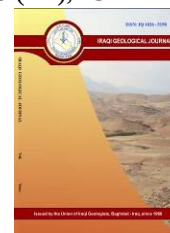




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Investigating the Geomorphological Impact of the Euphrates River on Paleolakes and River Meanders Using Remote Sensing Techniques: A Case Study of Ramadi, Iraq

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Abstract

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Remote sensing techniques and field surveys were combined to evaluate the hydrological and geomorphological effects of the Euphrates River on the lakes and ancient buried meanders in the Ramadi region. This study addresses the problem of identifying the sources of recharge and the seasonal dynamics of these water bodies. Remote sensing and field survey techniques were employed, including satellite image analysis, topographic measurements, soil texture assessment, and chemical analysis of water samples from lake, wells, and river. The results of the soil sample analysis revealed the presence of coarse, highly porous sediments in the buried meanders, confirming their potential role as subsurface reservoirs. Water quality analyses showed a strong similarity between the lake and river samples suggesting that groundwater recharge is strongly influenced by the Euphrates River. In addition, the lake 2 showed slight fluctuations in surface area between 1997 and 2025, while the lake located farther from the river showed large seasonal differences. These results indicate the role of the Euphrates River in maintaining nearby water bodies, and highlight the importance of integrating remote sensing with field surveys to provide a comprehensive understanding of water body dynamics.

Keywords: Ancient meanders; Euphrates river; Geomorphology; Lakes; Remote sensing

1. Introduction

Remote sensing techniques utilize spectral data derived from satellite imagery to provide accurate insights into water characteristics, surface area fluctuations, and sources of water input—whether from underground aquifers or surface runoff. To ensure the reliability of these interpretations, field surveys are conducted to validate the remote sensing results and strengthen the scientific conclusions. The integration of satellite analysis with fieldwork offers a comprehensive understanding of water body dynamics. This combined approach supports the development of sustainable strategies for effective water resource management (Pitcher et al., 2020). The present study aims not only to advance scientific knowledge in this domain but also to offer practical data for policymakers engaged in environmental planning and water governance. Previous studies that applied remote sensing techniques to detect river changes are summarized below:

Xu (2006) suggested that the Modified Normalized Difference Water Index (MNDWI) is more appropriate for highlighting and retrieving water data for a water body with the background dominated by built up land areas because of its benefit in reducing and even removing built-up land effects over the NDWI.

Ismail (2014) outlined a segmentation-based method for extracting geographic features like river, road, and urban areas from satellite data. The study showed that the segmentation was able to improve accuracy over classification making it suitable for such spatial tasks in the context of civil engineering and urban planning.

Li et al. (2014) stated that water body extraction has become a very important part of remote sensing science since water monitoring plays an important role in water resource management. Water body extraction from remotely sensed images has been a problem for over two decades. A number of indexes have been developed over the years in order to try to eliminate misleading information, such as topographic effects and built-up areas. The reason for misleading information comes from the difficulty in distinguishing water from other surfaces with a low albedo.

Hook and Ramseier (2016) investigated changes occurring in buried river channels using remote sensing technology by applying digital processing to shortwave thermal infrared data from Landsat imagery. This was done to monitor the behavior of these river changes and identify the most influential factors over long periods.

Andik and Sarang (2017) concluded that restoring and maintaining Tehran's rivers and streams can reduce flood-related problems and improve environmental quality.

Jaafar and Daliman (2022) revealed that the remote sensing resources provide reliable tools to study the shifting nature of rivers channel. The study also employed remote sensing to study the shifting of the river channels in Kelantan River and its demonstrated useful method in water quality assessment through digital image analysis.

The problem addressed by this study is the knowledge gap regarding the understanding of river morphological changes and their direct impact on the environment and water resources.

The study relied on multi-source satellite data, such as Landsat and Sentinel-2 image, to cover extended time periods and provide more accurate depictions of water bodies.

The results were further supported by field surveys to create a comprehensive picture of river dynamics and its environmental impact.

2. Location of Study Area

Ramadi city is located in the western part of Iraq, at the eastern part of Al-Anbar Governorate. It is located between latitudes ($33^{\circ} 21' 0''$ N - $33^{\circ} 24' 0''$ N) and longitudes ($43^{\circ} 33' 0''$ E - $43^{\circ} 39' 0''$ E). The Heet District to the northwest and Habbaniyah Subdistrict to the southeast, the eastern edge of the Al-Jazeera plateau to the north and east, and the eastern edge of the western plateau to the west and south (Fig. 1).

Geomorphologically, the study area is dominated by a river plain with an almost flat surface, with some slopes towards the south and west. The soil consists mainly of silt, clay, and sand with a loose texture. These geomorphological features play an important role in urban growth and land use patterns, making them critical components of environmental planning and sustainable development. Geomorphological studies can provide a basis for regional classification of terrain. Moreover, other environmental variables of interest are often controlled by geomorphological units. Therefore, geomorphology has a unique role in the management and planning of urban development (Bety, 2013; Hamad, 2022).

The Ramadi City lies within the unstable continental shelf, while the Rutba and Jazeera regions are part of the stable continental shelf. The area is intersected by various fault zones, with the Abu al-Jeer fault, extending from the northwest to the southeast, being the most significant structural element. Its presence is evidenced by numerous springs in the Heet, Kubaisa, and Abu al-Jeer areas, from which mineral water and bitumen emerge. Several sub-geological zones intersect the area, from the Tigris sub-region in the east to the Salman-Khalisiya regions of the stable continental shelf in the west. The

transverse Samarra-Halabja fault is considered one of the most influential geological structures (Fouad, 2012). Fig 1 shows the location of buried ancient meanders.

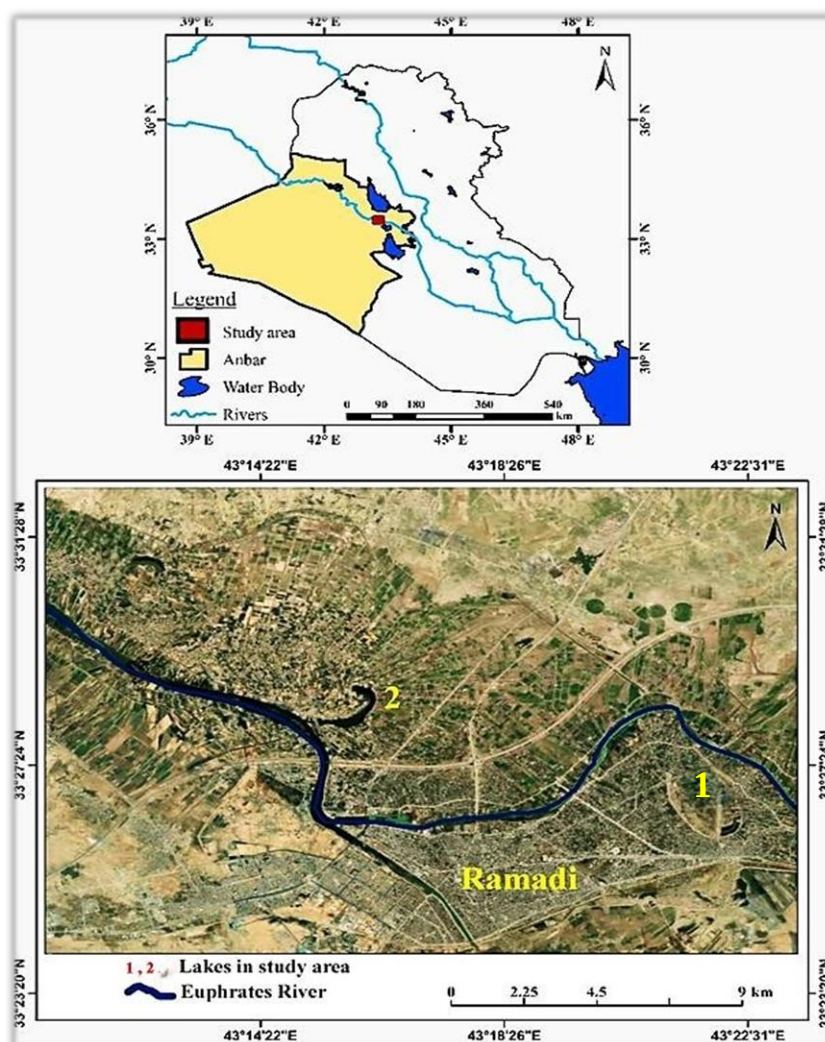


Fig. 1. The study area shows the location of buried ancient meanders

3. General View of Lakes

A lake is a relatively stable natural water body that plays a vital role in the Earth's hydrological cycle, interacting hydrologically with rivers and groundwater systems (Zhiyuan et al., 2025). Most lakes contain fresh water, and some are saline. Lakes vary widely in size and depth, influencing their environmental and hydrological significance (Cael and Seekell, 2016).

Rivers are a naturally occurring freshwater streams. A river may only flow during specific seasons or run dry before it reaches the end of its course (Ravazzolo et al., 2020). The water cycle, or the mechanisms through which water circulates on Earth, controls rivers. Sources of river flow include precipitation, surface runoff, snowmelt, glacier melt, and groundwater discharge (Guo et al., 2024).

Rivers drain water through drainage basins regions where surface water converges toward a common outlet—by channeling their courses and merging at confluences. These rivers significantly influence the surrounding environment. During flood events, they may overflow their banks and deposit nutrient-rich sediments across adjacent floodplains. The surrounding terrain is shaped by erosion, transport, and deposition processes creating islands and deltas where the flow slows (Williams, 2004; Huggett, 2007). Rivers frequently bend or meander rather than flow in a straight line, and the locations

of their banks can change over time. Rocks are carved into valleys and canyons by erosion (Edgeworth and Benjamin, 2018).

The study area includes lakes near the Euphrates River, which represent the remains of ancient river meanders that arose due to hydrological and geomorphological changes. They vary in depth, area, and connection to the river, making them key elements in the local water system. This study aims to understand their role in water supply and the environmental changes associated with the region.

4. Old Buried River

The buried river valley is considered a large, elongated geomorphological feature overlain by younger sediments. To understand its past hydrological function before burial, it is essential to have sufficient topographic and sedimentological data. In cases where the original fluvial structure cannot be interpreted—often due to the displacement of sediments from their primary location—these deposits are referred to buried alluvial deposits rather than preserved river valleys (Falkowski and Kowalski, 1987).

The Earth's surface is constantly changing due to the actions of numerous natural and man-made agents. Materials are cut, transported, removed, and deposited from the land surface by these agents (Anderson and Anderson, 2010). The erosive power of flowing water exceeds that of other geomorphological agents. When it comes to identifying and mapping river changes and bank erosion, remote sensing (RS) can be a highly effective tool (Aher et al., 2012). However, interpretation may still be affected by image quality, vegetation cover, and temporal variability.

The global classification of river morphology presented by Li et al. (2025) demonstrates that inland water dynamics—captured via satellite imagery and digital elevation models—can reveal inactive or ancient channels that still affect sediment distribution, groundwater recharge, and floodplain evolution. In Ramadi, these subsurface systems may appear as elevation depressions or spectral anomalies, indicating ancient fluvial activity. By integrating these datasets with high-resolution DEMs, researchers can trace the geomorphic signatures of buried rivers, which contribute to the formation of dry valleys, soil moisture variation, and long-term restructuring of the landscape.

5. Materials and Methods

5.1. Field and Office Work

Two field trips were conducted to the study site to visit the two lakes in the study area as shown in Figs 1 and 2. The trips took place at two different times over six months:

- The first trip was at the end of the dry season on October 9, 2024
- The second trip was during the spring and rainy season on April 9, 2025

These visits aimed to investigate the impact of river flow and climatic conditions on the status and extent of the lakes (Figs. 2 and 3).

5.2. Detection of Ancient Buried Meanders Using Satellite Image Filters

The emboss filter, also known as a directional difference filter, enhances edges in the direction of the selected convolution mask(s). The filter matrix performs a convolution operation over the corresponding square area of the original image. This process involves a significant computational load, especially when the image size or the dimensions of the emboss filter mask are large.

The emboss filter executes the convolution operation on every pixel. The procedure compares neighboring pixels and marks locations where a sharp change in pixel value is detected. These edge responses form linear features that follow object boundaries. Fig. (4) shows parameters of the applied filter. As a result, the output is an embossed image with highlighted edges, as demonstrated in the resulting images below for Lake 1 and Lake 2, as shown in Figs 5 and 6.

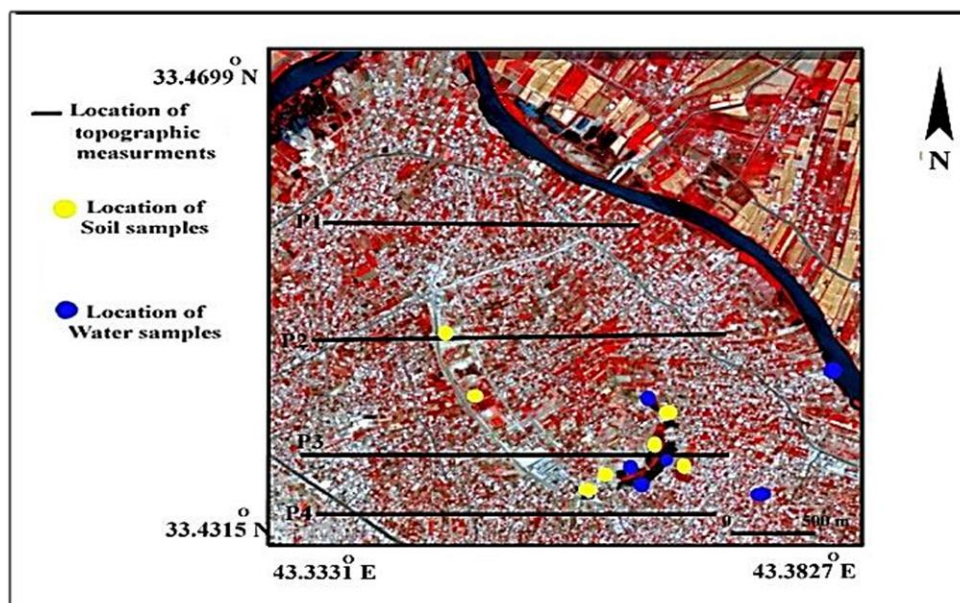


Fig. 2. Fieldwork locations for Lake 1

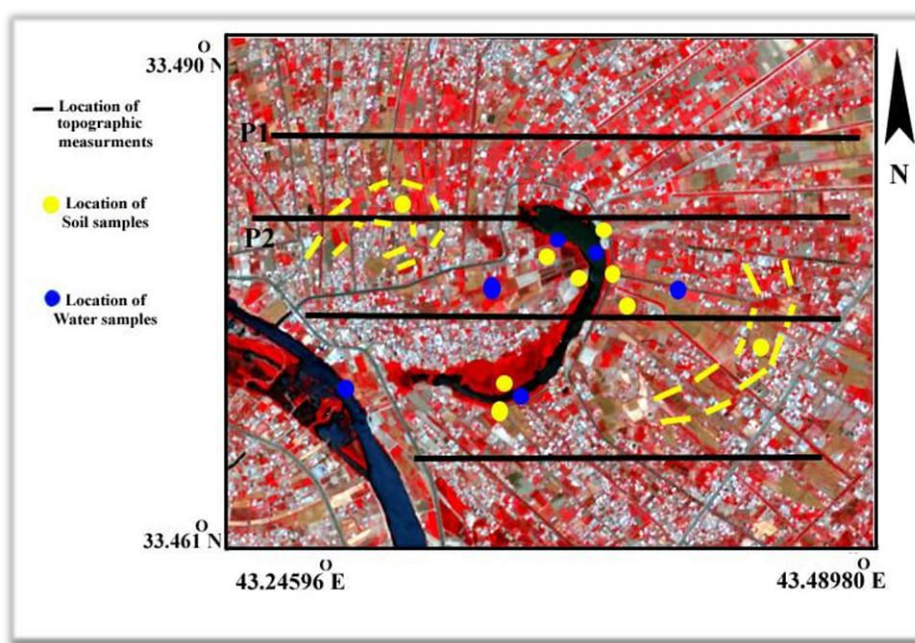


Fig. 3. Fieldwork locations for Lake 2

0	0	+1
0	0	0
-1	0	0

Fig. 4. Parameters of the emboss filter

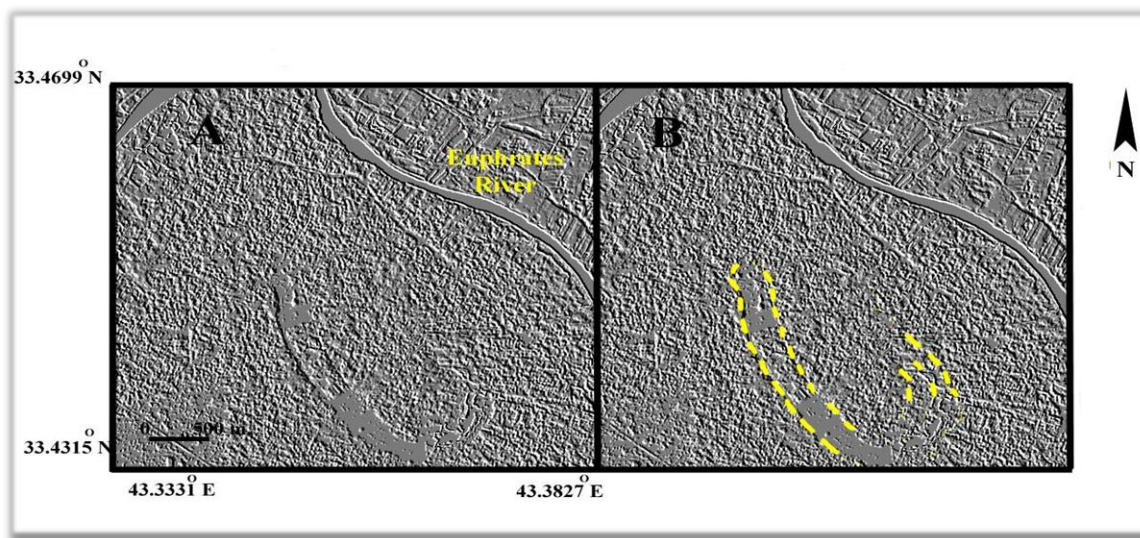


Fig. 5. A) Application of the Emboss filter to enhance the visibility of ancient buried meander for Lake1; B) Visual interpretation with yellow lines delineating the traces of the ancient buried meander

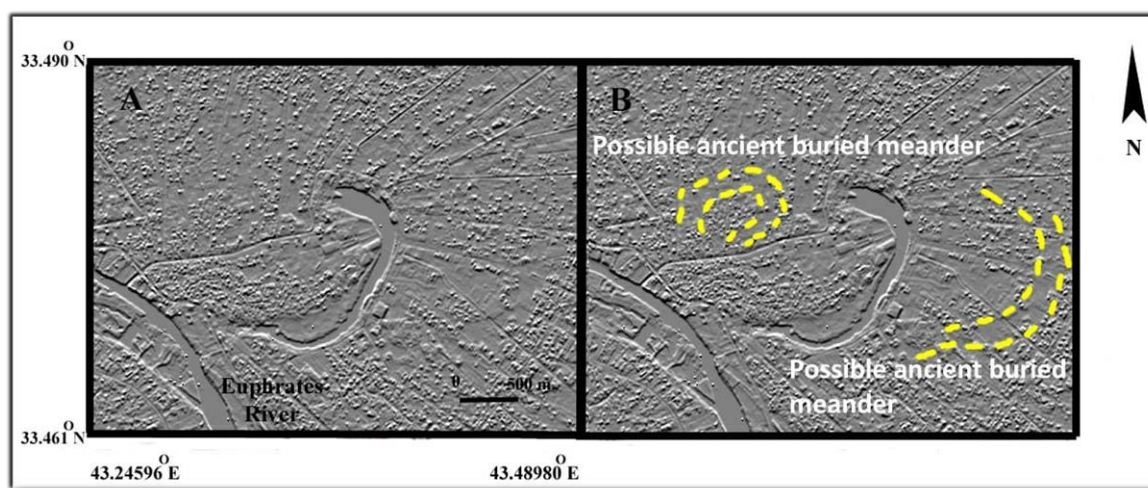


Fig 6. A) Application of the Emboss filter to enhance the visibility of the ancient buried meander for Lake2; B) Visual interpretation with yellow lines indicating possible traces of ancient buried meander on both sides of Lake 2

5.3. Topographic Measurements

Field measurements were conducted along predetermined paths located to the north of the lake, across the water body, to the south, with an average spacing of approximately 10 m between measurement points, adjusted according to field accessibility and site conditions. The purpose of these measurements was to spectrally isolate the lake's body from its surrounding area, investigate historical lake boundaries of the lake, and identify buried ancient meanders and their relationship to the lake's geomorphology, Figs. 7–16.

These measurements were taken using a Garmin eTrex 10 GPS receiver along the designated paths. At each point, elevation and coordinate data were collected to generate a contour map of the lake and its surrounding areas. The device's positional accuracy ranges between 3 and 10 m.

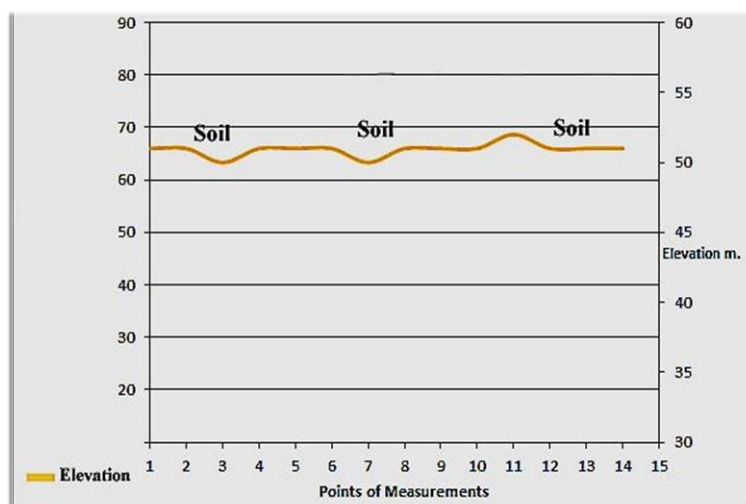


Fig. 7. Topographic profile P1 showing the absence of a lake within the surveyed area

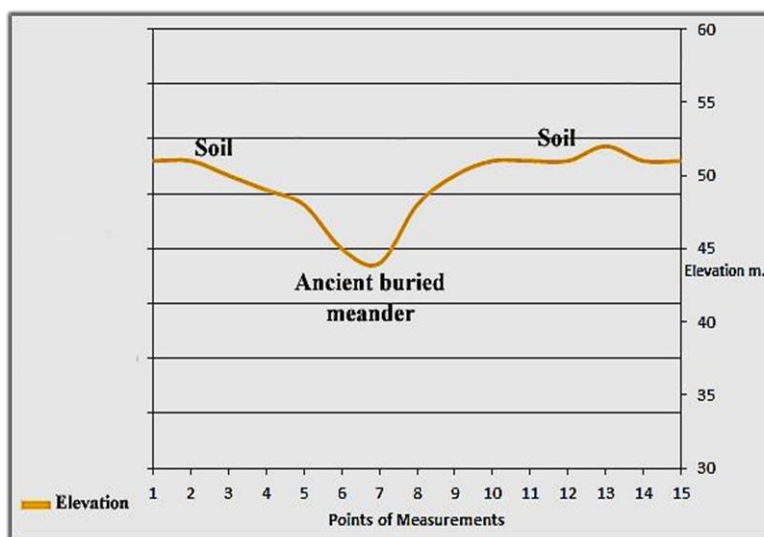


Fig. 8. Topographic profile P2 showing only ancient buried meander with absence of a lake within the surveyed area

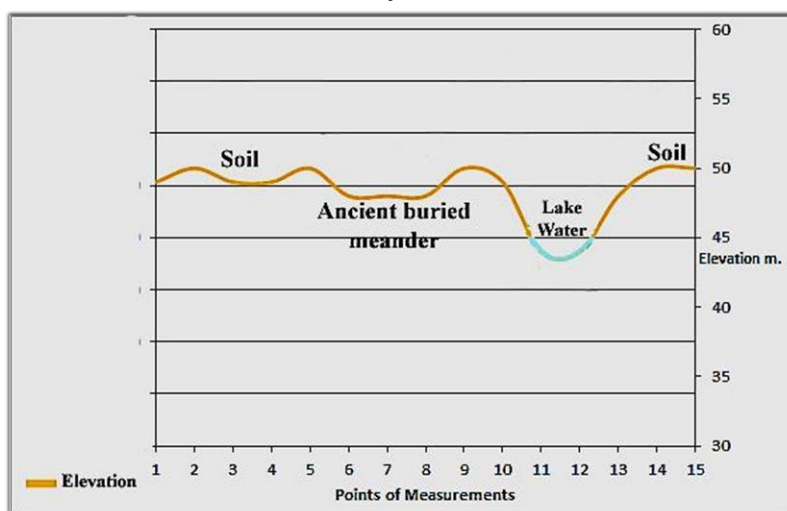


Fig. 9. Topographic profile P3 showing lake and ancient buried meander

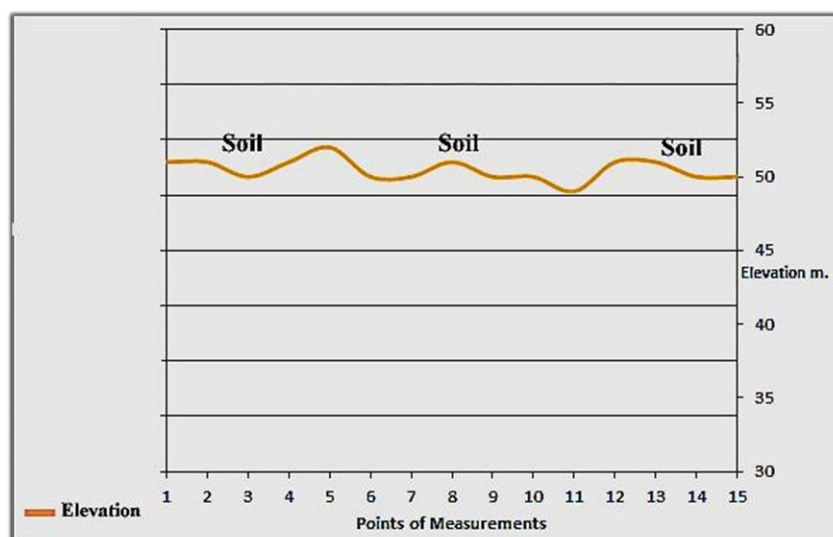


Fig. 10. Topographic profile P4

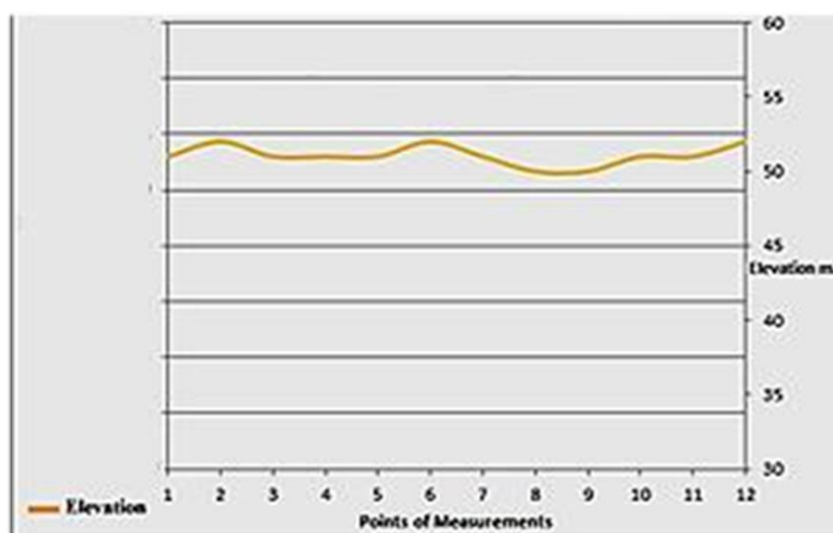


Fig. 11. Topographic profile P1 showing the absence of a lake within the surveyed area

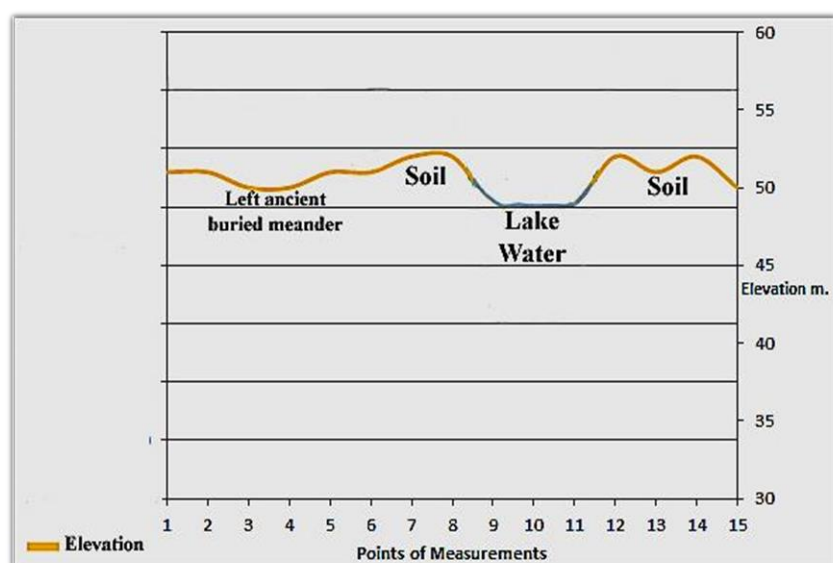


Fig. 12. P2 Topographic profile left ancient buried meander with Lake

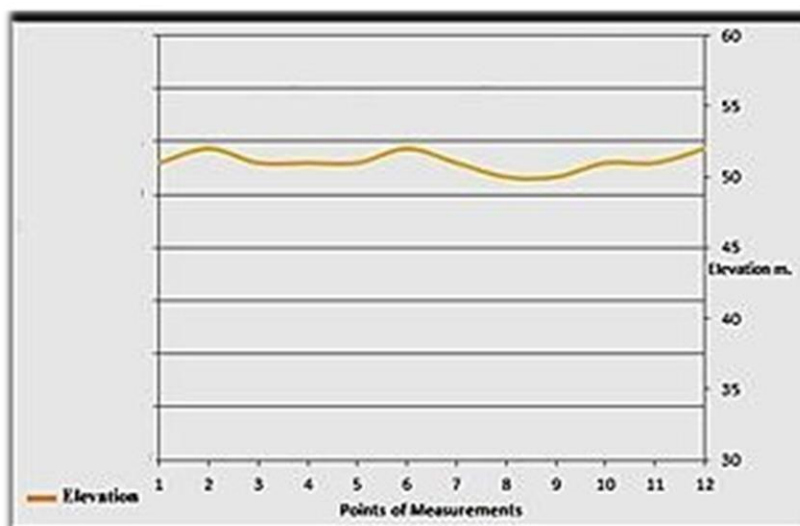


Fig. 13. Topographic profile P1 showing the absence of a lake within the surveyed area

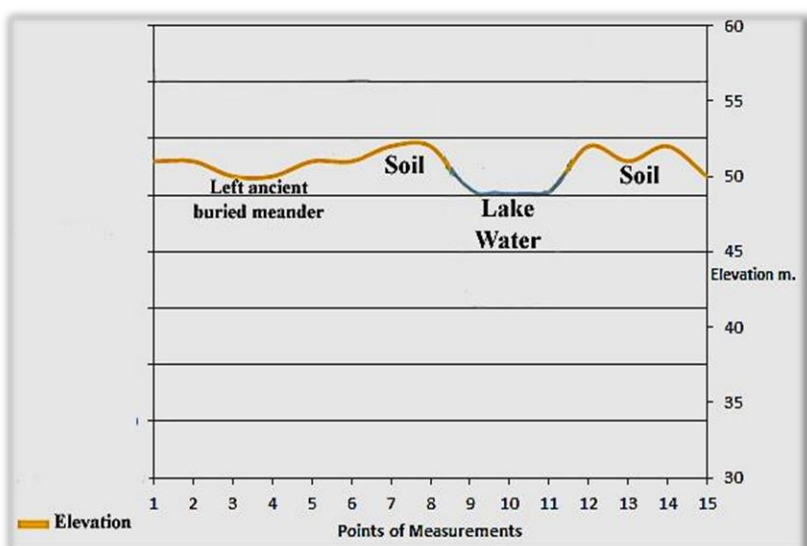


Fig. 14. Topographic profile P2 showing left buried meander with Lake

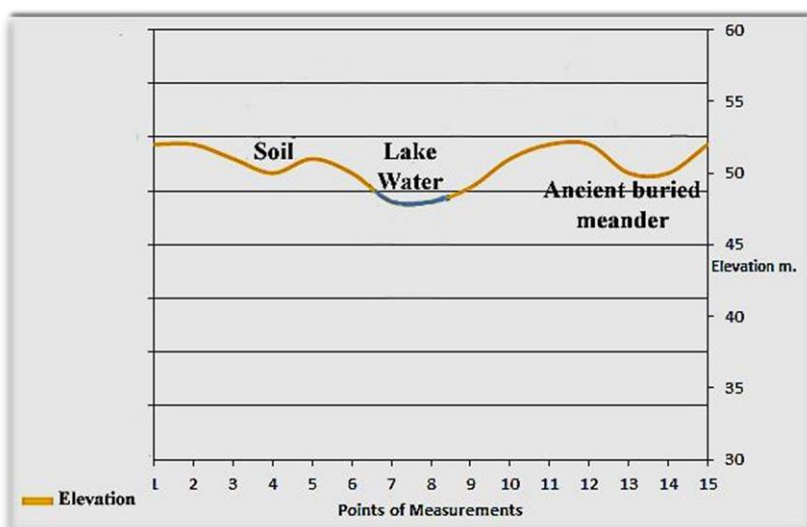


Fig. 15. Topographic Profile P3 showing right buried meander with Lake

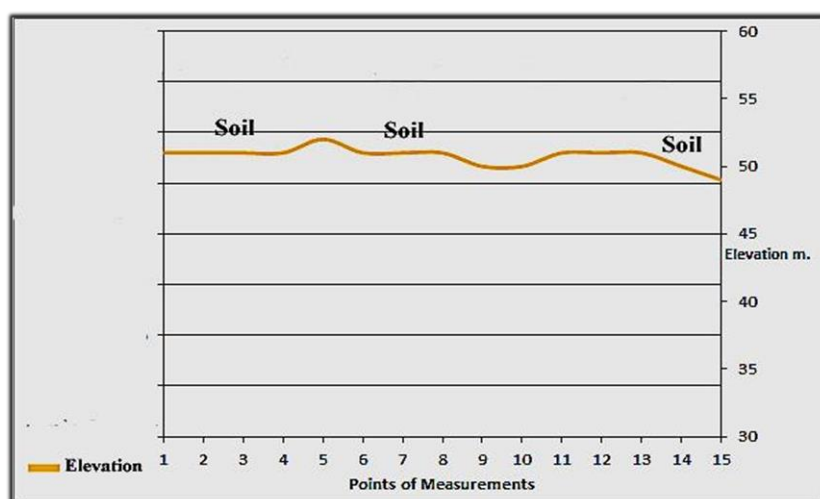


Fig. 16. Topographic Profile P4 showing the absence of a lake within the surveyed area. Then, a contour map of the two-lake area was created to show the overall flow direction and surface slope, Figs. 17,18

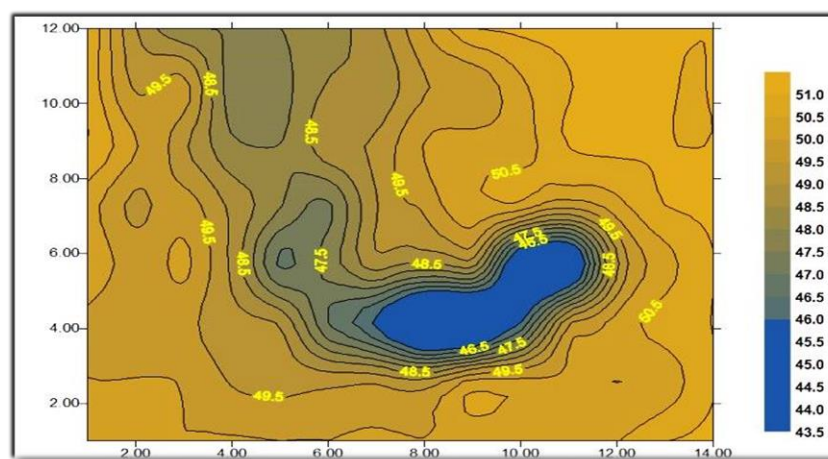


Fig. 17. Contour map for lake 1 and surrounding topographic features. The color scale on the right represents elevation values (43.5–51.0 m), indicating depth variations within the lake. The X and Y axes denote spatial coordinates of the surveyed area

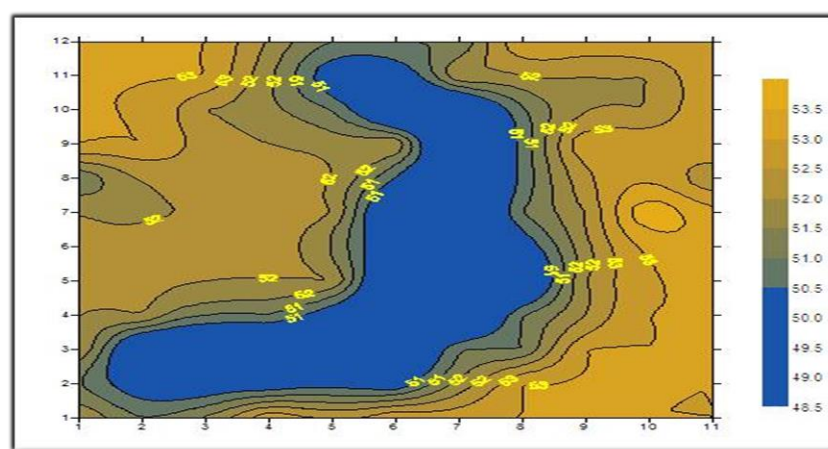


Fig. 18. Contour map for lake 2 and surrounding topographic features. The color scale on the right represents elevation values (48.5–53.5 m), indicating depth variations within the lake. The X and Y axes denote spatial coordinates of the surveyed area

5.4. Soil Sample Analysis

Soil samples were collected from the banks of the lakes and surrounding areas, as well as from sites of ancient buried meanders, to analyze the distribution of sediment sizes in the region. A total of 27 soil samples were collected from 19 locations within the lake environments and surrounding areas. The samples were dried in an electric oven, after which one kilogram from each was selected for the sieving process.

Sieving was carried out using a vibrating sieve device (model SI 90), with mesh sizes corresponding to sand (2 mm), silt (1/16 mm), and clay (1/256 mm) using sedimentation isolation. The results were then compared with international reference charts to determine the percentages of sand, silt, and clay. Each sieve fraction was weighed after sieving to determine its percentage relative to the total sample mass. The particle size analysis results were compared to international reference tables to determine the percentages of sand, silt, and clay. Soil texture classification was performed using the USDA Soil Texture Triangle (2022). The resulting soil texture classes are presented in Tables 1 and 2 and illustrated in Figs. 19 and 20.

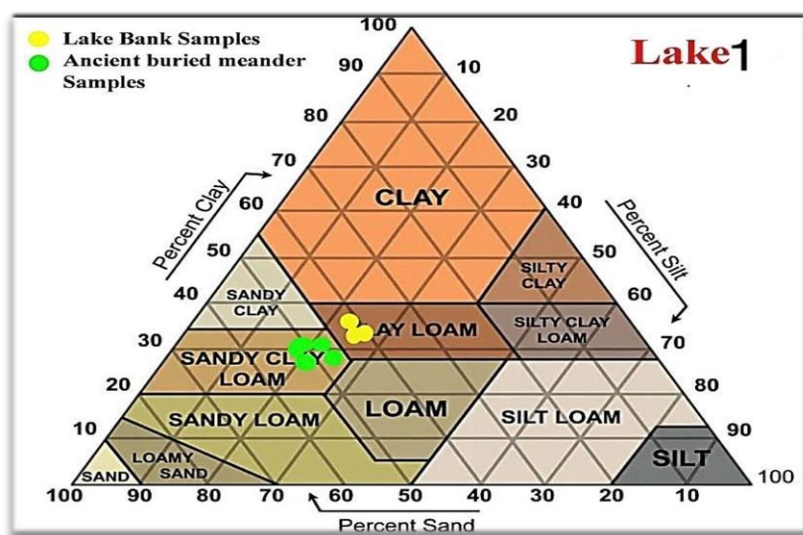


Fig. 19. Soil texture classification for Lake 1 (USDA, 2022)

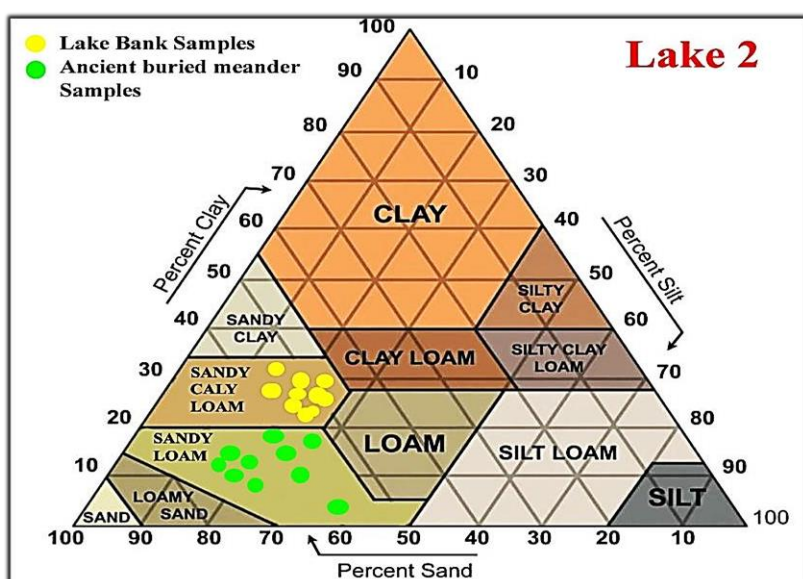


Fig. 20. Soil texture classification for Lake 2 (USDA, 2022)

Table 1. Sediment analysis for Lake 1

Location	Sand	Silt	Clay	Name
Lake banks	32%	34%	33%	Clay loam
Ancient buried meander and surrounding area	53%	21%	25%	Sandy clay loam

Table 2. Sediment analysis for Lake 2

Location	Sand	Silt	Clay	Name
Lake banks	54%	21%	24%	Sandy clay loam
Ancient buried meander and surrounding area	62%	22%	15%	Sandy loam

5.5. Water Sample Analysis

Water samples were collected during two field excursions to evaluate the chemical characteristics of the water levels of the studied elements. These samples were categorized into three types:

Direct samples from the lake water itself; samples from the nearest well to the lake, with water depths typically ranging between 6 to 11 m based on conversations with local farmers residing in the area; and the third type included samples from the Euphrates River at the closest point to the lake.

This diversity of sampling aimed to determine the extent of similarity in element concentrations between the lake water and other sources, to identify possible hydrological connections and recharge sources to the lake at each site, three samples were collected. After analysis, the mean concentration values was calculated and used in the Tables 3 and 4 .The samples were analyzed in the laboratories of the Upper Euphrates Basin Development Center at Anbar University and the Ramadi Agriculture Directorate .

Table 3. Results of Water analysis for Lake 1

Sample type	First Field 9 / Oct / 2024					Second field 9 / Apr / 2025				
	Ca mg/l	Mg mg/l	K mg/l	SO ₄ mg/l	NO ₃ Mg/l	Ca mg/l	Mg mg/l	K mg/l	SO ₄ mg/l	NO ₃ mg/l
Lake Water	1800	306.3	32.5	8500	0.4	36	20	108.3	14.8	91.05
Well Water	271	94	30.6	757	8.8	27	15	13.3	5.16	63.04
Euphrates Water	92	28.8	3.9	500	14.1	8	4	6.7	24.74	56.04
Drainage Water	No Data					No Data				
Precipitation Water - Date 10/Apr/2025	No Data					4	2	2.2	7.15	91

Table 4. Results of Water analysis for Lake 2

Sample type	First Field 9 / Oct / 2024					Second field 9 / Apr / 2025				
	Ca	Mg	K	SO ₄	NO ₃	Ca	Mg	K	SO ₄	NO ₃
	mg/l	mg/l	mg/l	mg/l	Mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Lake Water	930	339.4	40.9	4250	18.8	25	17	69.7	17.08	64.06
Well Water	168	84	23.4	667	9.5	22	15	8.9	5.7	63.04
Euphrates Water	91	27.24	3.7	482	18.8	5	3.5	5.3	13.67	112
Drainage Water			No Data			31	7	21.8	6.4	71
Precipitation Water - Date 10/Apr/2025			No Data			4	2	2.2	7.15	91

5.6. Changes in Lake Surface Area Derived from Sentinel-2 and Landsat Imagery

The lake's surface area was calculated using ArcMap version 10.8 (Esri, 2023) covering the period from 1997 to 2025 during both spring and autumn seasons. A noticeable change in surface area was observed, with a variation of 25.7% between the smallest and largest recorded extents for Lake 1, as shown in Table 5 and Fig. 21 and 10% for Lake 2, Table 6 and Fig. 22, as shown in Table 6 and Fig. 22.

Table 5. Calculating Lake 1 Surface Area Variation Over Time

Date	Lake Surface Area (m ²)	Image from Satellite
12-04-2025	162104	Sentinel-2 L2A
12-11-2021	157000	Sentinel-2 L2A
1-11-2015	204877	Landsat 7 ETM +
16-04-1997	211248	Landsat 5 TM

**Fig. 21.** Changes in Lake 1 Surface Area with years**Table 6.** Calculating Lake 2 Surface Area Variation Over Time

Date	Lake Surface Area (m ²)	Image from Satellite
29-06-2025	776416	Sentinel-2 L2A
12-11-2021	702838	Sentinel-2 L2A
04-11-2015	711316	Landsat 7 ETM +
16-04-1997	754000	Landsat 5 TM



Fig. 22. Changes for Lake 2 Surface Area with years

6. Results and Discussion

Topographic profiles and contour mapping indicate that the surrounding land to both lakes sloped toward the lake basins and that there is at least some evidence of inflow of water from the surface, probably caused by either irrigation or rainfall in excess of that necessary for agricultural production. The Euphrates River borders the area to the north and east; measurement from the contour map indicate that the contour elevation of land decreases from 51 to 46 m above sea level in just 1 km, highlighting this slope is steeper than that on the western slope which has a more gradual slope extending over a much longer distance with little or no flooding from the river. Consequently, the greatest likelihood for the source of subsurface infiltration is due to the Euphrates River. Furthermore, the lake has been utilized by local inhabitants to discharge industrial wastes and domestic sewage, contributing to lake water inputs. In addition, profile measurements of the ancient, buried meanders indicate they are typically 1-2 m lower than surrounding terrain; while these differences may not be readily detected when viewed on the ground, they can be readily determined through the use of imagery taken from satellites and topographic elevations associated with those locations.

A sediment grain size analysis demonstrates that revealed variations in the abundance of clay, silt, and sand among different sites sampled. The data indicate that the percentage of clay would result from low velocity hydrologic environments where sediments can settle and remain stationary, whereas high amounts of sand would indicate high-energy hydrodynamic conditions including currents/wave activity, and erosion. In general, sediments from ancient buried meanders will generally have coarser grain sizes than Lake Banks from both lakes suggesting the potential presence groundwater may also exist due to porosity within the sediments, which in turn could provide a source of secondary supply to both Lakes.

Water samples analysis showed a range of concentrations from site to site. In areas where there were high levels of calcium and magnesium, it is likely the result of the rocks and sediments (geologic formations) and their interaction with groundwater. Sulfate concentrations showed variable levels in the various sites that could be due to either uncontrolled contamination from external sources, or due to a change in drinking water source. Nitrate levels were particularly high in some areas where there were agricultural practices, which is indicative of contamination from agricultural runoff and/or human-induced pollution. The available evidence suggests of water supply is groundwater, recharged by the Euphrates River. This is evident in the second lake: due to its proximity to the river, its surface area shows no significant seasonal or temporal variation, as it is continuously fed by groundwater seepage from the river. As for the remaining lakes, available evidence also indicates that groundwater is their primary source. The Calculation of the changes in Lake Surface Area using landsat and Sentinel-2 Satellite images supports the hypothesis that the Euphrates River is the primary source feeding the lakes,

and that lake size is influenced by proximity to the river. Further evidence confirms that the Euphrates River is the main source for Lake 2, as it lies only a few hundred meters away. Consequently, seasonal water fluctuations have minimal impact on this lake, unlike the other lake, where water level and surface area show clear variation.

The current study demonstrates that the Euphrates River is the main source of water for the nearby lakes, and the coarse sediments in the abandoned meanders indicate the presence of active fluvial sedimentation processes. Ghaib et al. (2024) emphasized the hydraulic processes that control sediment transport and deposition in meandering rivers. These studies support the conclusion that the Euphrates River is the main source of water and sediments for the nearby lakes, and they confirm the field observations of coarse sediment deposits in the abandoned meanders.

7. Conclusions

The results of the study support the idea that the Euphrates River is contributing significantly to sustain the lakes found in the Ramadi region via surface runoff and subsurface water movement, especially in close proximity to the river. Changes to the soil structure and/or chemical composition of the surface water caused by humans and local weather patterns, are indicators of how much they have affected regional hydrology. The abandoned meanders have sufficient hydrologic significance to influence the development of landscape features and to control water retention.

This research emphasizes the role of using remote sensing techniques within environmental research and highlights the necessity of conducting periodic surveys in order to validate spectral interpretations acquired through remote sensing techniques. This study encourages using these findings in support of water management strategies, particularly in light of climate change and increasing human impacts on natural resources, in order to contribute to the long-term viability of the lakes and wetlands in the Ramadi landscape.

Declaration of Competing Interest

The authors declare that they have no competing financial interests or personal relationships that could influence the work reported in this study.

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Data Availability

All data generated or analyzed during this study are included in this published article and its supplementary materials

References

- Aher, S.P., Bairagi, S.I., Deshmukh, P.P., Gaikwad, R.D., 2012. River change detection and bank erosion identification using topographical and remote sensing data. *International Journal of Applied Information Systems*, 2(3), 1–7.
- Anderson, R.S., Anderson, S.P., 2010. *Geomorphology: The Mechanics and Chemistry of Landscapes*. Cambridge University Press, Cambridge. <https://doi.org/10.1017/CBO9780511794827>
- Andik, B., Sarang, A., 2017. Daylighting buried rivers and streams in Tehran. *Water Conservation and Management*, 1(1), 1–6. <https://doi.org/10.26480/wcm.02.2017.01.04>
- Bety, A., 2013. *Urban Geomorphology of Sulaimani City Using Remote Sensing and GIS Technology*, Kurdistan Region, Iraq. PhD thesis, Sulaimani University, Sulaimani.

- Cael, B.B., Seekell, D.A., 2016. The size-distribution of Earth's lakes. *Scientific Reports*, 6, Article 29633. <https://doi.org/10.1038/srep29633>
- Edgeworth, M., Benjamin, J., 2018. What is a river? The Chicago River as Hyperobject. In: Kelly, J.M., Scarpino, P.V., Berry, H., Syvitski, J., Meybeck, M. (Eds.), *Rivers of the Anthropocene*. University of California Press, Oakland. <https://doi.org/10.1525/luminos.43.1>
- Esri, 2023. ArcGIS Desktop: Release 10.8 (Computer software). Environmental Systems Research Institute. <https://www.esri.com/en-us/arcgis/products/arcgis-desktop/overview>
- Falkowski, E., Kowalski, W.C., 1987. Buried river valleys and buried alluvia and their engineering geotechnical significance. *Bulletin of the International Association of Engineering Geology*, 35, 97–104. <https://doi.org/10.1007/BF02590476>
- Fouad, S.F.A., 2012. Tectonic Map of Iraq – 3rd Edition. *Iraqi Bulletin of Geology and Mining*, 11(1), 1–13.
- Ghaib, Z.G., Al-Murshedi, K.R., Naje, A.S., 2024. Hydraulic and sediment dynamics of the Euphrates River – Evaluating scouring, sediment transport, and riverbank soil characteristics at the Shatt Al-Hilla reach. *Ecological Engineering and Environmental Technology*, 25(11), 326–339. <https://doi.org/10.12912/27197050/192811>
- Guo, Y., Ayer, T., van Puijenbroek, P., Stokal, M., 2024. Microplastics in global rivers: Sustainable practices. *Sustainable Development*, 33(2), 2937–2950. <https://doi.org/10.1002/sd.3279>
- Hamad, W.H., 2022. The geomorphological and sedimentary forms of the valley of Euphrates River within the sedimentary plain in Anbar Governorate and the aspects of its investment. *Journal of Tikrit University for Humanities*, 29(1), 87–108. <https://doi.org/10.25130/jtuh.29.12.2.2022.05>
- Hook, S.J., Ramseier, R.O., 2016. Thermal Infrared Remote Sensing for Analysis of Landscape. NASA Jet Propulsion Laboratory.
- Huggett, R.J., 2007. *Fundamentals of Geomorphology*. 2nd ed. Routledge, London. <https://doi.org/10.4324/9780203947111>
- Ismail, T., 2014. Extraction of Special-Nature Geographical Features from Satellite Images Using Segmentation. MSc thesis, Damascus University, Damascus.
- Jaafar, E.N., Daliman, S., 2022. Analysis of river channel change using remote sensing images at Kelantan River Basin. *Institute of Physics Publishing Conference Series: Earth and Environmental Science*, 1102(1), 012082. <https://doi.org/10.1088/1755-1315/1102/1/012082>
- Li, B., Zhang, H., Xu, F., 2014. Water extraction in high resolution remote sensing image based on hierarchical spectrum and shape features. *Institute of Physics Publishing Conference Series: Earth and Environmental Science*, 17, 012123. <https://doi.org/10.1088/1755-1315/17/1/012123>
- Li, Y., Zhang, Y., Zheng, N., Li, L., Ji, H., Bao, Z., Feng, Z., 2025. Global classification of river morphology based on inland water dynamics characterization and digital elevation data. *Scientific Reports*, 15, Article 14258. <https://doi.org/10.1038/s41598-025-99174-7>
- Pitcher, L.H., Smith, L.C., Cooley, S.W., Zaino, A., Carlson, R., Pettit, J., Gleason, C.J., Minear, J.T., Fayne, J.V., Willis, M.J., Hansen, J.S., Easterday, K.J., Harlan, M.E., Langhorst, T., Topp, S.N., Dolan, W., Kyzivat, E.D., Pietroniro, A., Marsh, P., Yang, D., Carter, T., Onclin, C., Hosseini, N., Wilcox, E., Moreira, D., Berge-Nguyen, M., Crétau, J.F., Pavelsky, T.M., 2020. Advancing field-based GNSS surveying for validation of remotely sensed water surface elevation products. *Frontiers in Earth Science*, 8, 278. <https://doi.org/10.3389/feart.2020.00278>
- Ravazzolo, D., Mao, L., Bertoldi, W., 2020. The role of vegetation and large wood on the topographic characteristics of braided river systems. *Geomorphology*, 367, 107299. <https://doi.org/10.1016/j.geomorph.2020.107299>
- USDA, 2022. Soil Health Guide: Texture and Structure. Natural Resources Conservation Service, Washington, DC. https://www.nrcs.usda.gov/sites/default/files/2022-11/Texture%20and%20Structure%20-%20Soil-%20Health%20Guide_0.pdf
- Zhiyuan, X., Bin, W., Aili, A., Waheed, A., Yongqiang, Y., 2025. Hydrogeological dynamics, salinization risk and ecological vulnerability in an arid inland river basin. *Water, Air, and Soil Pollution*, 236, 236–1019. <https://doi.org/10.1007/s11270-025-08665-w>

- Williams, P., Whitfield, M., Biggs, J., Bray, S., Fox, G., Nicolet, P., Sear, D., 2004. Comparative biodiversity of rivers, streams, ditches and ponds in an agricultural landscape in Southern England. *Biological Conservation*, 115(2), 329–341. [https://doi.org/10.1016/S0006-3207\(03\)00153-8](https://doi.org/10.1016/S0006-3207(03)00153-8)
- Xu, H., 2006. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing*, 27(14), 3025–3033. <https://doi.org/10.1080/01431160600589179>