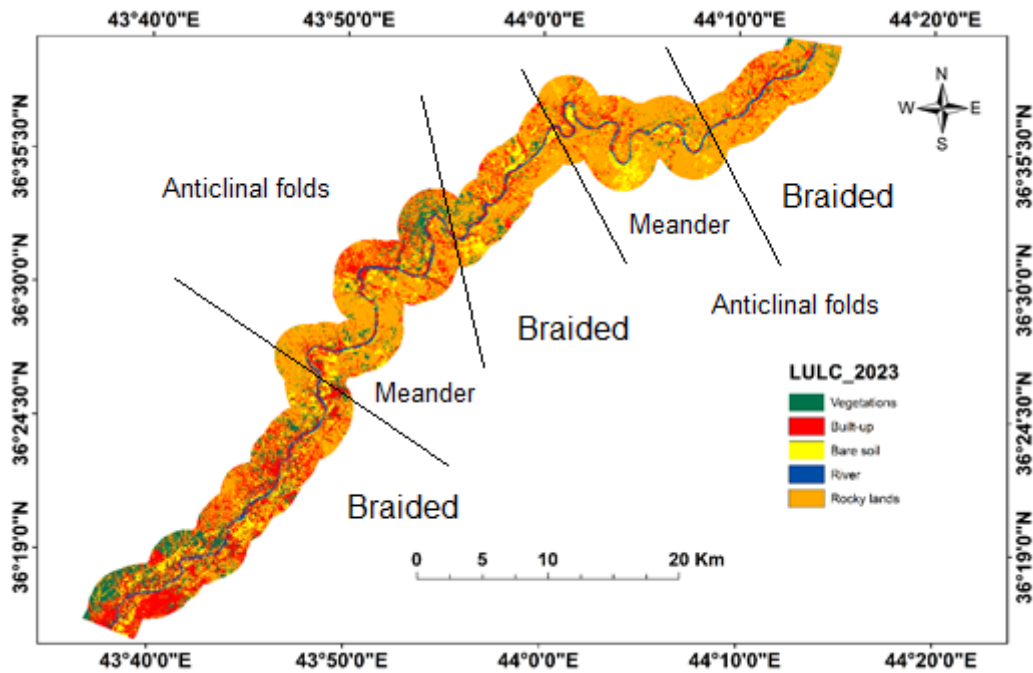


Fig. 6. Random Forest classification of GZR in 2023.

The GZR average channels were continuously altering between 1952 and 2023 according to the analysis of satellite images and a topographic map of the study area (Fig. 7). As a result of ongoing erosion and material deposition on its banks, the GZR will get shallower. This increases the likelihood that the river may flow in any direction, resulting in a lower channel gradient and larger sections (Sil et al., 2022).

Principally, meanders were formed in the middle of the course, as in the current study. The gradual development of these looping patterns is made possible by the gentle slopes and softer sediments that are typical of places with meandering rivers. Furthermore, continuous erosion on the outer bank and deposition on the inner bank form a meander in the river, which will migrate downstream and change shape over time (Kasvi et al., 2017).

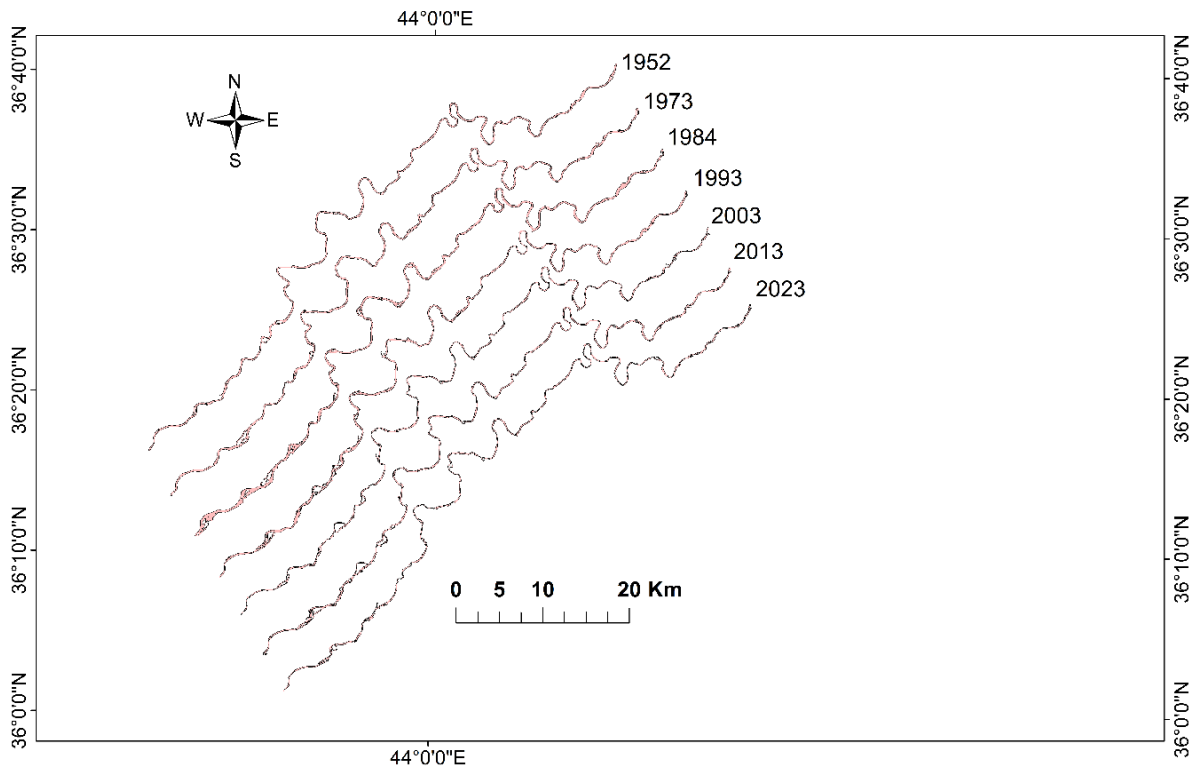


Fig. 7. GZR's stretches saw a series of channel planform modifications for GZR flow from NE to SW between 1952 and 2023.

Dynamics of Bank Erosion and Aggregation

The reduced erosion of 2.01 km² between 2003 and 2013 is seen in Table 2 at its lowest rate. However, between 1984 and 1993, the most significant rate of erosion increased by 9.38 km². In contrast, the rate of aggregation, which increased by 8.46 km², was at its highest between 1973 and 1984, and the minimum rate per 1 km² was 1.53 between 1993 and 2003. Moreover, the highest unchanged area is discovered between 1973 and 1984, reaching 16.59 km².

Table 2: Area of land aggregation, erosion, and unchanged water body (in km²) of the GZR between 1952 and 2003.

Years	Previous 10 years	Next 10 years	Unchanged	Erosion	Aggregation
1952-1973	18.23	19.25	12.17	6.06	7.07
1973-1984	19.25	25.06	16.59	2.66	8.46
1984-1993	25.06	19.11	15.68	9.38	3.40
1993-2003	19.11	12.89	11.36	7.72	1.53
2003-2013	12.89	15.48	10.88	2.01	4.60
2013-2023	15.48	12.72	10.34	5.13	2.10

The study area's status has gotten worse as a result of direct and indirect human influences, and recently, it has also become dangerous for the continued existence of several infrastructures close to the bank. According to this analysis, there has been significant land loss along both riverbanks. Within 71 years, there was a total of 32.96 km² of erosion in the studied area, compared to 27.16 km² of newly formed land. Therefore, the research region suffered from substantial erosion from 1952 to 2023. The lowest unchanged area was 10.34 km² as revealed between 2013 and 2023 (Fig. 8). Consequently, throughout the past 71 years, the GZR exhibited a dynamic behavior in terms of erosion, aggregation, and unaltered area.

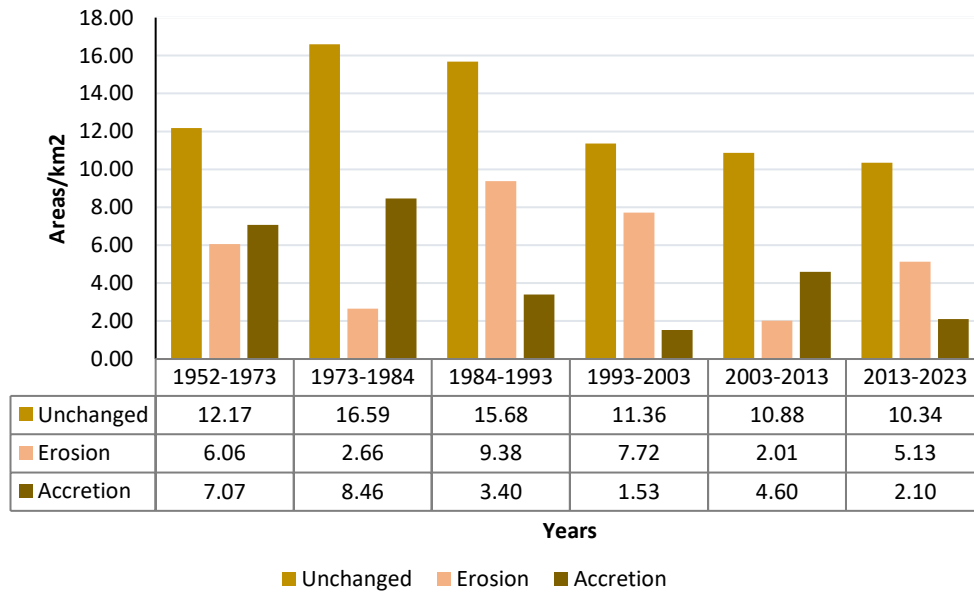


Fig. 8. GZR’s erosion, aggregation, and unchanged area between 1952 and 2023.

River Width

According to the findings shown in Table 3, the GZR's local width changed during the study period from a maximum of 545.8 m in 1984 to a minimum of 29.8m in 2003. Because of numerous variables such as erosion and aggregation, sand and gravel mining, rainfall changes, LULC changes, and temperature changes on both banks, the river's width has considerably varied over the past 71 years. For instance, between 1984 and 2023, the average river width substantially shrank from 318.1 m to 137.6 m; nevertheless, it also slightly increased from 215 to 218.25 m between 1952 and 1973, respectively.

From 1993 to 2023, the average width gradually decreased (Table 3 and Fig. 9). It is important to note that the average width of the river also increased from around 215 to 318.1 m between 1952 and 1984. With the lowest maximum width of 245.4 m, the lowest minimum width of 29.8 m, and the smallest area of 12.64 km², the GZR experienced a significant narrowing in 2023.

Table 3: Changes in the GZR’s width and area from 1952 to 2023.

Year	Maximum width (m)	Minimum width (m)	Average width (m)	Area (km ²)
1952	341.4	88.6	215	18.23
1973	359.7	76.8	218.25	19.24
1984	545.8	90.4	318.1	25.05
1993	350	71.5	210.75	19.10
2003	262	36.8	149.4	12.88
2013	263	47.5	155.25	15.47
2023	245.4	29.8	137.6	12.64

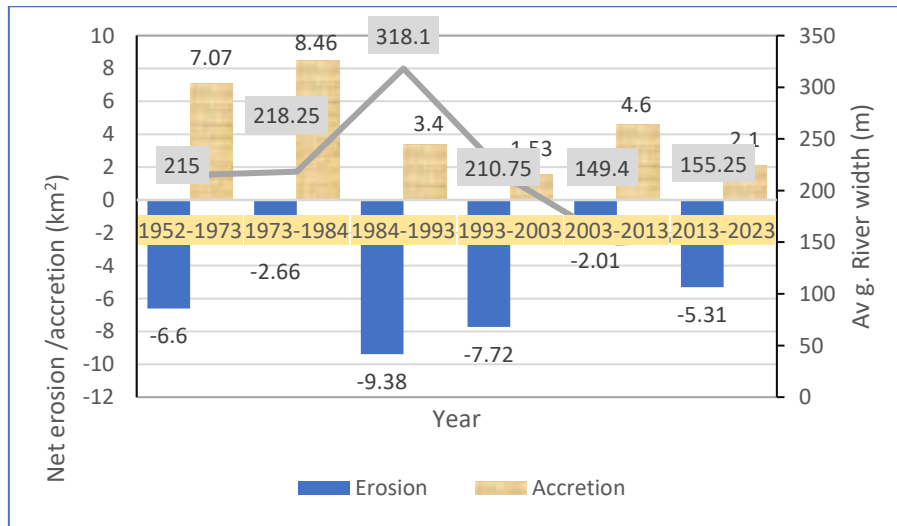


Fig. 9. Changes in the average river width of GZR under a net aggregation and erosion between 1952 and 2023.

Use of Goods and Services by Neighborhood Households Near the Greater Zab River

Compared to 1952, the area of the GZR was smaller, comprising nine patches and 18 islands in 2023 (Table 4). Water abstraction, sand and gravel mining, river channelization, and river fragmentation have all caused more and more harm to the Greater Zab River in the study area over the last seven decades.

The year 2023 experienced the highest fragmentation with nine patches, but had four patches in 1993. The increasing number of patches indicates ecosystem degradation; thus, it is a sign of an unhealthy ecology in the GZR in 2023 (Fig. 10). Consequently, a variety of pressures will apply to the GZR, such as point-source and diffuse contamination from sand and gravel mining, providing drinking water, invasive plant and animal species, physical change, and climate change (Ritter et al., 2002).

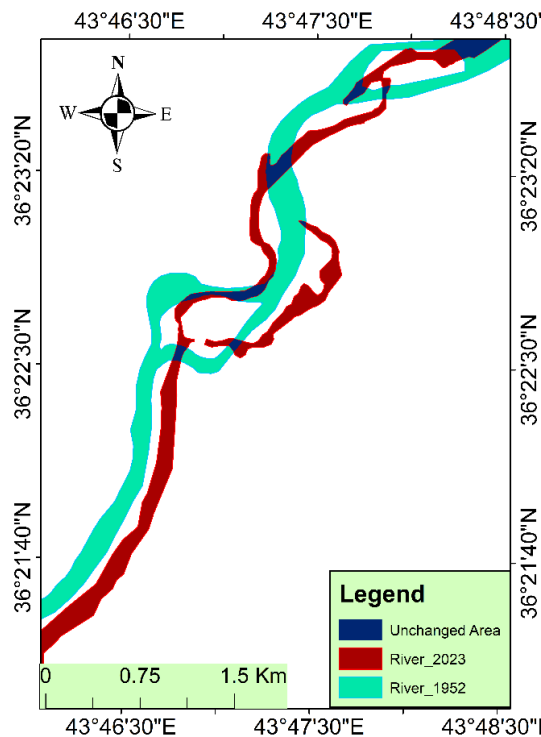


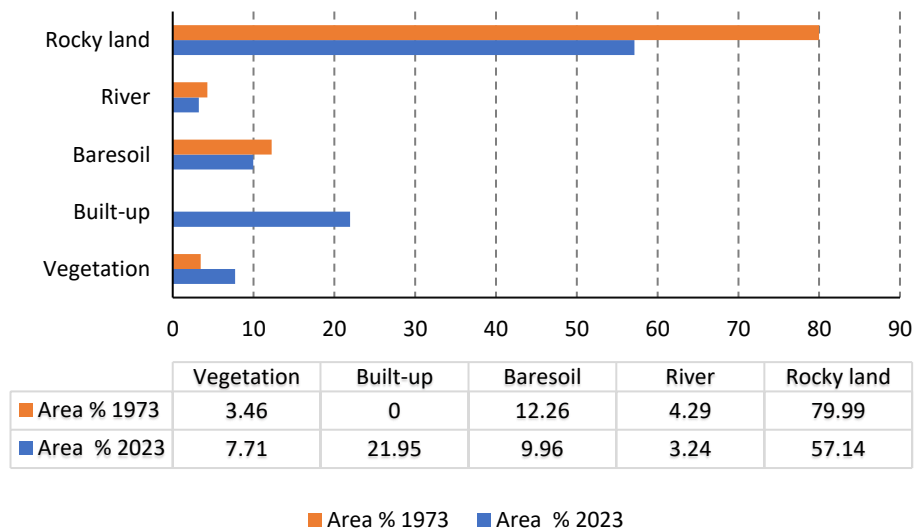
Fig. 10. Part of fragmented GZR in 2023 with red color indicating channel shifting during the research period; the river in 1952 is colored by beryl green; the unaltered sections are colored by blue.

Table 4: Areas, islands, and patches of the GZR in all years.

Year	Area (km ²)	No. of Islands	No. of patches including the river
1952	18.23	13	1
1973	19.24	8	1
1984	25.05	19	1
1993	19.10	36	4
2003	12.88	21	3
2013	15.47	47	2
2023	12.64	18	9

Effects on Household Livelihoods of Land Use and Land Cover Change

Two periods have been explained in this sub-section, which are 1973 and 2023. The categorization area statistics are shown in Figure (11), and percentages are used to measure the classed areas. The LULC maps are displayed in Figures 6 and 7 for two different time points. In the area of interest, rocky lands predominated the landscape in 1973 and 2023, taking up 79.99% and 57.14% of the total area respectively.

**Fig. 11. Percentage of changes in LULC within the study area between 1973 and 2023.**

The built-up area came next, accounting for 21.95% of the total area only in 2023, as there was no built-up area close to the river in 1973. Additionally, in 1973 and 2023, the percentage of bare soil was respectively 12.26% and 9.96%, that of vegetation was 3.46% and 7.71%, and the percentage of the river was 4.29% and 3.24%.

Thus, the results show that built-up and vegetation areas were significantly correlated with the water point's physical appearance. According to the results of the study conducted from 1973 to 2023 on various types of land, built-up and vegetated areas experienced the greatest positive changes, while bare soil, rivers, and rocky areas underwent the greatest negative changes.

Impacts on socioeconomics, biodiversity, hydrology, and the environment might result from changes in the rivers. In Table 5, further information is displayed along with explanations.

Table 5. Land class values in the GZR in 2003 and 1973 are expressed as areas in km².

Years	2023	1973
Land class	Area (in km ²)	Area (in km ²)
Cultivated land	1.41	0.63
Built-up	4	0
Bare soil	1.82	2.23
River	0.59	0.79
Rocky land	10.41	14.58
Total	18.23	18.23

Discussion

According to Table 2, erosion and aggregation are the main problems that are present in the alluvial plains of the GZR. The combined number of these problems is significant and concerning. In general, the Greater Zab riverine system underwent several alterations over the research period. For instance, there were significant positive changes between 1952 and 1984, when the area of the river increased from 18.23 km² to 25.05 km² respectively. The river area then underwent a severe decline between 1984 and 2003, shrinking to 12.88 km² in that year. Between 2003 and 2013, the river's area increased significantly, reaching 15.47 km². However, in 2023, the river's size began to decline once more, reaching 12.64 km², and recording the lowest area in the last seven decades (Fig. 12).

According to the findings, the river has undergone significant channel alterations over the past century, particularly in the most recent decades, as a result of declines in width. Since the river hasn't yet reached a new equilibrium condition, the observed trends of channel alteration allow us to project that there will be declines in width and braiding intensity. This will probably continue shortly as the channel moves closer to a new equilibrium state due to a change in the river.

Moreover, the level of morphological reaction was high. The river has narrowed significantly, which is the most noticeable difference. This has caused the average width to drop to barely 28.11 percent of its original value throughout the period. This is shown due to a change in river pattern from braiding to meandering.

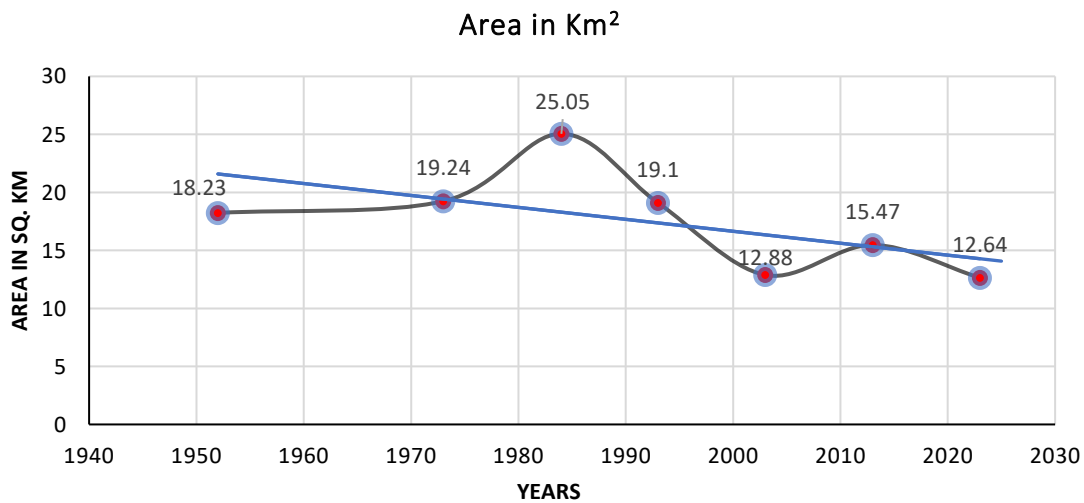


Fig. 12. Area (in km²) of the study area between 1952 and 2023.

The first period, which lasted from the turn of the 20th century until the end of the 1980s, saw few human influences on the river and river morphology that was either in or very similar to its natural state. There was no fragmentation of the river, and the river also expanded. However, the river began to split, the number of islands increased, and the river's area shrank beginning in the 1990s. This is due to increasing human impacts, the extraction of more sand and gravel, the use of the river as a source of drinking water, and decreased rainfall, with the lowest recorded amount of 355.3 mm in 2021 (Fig. 2).

A temporal analysis of land use and land cover shows that certain classes are growing while others are shrinking. For instance, built-up areas and vegetation land between 1973 and 2023 were rapidly developed from 0% and 3.46% to 21.95% and 7.71% respectively at the expense of other land classes including bare soil, river course and rocky lands (Fig. 11). Because

of the additive effects of various human activities to some extent, the amplitude of morphological responses has been quite high in the case of the GZR. Along with this, one of the main trends for expanding the vegetation area is the growth of human settlements and other infrastructure-related activities, including the extension of road networks. Additionally, many people rely on agriculture for their livelihood, and they practice it along the adjacent banks of the river. However, their lives are terrible, and they suffer significant financial losses as a result of the frequent shifting of riverbanks.

Many factors have influenced the environment in the research region; for example, on both sides of the GZR, there are around seventy (both legal and unlawful) sand and gravel mines. Increasing mines of sand and gravel means destroying the riparian vegetation and degrading the river ecosystem. Overall, agricultural areas have increased from 3.46% in 1973 to 7.71% in 2023 (Fig. 11), leading to significant bank erosion. All things considered; the risk of bank erosion is reduced when there is any kind of vegetative cover along the riverbanks.

These mines are the main cause of habitat loss (Das et al., 2014), physical habitat disturbance, riparian habitat destruction (Koehnken et al., 2020), increased water turbidity (Padmalal and Maya, 2014), increased water salinity (Ashraf et al., 2011), increased water treatment costs (Ashraf et al., 2011), lateral channel erosion and instability (Mukherjee et al., 2017), influencing the uncertainty of the slope (Hackney et al., 2021), and changes in water flows (Rentier and Cammeraat, 2022). All of which had affected the river ecosystems. Furthermore, this has caused a decline in soil erosion and soil quality that was drastically altering the landscape. Thus, sand mining changed the GZR ecosystem.

All impacts realized in this research indicate that river sand extraction has damaged the biological environment and affected the entire food chain and ecosystem services. Moreover, the depletion of natural resources in the study area is causing a loss of ecosystem services as well, such as the provision, regulation, and support of services (Blumstein and Thompson, 2015). On the other hand, it is essential to identify land uses that are extremely sensitive to human activities to prevent harm to ecosystem services for drinking water surrounding the basin (Davids et al., 2018). Additionally, a large temperature change can reduce biodiversity, and a warmer river holds less dissolved oxygen in its water (Scarano, 2019).

Moreover, sand and gravel excavations, along with rainy weather, led to riverbank erosion in the study area. Thus, the development and modification of the surrounding GZR occurred at different periods, which led to the destruction of the biological environment. Also, all of these human-induced channel changes can have adverse impacts on the environment, society, and economy, including the destruction of riparian vegetation and infrastructure, an increase in the danger of flooding, and adjustments for aquatic and riparian vegetation ecosystems. Similarly, it has been noted that as river discharge and flow velocity have increased, bank erosion has accelerated (Sil et al., 2022).

Since the majority of alluvial rivers are found in the study area due to geology, monsoon rains are another factor that significantly affects bank erosion. During this time, the river reaches its peak flow, and its capacity and speed increase, causing the side banks to overflow and causing severe bank erosion.

Human activities were the key factor that induced flow alteration in the natural flow regime of the GZR. For the planning, development, delivery, and evaluation of the results of environmental water regimes, it is imperative to comprehend the implications of these flow regime modifications (Rolls and Bond, 2017). As a result, various disturbances will have an impact on the biodiversity and ecological functioning of the GZR and its floodplain (Poff and Zimmerman, 2010).

The biggest dangers to the world's biological diversity in riverine systems are thought to be river fragmentation and riparian vegetation loss, and this is as of 2023 (Table 4). Due to a

decrease in aquatic areas, fragmentation isolates the patches and harms species composition. The movement and protection of species depend on habitat corridors. To preserve green spaces that can serve as important recreational areas, their development and administration are crucial. Therefore, riverbank erosion is strongly related to vegetation. Consequently, the GZR is under threat because all indications point to the river ecosystem's decline.

Accordingly, human involvement can directly cause channel shape changes, which are typically detectable only over decades (Kang and Kanniah, 2022). Thus, these results explain the decline in natural resources in the GZR basin by demonstrating an inherent drop in resources brought on by growing agriculture and urbanization.

The current study has shown how social and economic factors stress the GZR, altering its ecological processes and impacting its fauna and flora. A multitude of factors, such as water discharge, anthropogenic activities, and climate change, constantly alter the dynamics of the GZR channel. Among these, flood-related incidents have the potential to drastically and unpredictably change river courses.

Thus, the region covered by erosion was generally shown to be more dynamic between 1952 and 2023 than the area covered by aggregation (deposition). The dynamics of the GZR and other rivers of a similar nature around the world will be better understood thanks to this study. Doing micro-research in this sensitive area is therefore vitally needed to support the preservation of the river's ecosystem.

Finally, in the last three decades, the GZR habitats were most negatively damaged and took the biggest hit by human activity, particularly sand and gravel mining, although most reaches were affected for a variety of reasons. Unfortunately, there is no strategy for river restoration in this area or even in the whole of Iraq to protect biodiversity and stop further deterioration.

Conclusion

1. The present work demonstrates how Landsat satellite data can be successfully applied to RS and GIS using multi-temporal satellite imagery to monitor riverbank erosion and aggregation.
2. Due to the characteristics of the research area, the sand and gravel mining activities influence changes in river morphology (shape) at different levels.
3. This study highlights the effects of operations along the GZR, including sand mining and artificial meander closures for irrigation purposes, on the river migration.
4. Continued river channel narrowing results in a shift in the behavior of the river system, necessitating an urgent management strategy combining the river's risk reduction and improvement.
5. This investigation of the GZR has shown that the year 2023 saw a notable shortening of the waterway.
6. It has undergone significant modifications to accommodate human demands, including the removal of sand and gravel from the river, the riparian vegetation buffer zone, 's destruction and the provision of irrigation water.
7. In 2023, clearing land utilized for extensive residential, agricultural, and industrial purposes, like sand and gravel mining, was the most typical change. Therefore, across all time scales, human intervention has grown to be a significant force affecting river dynamics.

Conflict of Interest

The author declares that there are no competing interests.

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