Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

The Impact of Quarrying on Aquatic Flora within the Middle Course of Sirwan River, Iraqi Kurdistan Region

O impacto da exploração de pedreiras na flora aquática no curso médio do rio Sirwan, na região do Curdistão iraquiano

Sarkawt Ghazi Salar [1*(ORCID 0000-0002-9718-404X)], Mohammed I. Khalil [1(ORCID 0000-0002-9310-2780)], Arsalan Ahmed Othman [2,3(ORCID 0000-0002-4212-228X)], Salahalddin S. Ali [3(ORCID 0000-0002-0337-4839)], Bakhtyar Ali Ahmad [4(ORCID 0009-0002-3071-3362)], Ahmed K. Obaid[5,6(ORCID 0000-0003-4057-6314)]

[1]University of Garmian, Bardesur, Kalar, Iraq. *Author for correspondence: sarkawt.ghazi@garmian.edu.krd
[2]Iraq Geological Survey, Sulaymaniyah Office, Sulaymaniyah, Iraq.
[3] Komar University of Science and Technology, Sulaimaniyah, Iraq.
[4]Salahaddin University-Erbil, Erbil, Iraq.
[5]University of Baghdad, Al-Jadiryah Street, Baghdad, Iraq.
[6]University of Durham, Durham, United Kingdom.

Submission: May 03th, 2025 | Acceptance: July 28th, 2025

ABSTRACT

The Sirwan River, a tributary of the Tigris River, flows from the northwest of Iran and continues through the Iraqi Kurdistan region. It has undergone significant changes due to human activities over the past three decades. This research examines the geomorphological and biological changes from 1990 to 2022 caused by man-made disruptions. Fieldwork was conducted to determine and assess the occurrence of aquatic plants in ponds formed by quarrying along the middle course of the river, along with measurements of the ponds' chemical and physical properties. Satellite imagery from Landsat 5, Landsat 7, and Landsat 8 was used to analyze land cover changes over the study period. The images indicated substantial impacts of quarrying on land cover, with an increase in barren land at the expense of vegetation cover. According to the results, throughout 33 years, the vegetation cover declined and was replaced by bare soil. There was a clear, strong correlation between the two land cover classes: vegetation cover vs. barren soil ($r=0.983$, $p < 0.05$). Also, the results revealed significant changes in aquatic plant diversity between pond habitats and running water. We are recommending that monitoring of weed species distribution in the Sirwan River helps to mitigate ecological imbalances and protect both living and non-living river components. Additional research is required to identify strategies for minimizing the environmental impact of quarries in this region.
KEYWORDS: Geomorphology. Anthropogenic Processes. Riverscape. Species Diversity. Aquatic Plants.

RESUMO

O rio Sirwan, um afluente do rio Tigre, flui do noroeste do Irã e continua através da região do Curdistão iraquiano. Ele passou por mudanças significativas devido às atividades humanas nas últimas três décadas. Esta pesquisa examina as mudanças geomorfológicas e biológicas de 1990 a 2022 causadas por perturbações causadas pelo homem. O trabalho de campo foi conduzido para determinar e avaliar a ocorrência de plantas aquáticas em lagoas formadas pela exploração de pedreiras ao longo do curso médio do rio, juntamente com medições das propriedades químicas e físicas das lagoas. Imagens de satélite do Landsat 5, Landsat 7 e Landsat 8 foram usadas para analisar as mudanças na cobertura do solo ao longo do período de estudo. As imagens indicaram impactos substanciais da exploração de pedreiras na cobertura do solo, com um aumento de terras áridas em detrimento da cobertura vegetal. De acordo com os resultados, ao longo de 33 anos, a cobertura vegetal declinou e foi substituída por solo descoberto. Houve uma correlação clara e forte entre as duas classes de cobertura do solo: cobertura vegetal vs. solo árido ($r = 0{,}983$, $p < 0{,}05$). Além disso, os resultados revelaram mudanças significativas na diversidade de plantas aquáticas entre habitats de lagoas e água corrente. Recomendamos que o monitoramento da distribuição de espécies de plantas daninhas no Rio Sirwan ajude a mitigar os desequilíbrios ecológicos e a proteger os componentes vivos e não vivos do rio. Pesquisas adicionais são necessárias para identificar estratégias para minimizar o impacto ambiental das pedreiras nesta região.

PALAVRAS-CHAVE: Geomorfologia. Processos Antropogênicos. Paisagem Fluvial. Diversidade de Espécies. Plantas Aquáticas.

INTRODUCTION

A river is a system that constantly seeks to achieve output and input balance. Any human intervention can significantly impact the entire system, and alluvial rivers' morphology might alter in reaction to this interference (GHOSH et al. 2016, WROBLESCKI et al. 2021). Humans act as geomorphic agents that sculpt and shape the Earth's surface through their activities. MIGOŃ & LATOCHA (2018) and SCHMUTZ & SENDZIMIR (2018) demonstrated how human activity affects the geomorphic environment and ecosystems directly and indirectly. RAHIMI et al. (2024) emphasize that human activities negatively impacted LULC changes and caused forest degradation in Kurdistan.

In recent years, numerous studies have delved into the environmental impact of quarrying activities (KONDOLF 1994, NEWSON & NEWSON 2000, MARCHETTI 2002, BRAUER & BEHEREGARAY 2020). However, research specifically focusing on sand and gravel extraction and its effects on various environmental components remains scarce. Sand and gravel are mechanically extracted from rivers and streams' active channels as part of an instream gravel mining operation. Because active channel deposits are usually durable, they are suitable as building aggregates (KONDOLF 1994, DEVI & RONGMEI 2017). According to BENDIXEN et al. (2021), sand and gravel are essential for economic development in both developed and developing countries. MARCHETTI (2002) and VANDANA et al. (2020) stated that economic growth alters the fluvial environment of an area through the extensive mining of sand and gravel for building purposes due to well-known urbanization.

Ecosystems and the environment are harmed mainly by human activity. The environmental difficulties caused by aggregate mining activities are severe and include noise, dust, air quality, suspended particulate matter, and gaseous emissions (UKPONG 2012). Excavating damages to the landforms and many ecological effects concerned with quarrying exercises near the stream can lead to health-related issues and harm biodiversity (OZCAN et al. 2012). BHATTACHARYA et al. (2019) investigated how quarrying's geomorphic reactions affected the dynamics of riverscapes, and their findings demonstrated that sustainable sand mining preserves the management of fluvial dynamics while including stable geomorphic responses.

According to DEL TÁNAGO et al. (2015), human behaviors influence the biogeomorphology of the fluvial ecosystem. (ELOSEGI et al. 2010) reported that geomorphology is fundamental to fluvial biodiversity and the environment since the stream shape gives a place for the biota and a physical system for environmental forms. Human activities progressively modify the waterway morphology on a worldwide scale. In addition, CASTALDINI et al. (2019) showed the mentioned channel morphological deformation by a map demonstrating fluvial and man-made landscapes utilizing remote sensing information and field investigations. For this purpose, AL-JAWADI et al. (2023) used aerial photographs and satellite image data to compare many isolated durations to explain the incredible deformations within the stream and its banks. Consequently, this led to a buildup of pools along the river and the growth of the aquatic vegetation.

Streams and rivers are fundamental to the existence of habitats that live along with them. Their preservation and protection are necessary for life continuity, climate amelioration, global biodiversity, complexity, agriculture, and sustainability (BRAUNS et al. 2022). Sirwan River is one of the main tributaries of the Tigris River in the Iraqi Kurdistan Region, which is identified as a very highly suitable zone for rainwater harvesting, as most of the drainage networks drain into this river (ALKARADAGHI et al. 2022, AZIZ et al. 2023). It originates from Zagros Mountain and covers an area of 32600 Km^2 (AL-KHAFAJI & AL-CHALABI 2019). Most of the basin area (57%) is located within the Iranian border, and the rest area (~43%) lies within the Iraqi border (AL-FARAJ & SCHOLZ 2014).

According to NAQI et al. (2021) and AL-JAWADI et al. (2023), this basin is divided into three parts: (1) the upper Sirwan River Basin, which forms the upstream area of the Darbandikhan dam; (2) the Middle Sirwan River Basin, which includes the area between Darbandikhan and Hamreen dams. and (3) Lower Sirwan River Basin, which forms the downstream area of Hamreen Dam. The water resources in the Sirwan River basin are used for domestic, agricultural, livestock, and industrial purposes (AL-KHAFAJI & AL-CHALABI 2019). In addition, it provides an appropriate habitat within the basin's boundary for aquatic plants and animals. Based on ABBAS & ABDUL-RAZZAK (2006), HAMZA (2012), ABDULLAH (2013), and AL-MUSAWI (2018), the river's hydrochemical properties indicate that its water quality is appropriate for irrigation and drinking within the basin area. Besides the surface water, a considerable portion of the groundwater is suitable for irrigation and drinking, too (ABDULLAH et al. 2019).

The aquatic weed plants or macrophytes have both negative and positive ecological roles in the aquatic ecosystem (MITCHELL 1989). For example, the positive impacts of controlled weeds are mediating many biogeochemical cycles and the flow of water in the river stream (MITCHELL 1989, FRENCH & CHAMBERS 1996), as well as providing food and shelter for vertebrates and invertebrate organisms (SUREN et al. 2000, GROSS et al. 2001). Despite the positive influence of weeds, they have adverse impacts when they get out of control. For example, the fast growth characteristics of the weeds allow them to invade the river, decrease the floral diversity, and competitively eliminate the niche of many other plants (HUANG et al. 2008). In addition, they will also reduce the water flow in the stream and cause eutrophication in the river (CARPENTER 2005). In addition, the disturbance due to ecological or anthropogenic factors (habitat destruction) inhibits the growth of native species and allows weeds to grow and invade the distributed area. Long-term anthropogenic activities will encourage weed establishment and cause a decrease in species diversity (species loss; HUSSEIN et al. 2021).

The Sirwan River, within the Kurdistan region, suffers from three main problems: runoff quantity, water quality, and environmental degradation. These problems are caused by climate change, water storage projects in upstream areas inside the Iranian border, municipal wastes of Sulaimaniyah City that polluted Tanjero stream (OTHMAN et al. 2021, OTHMAN et al. 2023, HASAN et al. 2023), and extreme excavation by gravel and sand quarries along the middle part of the river, especially between Kalar and Darbandikhan towns. The overall objective of this study is to investigate the effects of anthropogenic activities (geomorphological changes via the ponds made on the Sirwan River) on river flow and the growth of aquatic weeds. We hypothesized that the abundance of aquatic weeds increases in the ponds, which may serve as favorable habitats. The importance of this study is to pay more attention to restoring and rehabilitation the river to its previous condition prior to disturbance and to conserve the fluvial condition of the river.

MATERIAL AND METHODS

Study area

The study area includes a river course between Kalar and Darbandikhan towns. It comprises a part of the middle Sirwan River and covers an area of 134.33 km^2. It extends between latitude (34°30'36'' and 35°06'36'') N and longitude (45°13'30'' and 45°42'36'') E (Figure 1). Geologically, the present area comprises sedimentary rocks belonging to the Pilaspi, Fat'ha, Injana, Mukdadia, and Bai Hassan formations. Besides that, several Quaternary sediments outcrop in the study area, including polygenic, river terraces, alluvial fans, flood plains, and valley fill sediments (BUDAY 1980, ALI et al. 2016b).

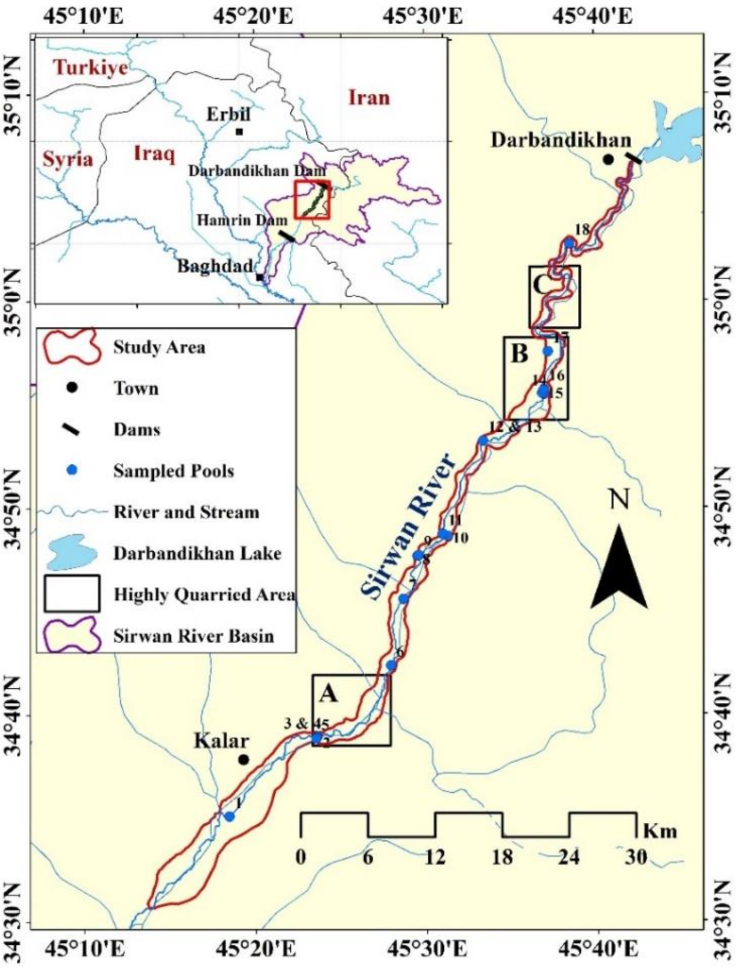

Figure 1. The study area is within the Sirwan River Basin. A, B, and C squares are highly quarried areas that represent intense human activities.

Climatically, the study area is characterized by moderate to hot temperate climatic conditions. On average, the study area receives rainfall of 290 – 665 mm·y-1. The amount of rainfall increases from the south to the northern parts of the study area. The study area's annual mean maximum, minimum, and average temperatures stand at 23.3 °C, 11.9 °C, and 17.6 °C, respectively (ALI et al. 2016a).

The study area shows high anthropogenic activities along the Sirwan River (Figure 2), which acts as a potential area for fluvial sediments. It provides raw materials (sand and gravel) for construction within the administrative border of the Sulaimaniyah governorate. Tens of sand and gravel quarries are active along the Sirwan River between Darbandikhan and Kalar towns, affecting the fluvial environment of the river. The excessive anthropogenic excavation, extraction, cutting, and filling in the quarries led to environmental degradation and changes in river morphology.

Field data collection

The required data were collected based on the suitable conditions for the life of the aquatic plants, their growth, and their spatial distribution along the middle part of the Sirwan River. These data included in-situ measurements of some chemical parameters of the water in the pools, such as electrical conductivity (EC), acidity (pH), dissolved oxygen (O_2), and total dissolved solids (TDS) measurements using an electrode-based device (Table 1). In addition, the geometry of the pools was measured, which included depth, width, and area. Furthermore, aquatic species (macrophytes) were identified according to Iraqi flora standards (TOWNSEND & GUEST 1980).

To estimate species richness (species abundance), a 1 m2 quadrat was applied randomly (average 4 locations per pond) to estimate species cover percentage per study site. Pearson's product-moment correlation (CHEE 2015) was used to find the relation between time (1990-2022) and vegetative status change and between bare soil and vegetative cover in the study area. In addition, the diversity of species among sites was calculated using the Shannon index (ORTIZ-BURGOS 2016).

Satellite Imagery

In addition to the fieldwork, we used the satellite imagery to assess the impact of quarrying. Quarrying activity in the study area began in 1990. Therefore, Landsat 5, 7, and 8 surface reflectance data were used for the period between 1990 and 2022 to shed light on the morphological changes of the river environment. Several reasons led to the selection of July, including the dry season, the cloud-free sky, and evergreen vegetation along the river's course.

In addition to visual image analysis, the Normalized Difference Vegetation Index (NDVI) was utilized as a tool to monitor the land cover change over the past 33 years in order to monitor the land degradation in the river course that occurred during the past 33 years as a result of anthropogenic activity (quarrying activity). It displayed the chronological sequence of the pools' formation to see whether there were differences between the oldest and youngest pools. The index data were acquired using the two European scientific platforms (EO-Browser and Landviewer), by applying Equation (1) (ROUSE et al. 1974) to visualize land cover classes (vegetation, water, and bare land) as shown in Appendix (A and B):

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

where NIR and R values are the infrared and red portions of the electromagnetic spectrum, respectively.

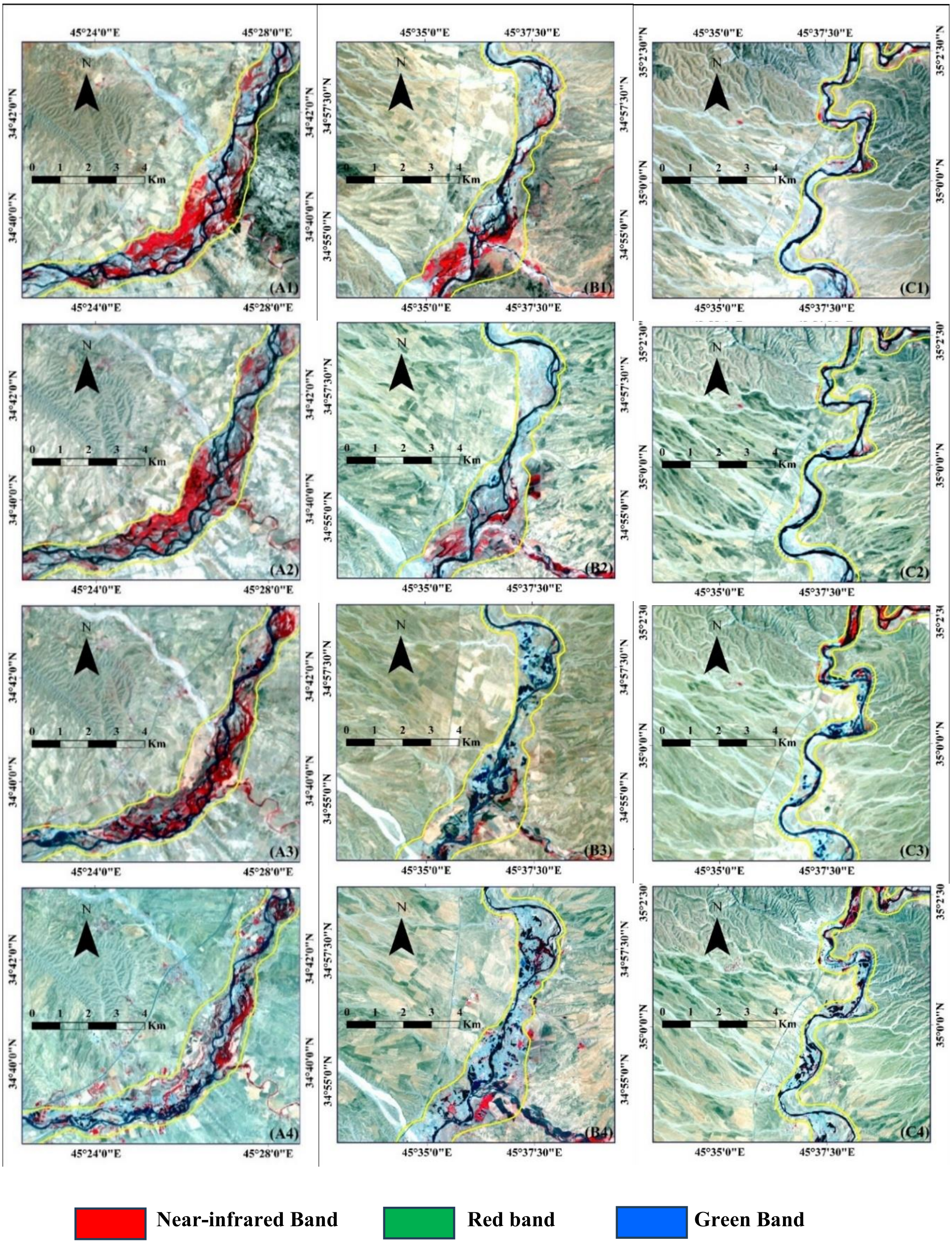

Figure 2. False colored satellite imagery show Sirwan River changes during the period 1990 to 2022 (A1, B1, and C1) Landsat 5 (432) 1990; (A2, B2, and C2) Landsat 5 (432) 2000, (A3, B3, and C3) Landsat 7 (432) 2010, and (A4, B4, and C4) Landsat 8 (**543**) 2022. The red color shows the vegetation cover, while the dark blue color shows the water bodies, and the light blue color shows the bare area.

Table 1. Chemo-physical properties of ponds along sites (with their GPS coordinates).

NO.	Location Name	Latitude	Longitude	Acidity (pH)	EC (2000 µS/cm)	Dissolved Oxygen (O_2%)	Area (m^2)	Perimeter (m)
1	Grdagozina Bridge	34.5847	45.307661			100	160	48
2	Bardasur1	34.64907	45.393359	8.02	0.237	100	6615	513
3	Bardasur2	34.64855	45.393681	7.59	0.251	100	2362	301
4	Bardasur3	34.64849	45.393208	7.59	0.251	100	2362	301
5	Bardasur4	34.64743	45.392517	7.59	0.251	100	1443	178
6	Tazade	34.70633	45.466034	7.86	0.23	100	140	44
7	Isayi	34.76048	45.478646	7.54	0.24	100	10163	447
8	Qula Barz 1	34.79445	45.491452	7.54	0.243	100	6587	512
9	Qula Barz 2	34.79484	45.493536	7.54	0.243	100	1302	146
10	Qaracham-Duck Lake	34.81082	45.521947	8.5	0.169	100	9565	422
11	Qaracham-Sirwan River	34.81182	45.516937			100	4962	464
12	Awakheri 1	34.88786	45.555445	7.9	0.189	100	40921	1275
13	Awakheri 2	34.88785	45.556256	7.9	0.189	100	40921	1275
14	Maidan1	34.92496	45.616311	8.07	0.17	100	19566	710
15	Maidan2	34.92586	45.615312	8.08	0.17	100	20120	758
16	Maidan3	34.92771	45.616874	8.08	0.17	100	20352	1008
17	Laly Khan Hama Faraj	34.96044	45.621475	8.015	0.19	100	56524	2395
18	Tuni Baba Umrah	35.046	45.641693	7.8	0.19	100	8107	801
19	Kampi Khuwar	35.10408	45.701412	7.48	0.207	100		

Change detection and statistical analysis

After calculating the areas of land cover classes, the multivariate analysis of variance was used to find the differences among land cover classes (vegetation, barren, and water) during the study period. In addition, trend analysis, linear regression, and the Pearson correlation coefficient were calculated to find out the relationship between land cover classes (Equation 2). ANOVA was used to test the spatial change in species diversity and to see the differences among study sites. All the statistical analyses were done using R (TEAM 2013). The change detection has been done using simple subtract methods for the land cover classes. The change in area has been calculated using ArcGIS 10.8.1.

$$\mathrm{r}_{xy} = \sum_{i=1}^{n} \frac{X_i - \bar{X}}{\sqrt{\sum_{k=1}^{n}(X_i - \bar{X})^2}} \cdot \frac{Y_i - \bar{Y}}{\sqrt{\sum_{k=1}^{n}(Y_i - \bar{Y})^2}} \qquad (2)$$

where X_i and Y_i are the values of each pixel in the X and Y classes. while $\bar{X}$ and $\bar{Y}$ represent the mean of the X and Y classes.

RESULTS

In addition to natural activity, where the rivers change their courses with time and Place (OTHMAN & GLOAGUEN 2013, SALAR 2013), there are man-made activities that lead rivers to change their courses (CHARLTON 2007). Satellite data analysis revealed two types of river course changes in the Sirwan River (Figure 2). The dominant changes were man-made, and the observed changes have been noticeable from 1990 till now. Our results show an increase in the number and size of man-made ponds over time due to quarrying activity along the river course. Figure 2 illustrates that the river bank and basin changed over time, and the green area was disturbed and covered with gravel. The most extensively impacted areas by quarrying along the river course are locations (A, B, and C), as they appear clearly in Figure 2.

The results showed that the vegetation cover declined and was replaced by barren soil over 33 years (Appendix A and Figure 3). Selected NDVI (1990 and 2022) has been reported to visualized the vegetation distribution in the Sirwan River course (Appendix B). Moreover, the temporal changes showed different patterns over the years. There was a strong correlation between the two land cover classes: vegetation cover vs. barren soil (r= 0.983, p= 0.000003; Figure 3B). The figure shows that the bare area increased and the vegetation decreased (concerning the year effect).

The temporal fluctuation patterns in the vegetation cover were complemented by an increase in the barren land cover (up-down peaks in Figure 3A, r= 0.51, and p= 0.006 for the vegetation and r= 0.47, and p= 0.002 for the barren area). The highest vegetation cover distribution was in 2003 (46.36 Km^2), while the lowest vegetation cover was in 2009 (8.4 Km^2) compared to other years. Oppositely, the barren soil cover in 2003 was the lowest (86.12 Km^2) than in other years. Different ponds (with the majority on the upstream side of the river) were created as a result of quarrying (man-made activities) along the river course.

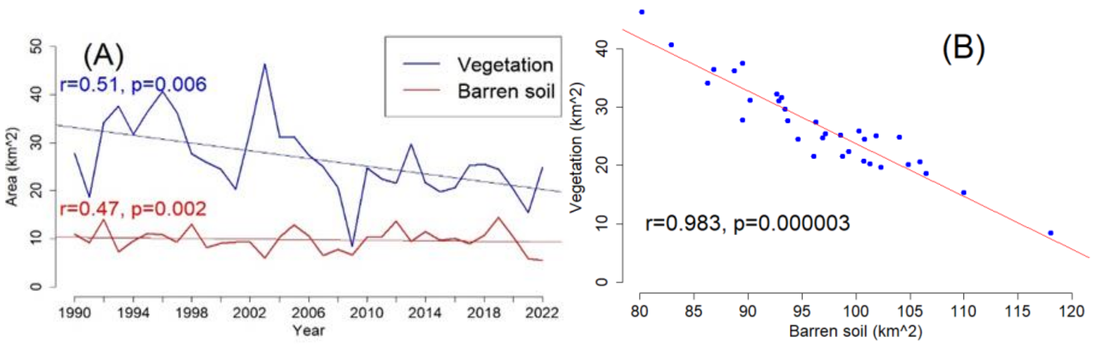

Figure 3. Line graphs show A) the change in the *vegetation* cover and barren area over time (1990-2022), and (B) the relationship between areas of the vegetation cover and barren soil.

Besides land cover changes, quarrying and fragmentation processes reflected on the aquatic flora along the river through habitat fragmentation. This habitat fragmentation (abiotic filtration) causes a decline in species diversity and allows only a few species to adapt to harsh environmental conditions. In addition, the oxygen availability in all ponds was (100%; Table 1). These man-made ponds became an excellent habitat for many invasive river weeds. The weed species found in the study area included: *Azolla filiculoides, Nitella spp, Chara spp, Potamogeton spp, Myriophyllum spicatum, Ceratophyllum demersum,* and *Potamogeton perfoliatus* (Figure 4). These weed species are found in almost all ponds, and they dominate the river ponds. The observed weed species belong to different families.

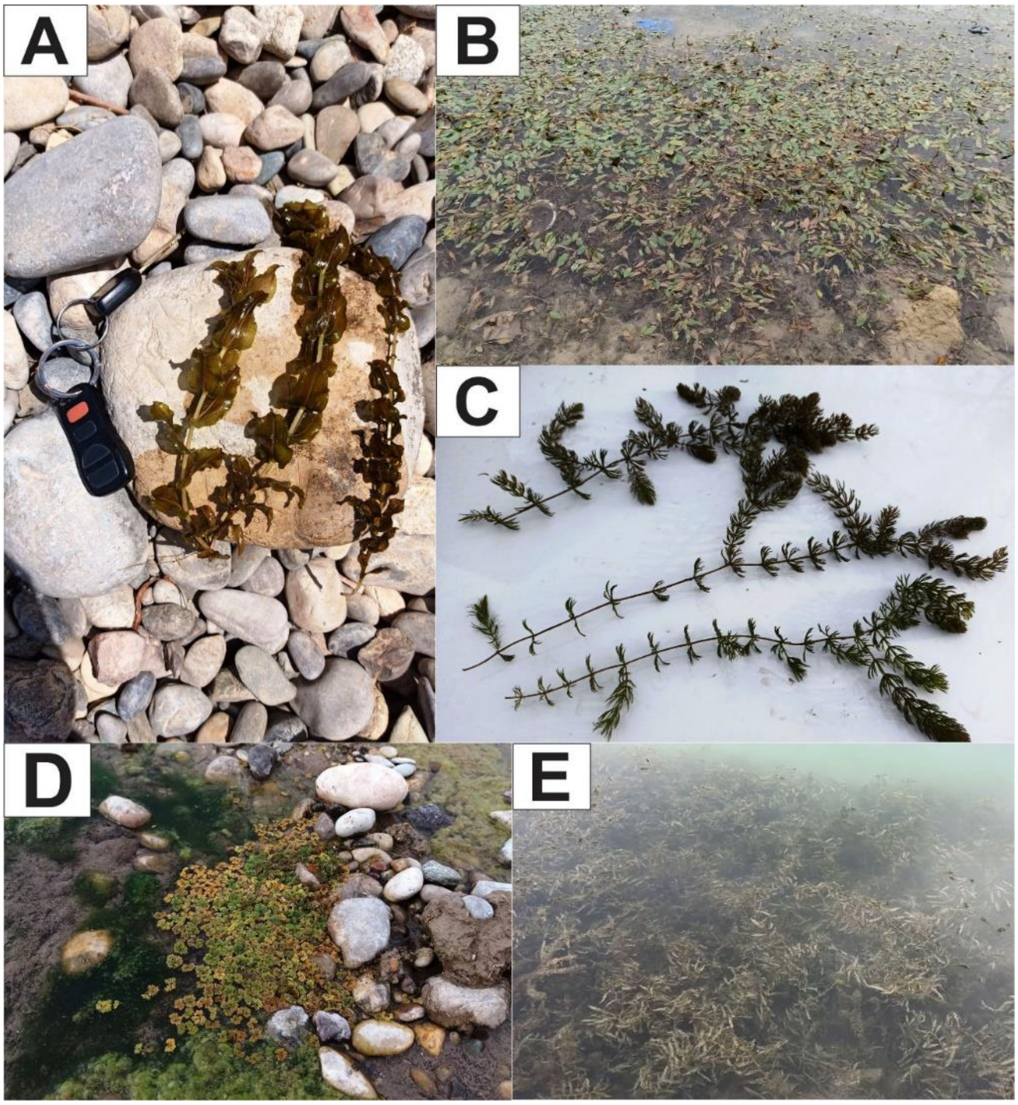

Figure 4. Fieldwork photos of (A) Clasped pondweed (*Potamogeton perfoliatus*), (B) Long-leaf pondweed (*Potamogeton nodosus*), (C) Hornwort (*Ceratophyllum demersum), (D)* Water fern (*Azolla filiculoides*), (E) Curly-leaf pondweed (***Potamogeton*** *crispus*).

There are no previous studies on the type and occurrence of these weeds in the river. To our knowledge, these species have not been recorded and studied in the Sirwan River. Furthermore, the increase in pond formation during 2021 was due to the occurrence of river weeds, and more of them were introduced into the river stream. It is expected to cover all of the rivers and get out of control, which may cause ecological problems for most vertebrate and invertebrate organisms in the river.

Compared with other locations, the species diversity in Qula Barz and Awakheri was higher than in others. At the same time, the lowest diversity was observed in Grdagozina (Figure 5). The diversity of the species among the ponds is due to the temporal changes in the pond formations. For example, the Qula Barz and Awakheri ponds formed much earlier than Grdagozina. In addition, the chemo-physical properties of the water in the ponds had no impact on species diversity. The pH is ranged between 7.48 and 8.5, and the EC (2000 μS/cm) ranged between 0.169 and 0.251, while the Dissolved Oxygen is 100% (Table 1).

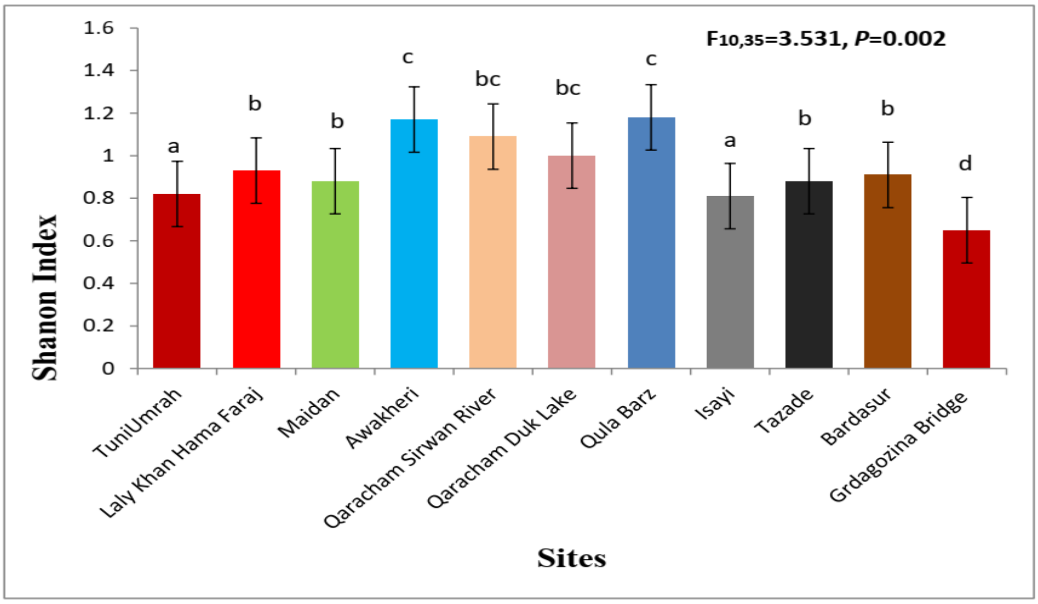

Figure 5. Change in species diversity (Shannon index) along the study area.

DISCUSSION

Field survey and remote sensing data analysis during the period between 1990 and 2022 show dramatic changes in land cover along the middle course of the Sirwan River. The main morphological change is the increase in the number of ponds due to anthropogenic activities and in response to people's requirements for raw materials to cover building purposes. This research pays attention to detecting ponds in the middle course of the Sirwan River rather than giving detailed information about suspended materials in pond water (GHIRARDI et al. 2023b), rehabilitating and enhancing the ecological environment (RINISHAKARTHEESHWARI et al. 2024). However, the novelty of this study is represented by specifying many weed species in the quarry's ponds. T

his step is very important to pave the way to understand the negative and positive consequences of these weeds' growth in the ponds. The NDVI was employed to reveal the land cover change during the past three decades. The present area has been subjected to huge transformation and deformation, which coincided with the political and socioeconomic transformation. In other words, the environmental changes belong to political and socioeconomic changes in the Iraqi Kurdistan Region during the mentioned period. Based on ALI et al. (2016b), GBANIE et al. (2018), and HAMAD et al. (2018), the main factors influencing changes in land use and land cover are spatiotemporal dynamics brought about by anthropogenic activity.

These changes impacted and reflected negatively on the fluvial environment and the land cover along the river course due to the extreme excavation, quarrying, and extraction of raw materials for construction and building in the growing residential areas. Many ecological effects will follow the current situation, which might cause health-related issues and hurt biodiversity (OZCAN et al. 2012). HAMAD et al. (2018) stated that anthropogenic activities are at the expense of vegetation cover, habitat area, and biodiversity. Hence, the bare area increased at the expense of vegetation cover, while plants constitute a major component of riverine ecosystems.

According to O'BRIAIN et al. (2023), plants play an important role in the biogeomorphic restoration of the fluvial environment. These distortions along rivers are big challenges that hinder any efforts toward rehabilitating the ecosystems within the fluvial environment of the river. Till today, the study area does not show any step toward environmental rehabilitation of this deformed area; on the contrary, the excavation processes are proceeding, and the man-made scape still increases at the expense of the riverscape. In some areas, it is difficult to recognize the original fluvial scape.

In addition, the deformation speed is much greater than that of the species' natural rehabilitation and life cycle. FULLER et al. (2015) revealed that the biodiversity of freshwater ecosystems is at risk due to increased river fragmentation. Hence, if quarrying continues in this manner, it is not far from showing the disappearance of some species in the fluvial environment of the Sirwan River in the study area. BRAUER & BEHEREGARAY (2020) stated that man-made habitat fragmentation is frequently cited as the primary cause of the present worldwide extinction problem, particularly in freshwater environments.

The field survey results and remote sensing data for the stream of the river (upstream to downstream) showed remarkable changes in the river bank, basin, and flora over time. For example, increasing the number of man-made ponds (due to quarries) caused an increase in the number of aquatic weeds. These weeds could positively impact fish in the ponds because it is considered a good food source for them. On the other hand, forming different-sized closed ponds along the Sirwan River may decrease the aquatic biodiversity (due to competition exclusion by strong competitors (HUANG et al. 2008).

The spatial change in the diversity of aquatic weeds could be due to the heterogeneity in biotic (competition among coexisting species) and abiotic (geomorphological status of each pond) characteristics among the study sites. The active ponds or pit lakes resulting from sand and gravel quarrying in the middle course of the Sirwan River could be a possible solution for riverscape rehabilitation (GHIRARDI et al. 2023a). These ponds could help in addressing water scarcity in the region. The expected confounding variables that may affect the results could be the velocity rate of the river over the years and the age of the produced ponds (oldest vs. youngest one). To decrease the influence of the confounding factors, continuous monitoring and regulations need to be followed by local authorities and researchers.

Despite the lack of weed species coverage data in the study area over the past decades, this study provides updated information for 2024. We therefore recommend establishing ongoing monitoring of weed species in the Sirwan River and creating a comprehensive database that includes the location, species, sampling dates, and fieldwork photographs.

CONCLUSION

Based on our observations from satellite images and fieldwork, the Sirwan River exhibits two kinds of variations in the river course. Most of the alterations that were detected between 1990 and the present were of a man-made nature. Also, the images from previous years demonstrate how the quarries beside the river have caused a rise in the quantity and size of man-made ponds over time. We concluded that over 33 years, the barren soil had increased at the expense of vegetation cover. Not only do quarrying and fragmentation processes alter the land cover, but they also cause habitat fragmentation, which affects the aquatic plants along the river. The formation of different ponds along the Sirwan River due to anthropogenic activity makes a good microhabitat for some aquatic weeds to grow and bloom.

No studies have been done on these weeds before. So, the importance of this study is to show the impact of human activity on the biotic and abiotic aspects of the river. The existence of weed species could improve the fauna in the river; still, when the situation gets out of control, it will disturb the living and nonliving components of the river. Therefore, it is important to pay more attention and do more research and management to avoid the outgrowth of weeds and keep the river healthy. Besides, this study is considered the first study on the occurrence and abundance of aquatic weeds in the river. Therefore, the aquatic flora along the study area has not been previously studied or documented. This will pave the way for doing more ecological studies in the future.

From the point of view of the concluded results, our strong recommendation is that the local authorities cease all quarrying operations along the river and reduce the adverse impacts of human activities on the fluvial environment to restore the riverscapes to their natural state and to better manage the flora of the river. It is recommended to use these quarrying ponds for riverscape rehabilitation. Furthermore, the findings of this study showed that further geomorphological studies are needed to monitor the fluctuation in the diversity of aquatic flora in response to biotic and abiotic factors.

AUTHOR CONTRIBUTIONS

Conceptualization, S.G.S. and M.I.K.; methodology, S.G.S. and M.I.K.; software, S.G.S., M.I.K., and A.A.O.; validation, S.G.S. and M.I.K.; formal analysis, S.G.S., M.I.K.; investigation, S.G.S. and M.I.K.; resources, A.K.O., and S.S.A.; writing—original draft preparation, S.G.S., M.I.K., and A.A.O.; writing—review and editing, S.G.S., M.I.K., and A.A.O.; visualization, S.G.S., M.I.K., and B.A.A.; supervision, S.G.S. and M.I.K.; project administration, S.G.S.; funding acquisition, and S.S.A.. All authors have read and agreed to the published version of the manuscript

FUNDING

This work was not supported by any funding agency.

INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable for studies not involving humans or animals.

INFORMED CONSENT STATEMENT

Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT

The data can be made available under request.

ACKNOWLEDGEMENTS

We thank USGS for providing Landsat data used in our study. In addition, our sincere thanks to Dr. Rahman Azeez Mohammed Murad from the University of Garmian, the geologist Fatih Hussein Abdulkader, and Hemin Ahmed Abdulla, from the General Directorate of Education of Sulaymaniyah and the Darbandikhan Dam administration, respectively, for helping us with our fieldwork.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

REFERENCES

ABBAS MK & ABDUL-RAZZAK M. 2006. Adequacy determination of irrigation water in Upper Diyalah River Basin/Iraq. IRAQI J Agric Sci 37: 1–12.

ABDULLAH EJ. 2013. Evaluation of surface water quality indices for heavy metals of Diyala River-Iraq. J Nat Sci Res 3: 63-70.

ABDULLAH TO et al. 2019. Hydrogeochemical Evaluation of Groundwater and Its Suitability for Domestic Uses in Halabja Saidsadiq Basin, Iraq. Water 11

AL-FARAJ FAM & SCHOLZ M. 2014. Assessment of temporal hydrologic anomalies coupled with drought impact for a transboundary river flow regime: the Diyala watershed case study. J Hydrol 517: 64–73

AL-JAWADI AS et al. 2023. Sustainability of the Tigris River Between Environmental Conditions and Oppressive Quarrying in Northern Iraq. In: IOP Conference Series: Earth and Environmental Science. p 12017

AL-KHAFAJI MS & AL-CHALABI RD. 2019. Assessment and mitigation of streamflow and sediment yield under climate change conditions in Diyala River Basin, Iraq. Hydrology 6: 63.

AL-MUSAWI N. 2018. Evaluation water quality of Diyala River in Iraq using Bhargava method. In: MATEC Web of Conferences. p 5001

ALI S et al. 2016a. GIS based soil erosion estimation using EPM method, Garmiyan Area, Kurdistan Region, Iraq. J Civ Eng Archit 10: 291–308.

ALI SS et al. 2016b. Geomorphology of Garmiyan Area Using GIS Technique, Kurdistan Region, Iraq. J Earth Sci Geotech Eng 6: 63–87.

ALKARADAGHI K et al. 2022. Geospatial Technique Integrated with MCDM Models for Selecting Potential Sites for Harvesting Rainwater in the Semi-arid Region. Water, Air, Soil Pollut 233: 1–22.

AZIZ SF et al. 2023. Water Harvesting in the Garmian Region (Kurdistan, Iraq) Using GIS and Remote Sensing. Water 15

BENDIXEN M et al. 2021. Sand, gravel, and UN Sustainable Development Goals: Conflicts, synergies, and pathways forward. One Earth 4: 1095–1111.

BHATTACHARYA RK et al. 2019. Geomorphic response to riverine land cover dynamics in a quarried alluvial river Kangsabati, South Bengal, India. Environ Earth Sci 78: 1–18.
BRAUER CJ BEHEREGARAY LB. 2020. Recent and rapid anthropogenic habitat fragmentation increases extinction risk for freshwater biodiversity. Evol Appl 13: 2857–2869.
BRAUNS M et al. 2022. A global synthesis of human impacts on the multifunctionality of streams and rivers. Glob Chang Biol 28: 4783–4793.
BUDAY RT. 1980. The Regional Geology of Iraq: Stratigraphy and Paleogeography, 1st edn. D.G Geo. Surv. Min. Invest. (SOM), Baghdad, Baghdad
CARPENTER SR. 2005. Eutrophication of aquatic ecosystems: bistability and soil phosphorus. Proc Natl Acad Sci 102: 10002–10005.
CASTALDINI D et al. 2019. Geomorphology of the central Po Plain, Northern Italy. J Maps 15: 780–787.
CHARLTON R. 2007. Fundamentals of fluvial geomorphology. Routledge.
CHEE JD. 2015. Pearson's product-moment correlation: Sample analysis. Res Gate 4: 4–90.
DEL TÁNAGO MG et al. 2015. Biogeomorphic responses to flow regulation and fine sediment supply in Mediterranean streams (the Guadalete River, southern Spain). J Hydrol 528: 751–762.
DEVI MA & RONGMEI L. 2017. Impacts of sand and gravel quarrying on the stream channel and surrounding environment. ASIA PACIFIC J ENERGY ENVIRON 4: 7–12.
ELOSEGI A et al. 2010. Effects of hydromorphological integrity on biodiversity and functioning of river ecosystems. Hydrobiologia 657: 199–215.
FRENCH T & CHAMBERS P. 1996. Habitat partitioning in riverine macrophyte communities. Freshw Biol 36: 509–520.
FULLER MR et al. 2015. Causes and consequences of habitat fragmentation in river networks. Ann N Y Acad Sci 1355: 31–51.
GBANIE SP et al. 2018. Impacts on the urban environment: Land cover change trajectories and landscape fragmentation in post-war Western Area, Sierra Leone. Remote Sens 10: 129.
GHIRARDI N et al. 2023a. Pit lakes from gravel and sand quarrying in the Po River basin: An opportunity for riverscape rehabilitation and ecosystem services improvement. Ecol Eng 196: 107103.
GHIRARDI N et al. 2023b. The Long-Term Detection of Suspended Particulate Matter Concentration and Water Colour in Gravel and Sand Pit Lakes through Landsat and Sentinel-2 Imagery. Remote Sens 15:1–20.
GHOSH PK et al. 2016. Sand quarrying activities in an alluvial reach of Damodar River, Eastern India: towards a geomorphic assessment. Int J River Basin Manag 14: 477–489.
GROSS EM et al. 2001. Experimental evidence for changes in submersed macrophyte species composition caused by the herbivore Acentria ephemerella (Lepidoptera). Oecologia 127: 105–114.

HAMAD R et al. 2018. Post-war land cover changes and fragmentation in Halgurd Sakran National Park (HSNP), Kurdistan region of Iraq. Land 7: 38.
HAMZA NH. 2012. Evaluation of water quality of Diyala River for irrigation purposes. Diyala J Eng Sci 5: 82–98.
HASAN QM et al. 2023. When the law is unclear: challenges and opportunities for data and information exchange in the Tigris-Euphrates and Indus river basins. Water Policy 25: 780–796.
HUANG L et al. 2008. Scale impacts of land cover and vegetation corridors on urban thermal behavior in Nanjing, China. Theor Appl Climatol 94: 241–257.
HUSSEIN EA et al. 2021. Do anthropogenic activities affect floristic diversity and vegetation structure more than natural soil properties in hyper-arid desert environments? Diversity 13: 157.
KONDOLF GM. 1994. Geomorphic and environmental effects of instream gravel mining. Landsc Urban Plan 28: 225–243.
MARCHETTI M. 2002. Environmental changes in the central Po Plain (northern Italy) due to fluvial modifications and anthropogenic activities. Geomorphology 44: 361–373.
MIGOŃ P & LATOCHA A. 2018. Human impact and geomorphic change through time in the Sudetes, Central Europe. Quat Int 470: 194–206.
MITCHELL DS. 1989. Aquatic weed problems and management in Africa. In: Pieterse AH & Murphy K. (Eds.). Aquatic Weeds: The Ecology and Management of Nuisance Aquatic Vegetation. OXFORD: Oxford Univ. Press. p. 341-354.
NAQI NM et al. 2021. Statistical analysis of extreme weather events in the Diyala River basin, Iraq. J Water Clim Chang 12: 3770–3785.
NEWSON MD & NEWSON CL. 2000. Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. Prog Phys Geogr 24: 195–217.
O'BRIAIN R et al. 2023. Towards Biogeomorphic River Restoration: Vegetation as a Critical Driver of Physical Habitat. Authorea Prepr
ORTIZ-BURGOS S. 2016. Shannon-weaver diversity index. Encycl estuaries 572–573.
OTHMAN AA et al. 2023. Insights for Estimating and Predicting Reservoir Sedimentation Using the RUSLE-SDR Approach: A Case of Darbandikhan Lake Basin, Iraq–Iran. Remote Sens. 15
OTHMAN AA & GLOAGUEN R. 2013. River Courses Affected by Landslides and Implications for Hazard Assessment: A High Resolution Remote Sensing Case Study in NE Iraq–W Iran. Remote Sens 5: 1024–1044.
OTHMAN AA et al. 2021. Insights for Landfill Site Selection Using GIS: A Case Study in the Tanjero River Basin, Kurdistan Region, Iraq. Sustain. 13
OZCAN O et al. 2012. Environmental impact analysis of quarrying activities established on and near a river bed by using remotely sensed data. Fresenius Environ Bull 21: 3147–3153.
RAHIMI I et al. 2024. Zagros Grass Index. A New Vegetation Index to Enhance Fire Fuel Mapping: A Case Study in the Zagros Mountains. Sustainability 16: 3900.
RINISHAKARTHEESHWARI M et al. 2024. Innovative water management using

abandoned quarries for urban water supply and flood mitigation. Environ Dev Sustain.
ROUSE JW et al. 1974. Monitoring the vernal advancement of retrogradation of natural vegetation. NASA/GSFC, type III, Final report, greenbelt, MD 371.
SALAR SG. 2013. Geomorphic Analysis for Water Harvesting Using GIS Technique in Selected Basins/ Garmiyan Iraqi Kurdistan Region. University of Sulaimani
SCHMUTZ S & SENDZIMIR J. 2018. Riverine ecosystem management: science for governing towards a sustainable future. Springer Nature
SUREN AM et al. 2000. Drag coefficients of stream bryophytes: experimental determinations and ecological significance. Freshw Biol 45: 309–317.
TEAM RC. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing. (No Title)
TOWNSEND CC & GUEST E. 1980. Flora of Iraq (Vol. 4). Ministry of Agriculture and Agrarian Reform
UKPONG EC. 2012. Environmental impact of aggregate mining of crush rock industry in Akamkpa local government area of cross river state. Niger J Technol 31: 128–138.
VANDANA M et al. 2020. Environmental impact assessment (EIA) of hard rock quarrying in a tropical river basin-study from the SW India. Environ Monit Assess 192: 1–18.
WROBLESCKI FA et al. 2021. Assessed impact of anthropization on water and soil quality in a drainage basin in southern Brazil. Rev Ciências Agroveterinárias 20: 74–85.

Appendix A. Ground cover components of the study area during (1990 – 2022), depending on NDVI.

NO.	Satellite Imagery	Date	Area of Class km²			Total Area km²
			Vegetation	Bare Land	Water	
1	Landsat 5 (TM)	27 Jul 1990	27.81	89.49	11.01	128.31
2	Landsat 5 (TM)	30 Jul 1991	18.64	106.51	9.18	134.33
3	Landsat 5 (TM)	16 Jul 1992	34.11	86.25	13.97	134.33
4	Landsat 5 (TM)	04 Aug 1993	37.56	89.48	7.29	134.33
5	Landsat 5 (TM)	06 Jul 1994	31.71	93.10	9.52	134.33
6	Landsat 5 (TM)	09 Jul 1995	36.46	86.80	11.07	134.33
7	Landsat 5 (TM)	12 Aug 1996	40.65	82.90	10.78	134.33
8	Landsat 5 (TM)	30 Jul 1997	36.29	88.73	9.31	134.33
9	Landsat 5 (TM)	17 Jul 1998	27.66	93.66	13.00	134.32
10	Landsat 7	13 Aug 1999	25.87	100.28	8.17	134.32
11	Landsat 5 (TM)	08 Aug 2000	24.47	100.79	9.07	134.33
12	Landsat 5 (TM)	09 Jul 2001	20.21	104.85	9.28	134.34
13	Landsat 5 (TM)	28 Jul 2002	32.30	92.69	9.34	134.33
14	Landsat 7	25 Sep 2003	46.36	80.14	5.98	132.48
15	Landsat 5 (TM)	02 Aug 2004	31.11	92.88	10.34	134.33
16	Landsat 5 (TM)	05 Aug 2005	31.22	90.18	12.93	134.33
17	Landsat 5 (TM)	23 Jul 2006	27.46	96.27	10.59	134.32
18	Landsat 7	02 Jul 2007	25.05	101.85	6.48	133.38
19	Landsat 5 (TM)	28 Jul 2008	20.62	105.89	7.82	134.33
20	Landsat 7	23 Jul 2009	8.46	118.03	6.57	133.06
21	Landsat 7	10 Jul 2010	24.76	96.91	10.37	132.04
22	Landsat 7	13 Jul 2011	22.39	99.30	10.44	132.13
23	Landsat 7	15 Jul 2012	21.60	96.07	13.61	131.28
24	Landsat 7	03 Aug 2013	29.67	93.41	9.44	132.52
25	Landsat 7	21 Jul 2014	21.62	98.74	11.47	131.83
26	Landsat 7	24 Jul 2015	19.70	102.33	9.63	131.66
27	Landsat 7	26 Jul 2016	20.70	100.73	10.01	131.44
28	Landsat 7	29 Jul 2017	25.23	98.57	8.96	132.76
29	Landsat 7	01 Aug 2018	25.45	97.17	10.65	133.27
30	Landsat 7	19 Jul 2019	24.48	94.64	14.34	133.46
31	Landsat 7	21 Jul 2020	20.28	101.29	10.30	131.87
32	Landsat 7	24 Jul 2021	15.39	110.00	5.89	131.28
33	Landsat 8	19 Jul 2022	24.87	104.04	5.42	134.33

Appendix B. NDVI of the study area for (A) July 27, 1990 and (B) July 19, 2022.