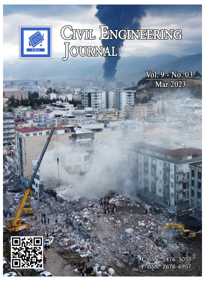
Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 9, No. 03, March, 2023



Monitoring and Modelling Morphological Changes in Rivers Using RS and GIS Techniques

Zainab Dekan Abbass [1, 2] *, Jaafar S. Maatooq [1], Mustafa M. Al-Mukhtar [1]

[1] *Civil Engineering Department, University of Technology-Iraq, Baghdad, Iraq.*

[2] *Department of Environmental Planning, University of Kufa, Kufa, Iraq.*

Received 29 September 2022; Revised 05 February 2023; Accepted 11 February 2023; Published 01 March 2023

Abstract

River geomorphological investigation issues have received little attention in most countries of the world. Such processes become a pressing necessity due to climate change and anticipated events of extraordinary surges and dry seasons, which may debilitate the security of adjacent and downstream cities, particularly in locales that are exceedingly delicate and influenced by climatic changes. Al-Abbasia reach is a river that runs through the middle of the Euphrates River and is known for its numerous bends and meanders. The study of hydraulic structures such as barrages can provide important information about their influences on morphological processes in river reaches near the barrage upstream and downstream. Hydraulic analysis is made of the river behavior in u/s and d/s of hydraulic structures like barrages as a result of sediment deposition and erosion in u/s and d/s. A study, i.e., research on the impacts of the Abbassia barrage on the river system, has been conducted to address this issue using multi-temporal Landsat satellite data from 1976 to 2022 provided by the USGS. The study reach is located 5 kilometres upstream and 5 kilometres downstream of the Abbassia reach. Following the construction of the barrage, which had an impact on the sedimentation and geometry of the river, morphological variations took place in this part of the Al Abbassia reach. In this study, morphological changes throughout 49 years between 1976 and 2022 were investigated utilising remote sensing (RS) and geographic information system (GIS) approaches. Additionally, four image groups from three separate decades were used to perform change detection (1990–2000, 2000–2010, and 2010–2022). In this study, a monitoring system using Landsat-3 MSS: 1985, Landsat-5 TM: 1990, 1995, 2000, 2005, and Landsat-8 OLI: 2010, 2011, 2015, 2021, 2022 were employed to map river planform changes. The long-term comparison of this series of satellite images and historical maps for the period 1976–2022 indicates a continuation of change in the reach study with a rate of approximately 56, 33, 97, and 55% for upstream and 19%, 26%, 3%, and 45% for downstream for the width, area, deposition, and erosion, respectively. Furthermore, it is observed that there is a shift in river course within 200 m downstream of the barrage for the period of 1985–1990. The findings of this study, which monitor river morphological change at finer temporal and spatial resolutions, are crucial for promoting sustainable river management. They also aid in the investigation of river behaviour, which is necessary for providing the best management possible and overcoming the difficulties posed by this important research issue.

Keywords: Abbassia Barrage; Landsat Images; River Morphology; Erosion; Sedimentation; Remote Sensing.

1. Introduction

The process of managing river basins is very significant when explaining the morphological aspects of rivers. Evaluation of these aspects of river planform, the land cover of floodplains, and geometry is of suitable importance for river hydrodynamics and ecosystem functions [1]. The river generally varies in shape because it carries different amounts of water and sediment in different phases depending on its topographical and other geomorphological

* Corresponding author: bce.19.83@grad.uotechnology.edu.iq

http://dx.doi.org/10.28991/CEJ-2023-09-03-03

conditions [2, 3]. Thus, it always changes its shape and position through changing the morphodynamic processes within due course of time.

A firm knowledge of channel migration and associated erosion and deposition processes will permit controlling river behaviour and the decision-making process [4]. Understanding the channel shifting issues and considering river morphological changes has long been of interest to water resources engineers. Barrages and weirs are relatively low-level dams constructed across a river to raise the river level sufficiently or to divert the flow in full or in part into a supply canal or conduit for irrigation, power generation, navigation, flood control, and domestic and industrial uses. These structures can locally create complex flow patterns, reduce flow velocities, and increase flood levels. The protection of hydraulic structures as well as their planning, design, and maintenance depend heavily on an accurate understanding of the river's behaviours close to the structures. There is an important matter that uncontrolled deterioration as well as degradation lead to serious problems in river training [5].

Efficient monitoring and identification of hydraulic characteristics, such as accurate delineation and mapping of the river system, land cover, planform, and flow rates, are required for sustainable water resource management. Recently, measurements of riverbank and channel shifting have been constructed employing remote sensing methods with the support of the Geographic Information System (GIS). These methods seek a large spatial and multi-temporal coverage with a direct, integrated, and comprehensive view of vast areas.

The Euphrates River is considered one of the most well-known historic rivers in the world, and it is the lengthiest river in southwest Asia, with a length of 2786 km and draining an area of about 440,000 km^2 [6]. Along this river, the stream repeatedly changes itself, causing deposition and erosion as the waterway passes through diverse geomorphic features along its course. Numerous reaches' of altered morphology have not yet been studied. Regarding morphological aspects, the Abbassia reach, which stretches 38 km from Abbassia city in Kufa to Al-Shamiya city in Dywania, is one of the unexplored reaches. In 1982, the Iraqi Ministry of Water Resources (IMoWR) started to construct a barrage, named Abbassia Barrage, downstream of Babylon governorate. The potential occurrence of morphological and flow changes along this reach prioritizes the need for a detailed study of the morphological characteristics. Most of the previous literature related to Abbassia reaches is confined to the geometry and/or the bed material. The commonly involved methodology in this literature was the cross-sectional survey and/or bed materials piece laboratory analysis and field survey [7–12]. These studies are all entirely focused on fieldwork and laboratory work without the use of any remote sensing techniques in the subject area. As a result, this study became the initial effort to comprehend the reaching behaviour using data from satellite images.

In the literature, many international studies were carried out to identify the morphological and spatio-temporal pattern of the river planform and their bankline migration with the aid of GIS and remote sensing tools [13–18]. Remote sensing has been used by researchers for more than thirty years to investigate the surface of the earth [19], of which supervised remote sensing techniques have been widely used for the analysis of satellite images. For example, in the river delta in Turkey [20], the Nile River delta in Egypt [21, 22], and many others. In this study, the temporal and spatial changes in the Euphrates River uses Landsat-3 MSS: 1985, Landsat-5 TM: 1990, 1995, 2000, 2005, and Landsat-8 OLI: 2010, 2011, 2015, 2021, 2022 were employed to map river planform changes along 5 km of river length upstream and 5 Km downstream of the Abbassia reach. The morphological changes were analyzed using Remote Sensing (RS) and Geographical Information System (GIS) techniques for 49 years between 1976 and 2022. In addition, change detection was performed from four image groups across three different decades. The outcomes of this study will help to understand future channel behaviour to support tackling the challenges generated by the dominant fluvial processes.

2. Implementation Details

2.1. Study Domain

Al-Abbasyia barrage was constructed on the Kifil-Shanafiyah branch of the Euphrates River downstream of Babylon governorate for irrigation purposes in 1982. Likewise, the barrage controls the flow for the downstream regulator in the middle Euphrates region. We have to mention some public information about the Abbasiya barrage, where the design discharge volume of the barrage is 1000 m^3/s with a downstream water level of 23.8 m.a.s.l. As stated in the operational report, operational discharge ranges from 50 to 230 m^3/s with a water level of 23.5 m.a.s.l. The barrage contains six rectangular openings, each with a dimension of 12 m in width × 6.3 m in height and equipped with a steel radial gate [8]. The length of the study reach is 5 km upstream and 5 km downstream of the barrage. Figure 1 shows the location and description, respectively, of the Al-Abbasyia barrage and the course of the river covered by the study.

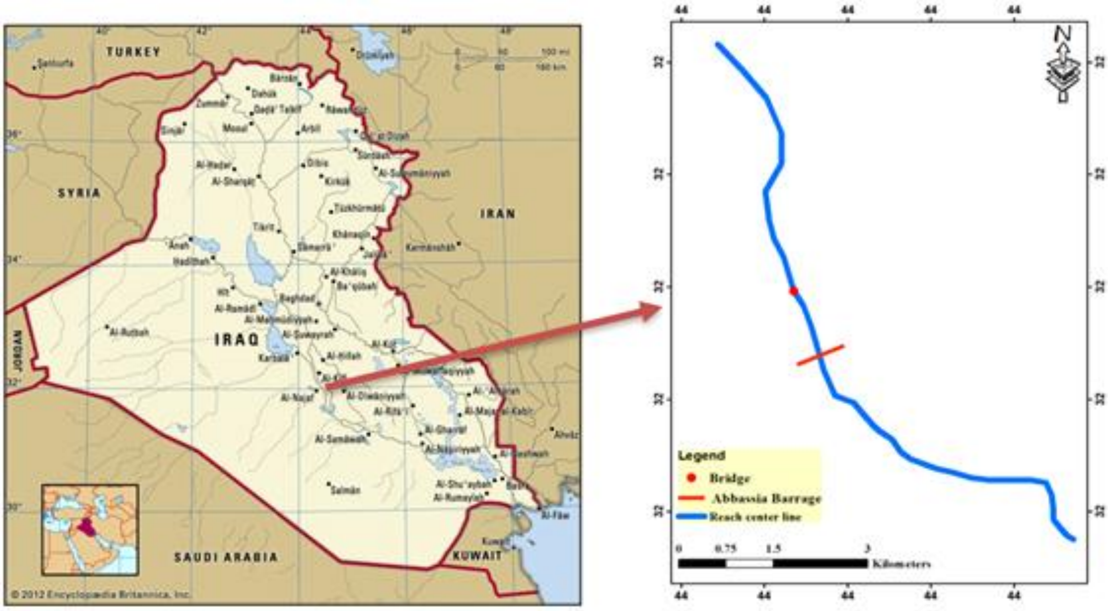


Figure 1. The upstream & downstream study area

2.2. Methodology

The considered methodology is mainly based on various basic thematic layers, including the map and satellite imageries obtained for the study domain. Employing ArcGIS 10.3 software tools, several maps were organized for the Abbassia Barrage for an interval of 1976–2022. The data used are multi-temporal, multi-spatial, and multi-spectral satellite remote sensing data that have been downloaded for the entire Abbassia river basin in Kufa, Iraq, from the U.S. Geological Survey [23]. Figure 2 depicts the schematic diagram of the methodology used in this article.

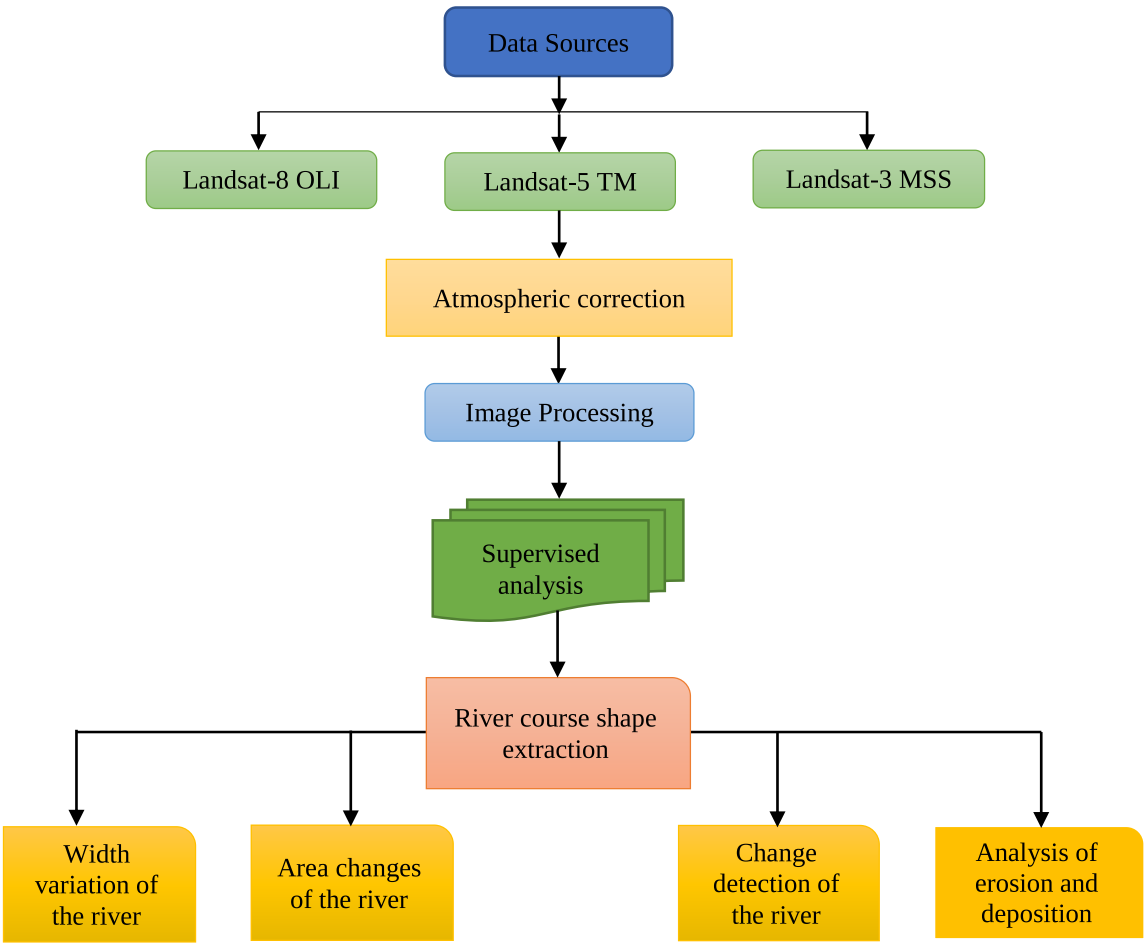


Figure 2. Flow chart of river course extraction

The satellite remote sensing data utilised is Landsat-3 MSS: 1985 Landsat-5 TM: 1990, 1995, 2000, 2005. Landsat-8 OLI: 2010, 2011, 2015, 2021, 2022. In this study, satellite images were downloaded from the USGS Earth Explorer location for the aforementioned period to investigate and monitor the morphological state of the Abbassia river during this period, pre- and post-construction, and after the operation of the Abbassia barrage. Image processing followed by classification was carried out. Image classification seeks to categorize all pixels in a digital image into various land use and land cover classes. In remote sensing, one of the most known types of classification that can be used to achieve classified outputs is called the Supervised Classification technique. In these techniques, analysts pick expected illustrations for each land cover class. The application then takes these "training sites" and involves them in the entire image. Furthermore, the supervised classification employs the features of the spectral signature described in the training set. In this study, supervised processes were applied as being more suitable to developing the final output and for classifying maps.

The river shape is then extracted to represent the river course through GIS tools. Area, width, erosion, sedimentation, and change detection were calculated for each image through these tools. Indeed, there were no previous literatures that included topographic surveys, technique analysis, and land cover investigations to study the planform and morphological aspects of this reach. To the best of my knowledge, there were no previous studies that applied satellite-based data to investigate the planform of the studied reach. Hence, validating the obtained results with other studies was not possible. Even on a global scale, the morphological aspects of the studied rivers are unique and differ from the river extent of interest. This paper, therefore, provides a basis for monitoring future changes in these aspects. Figure 3 shows the raw image data obtained from the satellite. Figure 4 depicts the supervised classification image of the study area. Finally, Figure 5 shows the extracted river course processed from the above two images.

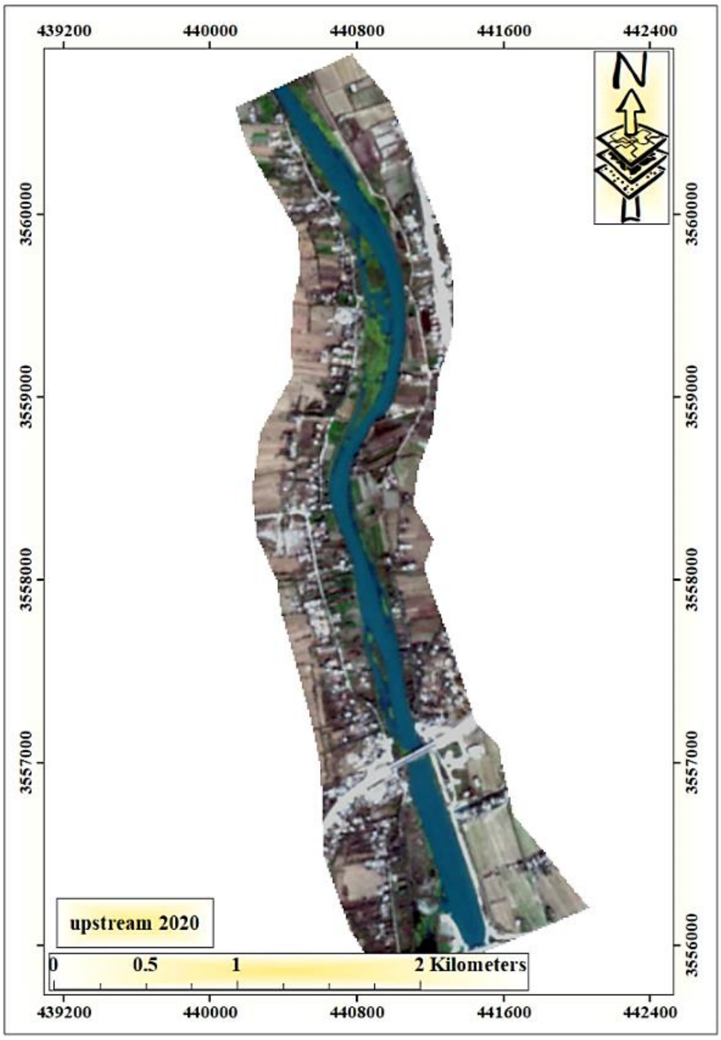


Figure 3. Raw image data of the study area

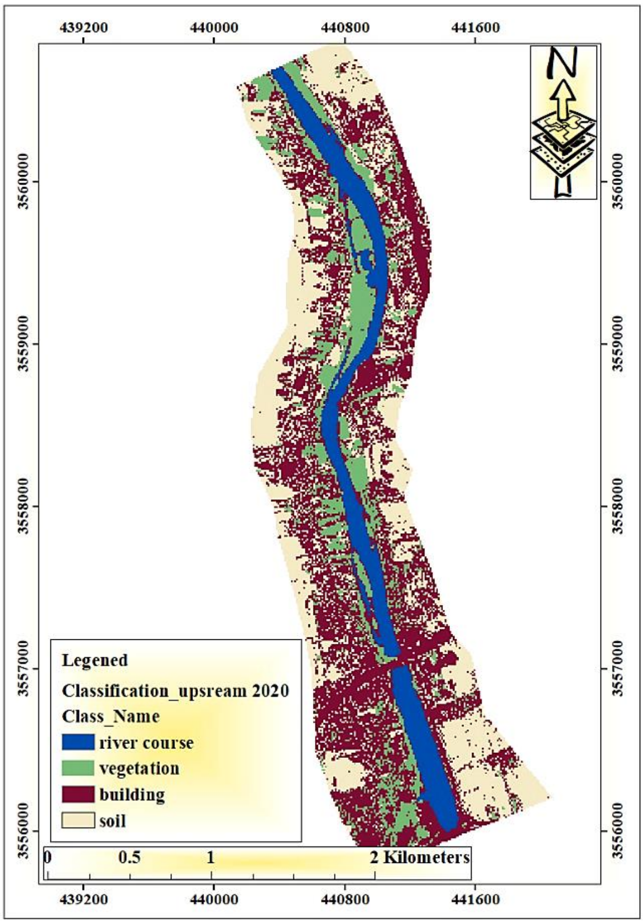


Figure 4. Supervised classification of the study area

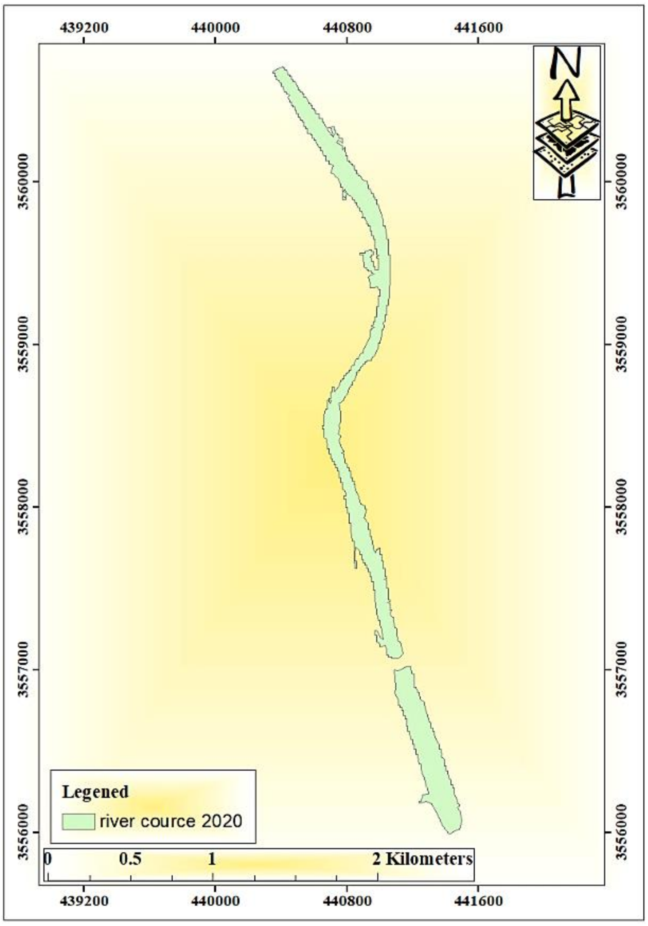


Figure 5. River course shape extraction of the study area

3. Results and Discussions

3.1. Morphological Aspects on the Upstream Barrage

The work included conducting several field trips to observe the morphological changes in the river course. It has been documented that the Euphrates River near the arrival of the Abbassia's reach adjusted its course over time. Thus, this article attempted to detect the change of river course in the study domain from 1976 to 2022. Figures 6 and 7 illustrate the change of the river channel at various times and at a distance of 5 KM upstream and 5 KM downstream. Both the upstream and downstream parts of the river were selected for the study of change detection in the river. A recorded analysis of river course change for 46 years was conducted to analyse the changes in river configurations, which reveals an abrupt change in the river course between the years 1976 to 2022.

In 1976 (the pre-installation barrage period), the river was steering in a meandering pattern. After the construction of the barrage (1982–1987), the river carried eastward but could not move further in this direction due to the presence of vast riparian vegetation. The influences of floodplain vegetation on river morphology can be seen in all spatial measurements where these cause deflection of the main flow towards the middle part of the main channel (Figure 8). Gurnell et al. [24] show that the floodplain vegetation enhances bank expansion by decreasing soil migration, while Allmendinger et al. [25] proved that it reduces bank retreat, leading to width reduction. After the blockage by the riparian vegetation, the river meandered in a zigzag pattern after passing the vegetative zone at the beginning of upstream. In the subsequent years, the upstream reach of the river moved gradually away from the vegetation zone, and several years after that, the river started to take a meandering pattern again with fluctuations in its width (Figures 6 and 7).

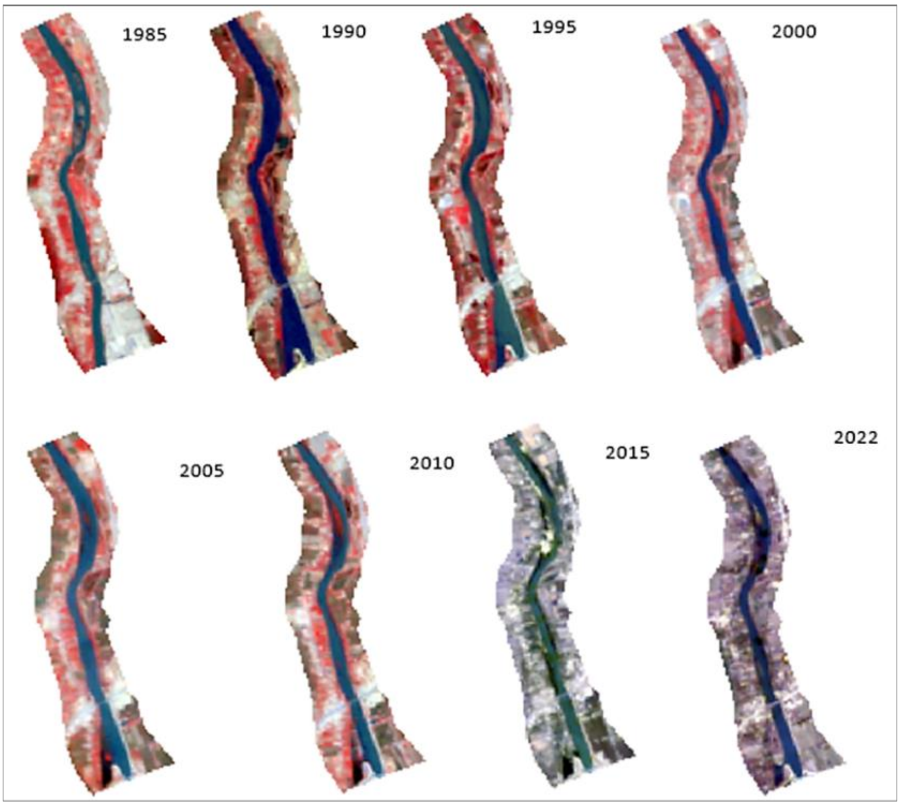


Figure 6. Upstream of the study area (1985-2022)

Figure 7. Multi-Temporal Landsat Satellite Imageries of Abbassia Barrage U/S (1976-2022)

Figure 8. The vegetation upstream of Al- Abbassia Barrage (2022)

3.2. Morphological Aspects on the Downstream Barrage

Before the construction of the barrage (1976), the river planform was straight and turned to the left, downstream from the barrage. After the barrage construction (1982–1987) and the operation in 1989, the river moved to the right, shifting into a downstream river course of about 200 m due to the influence of the barrage, as depicted in the images from 1985 and 1990. Figure 9 shows that the downstream meandering continues, but by 1995 the river became more undersized meandering. In the subsequent years, the downstream reach of the river formed to retake a meandering pattern with fluctuation in its width, as illustrated in Figures 10 and 11.

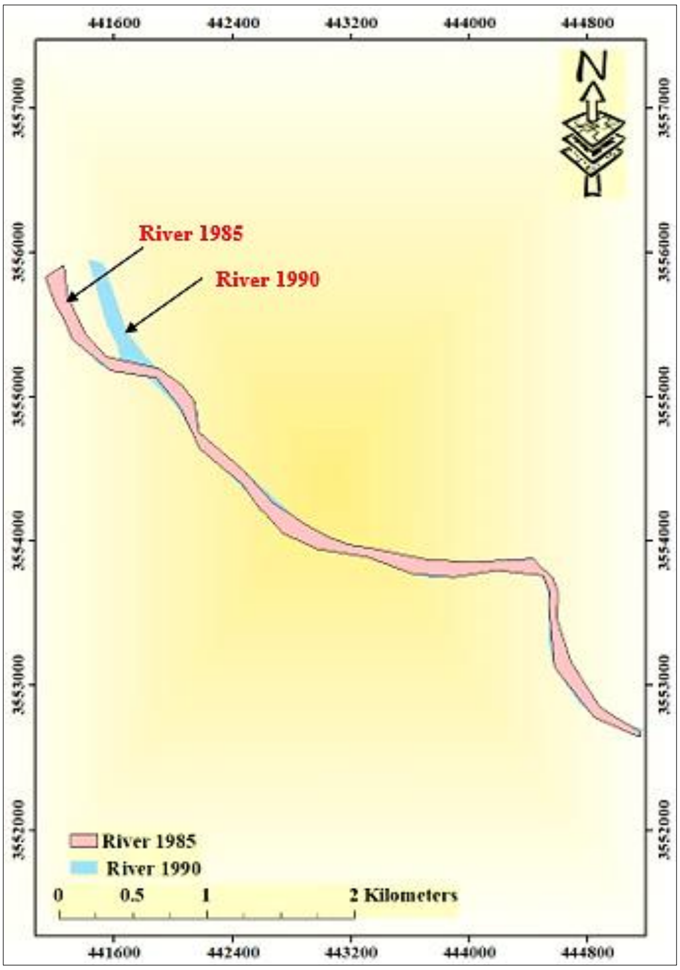


Figure 9. River course shifting (1985-1990) in D/S

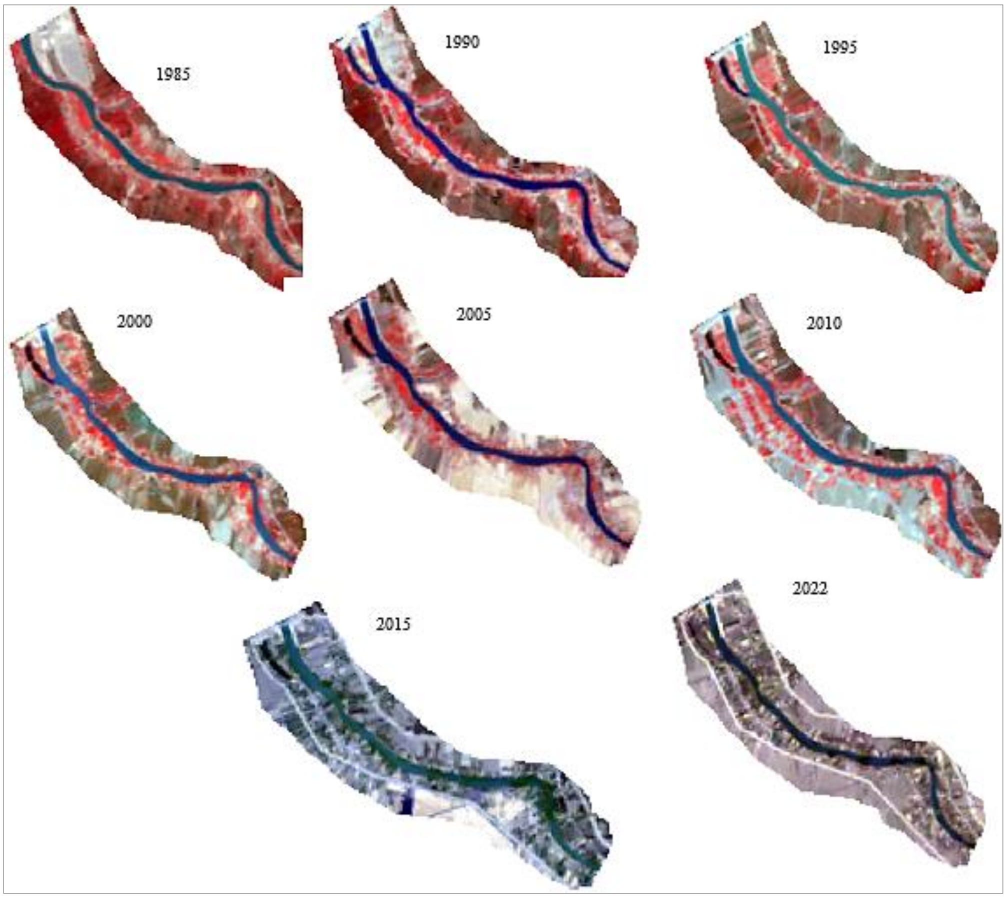


Figure 10. Downstream of the study area (1985-2022)

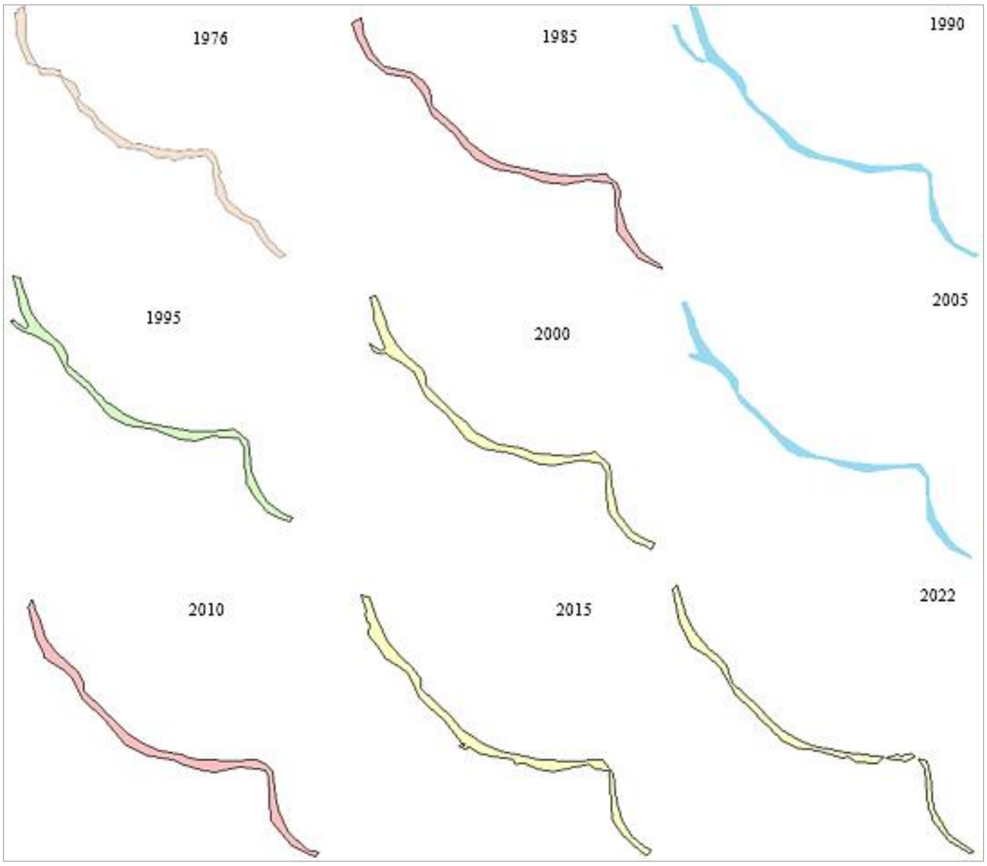


Figure 11. Multi-Temporal Landsat Satellite Imageries of D/S Abbassia Barrage (1976-2022)

3.3. River Width Variation of Euphrates near Abbassia reach

In the study area, the variations in channel width downstream and upstream from the Abbassia barrage before and after the barrage's construction were studied by comparing satellite images through GIS tools, as shown in Figure 12 below, from 1976 to 2022. Pre-installation period (1976), there was no considerable change in width at the upstream and downstream parts. In 1985, when the barrage was constructed on the river reach, the width variation was 66–74 m upstream and 65–42 m downstream. While the barrage operated in 1989, the upstream and downstream widths varied from 74 to 84 m and from 42 to 37 m, respectively, along the reach. Thereafter, in the subsequent years (1995, 2000, 2005, 2010, and 2015), the width fluctuation was recognized. In the same way, the width varied from (84 to 58) m in upstream and (37 to 30) m in downstream, calculated from the date where the barrage operated (1989).

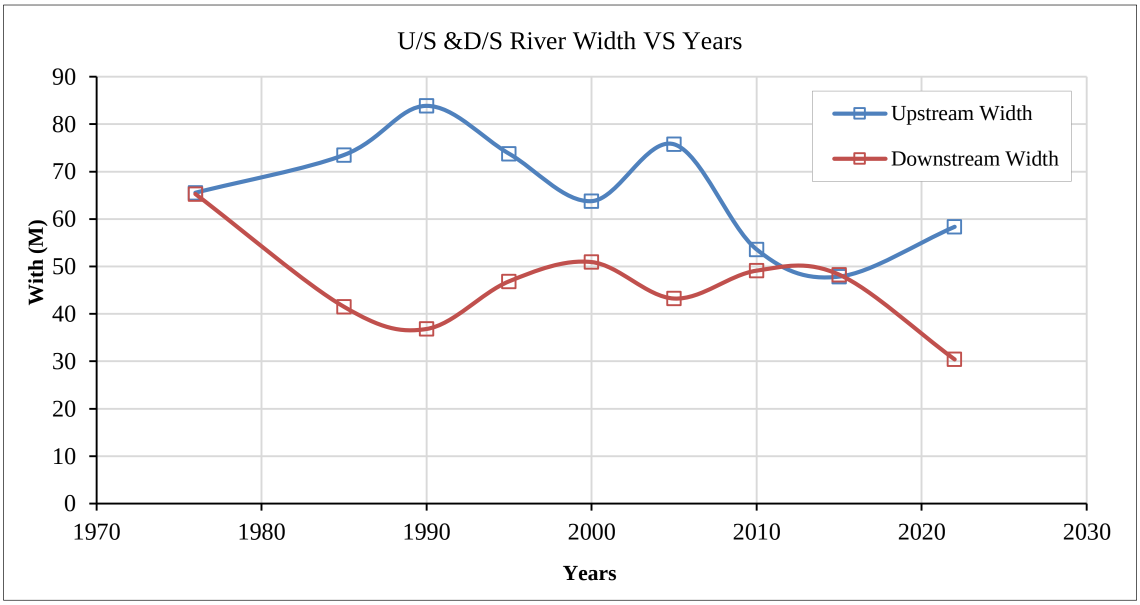


Figure 12. River Width during Pre-and-Post Installation Periods of Abbassia Barrage

3.4. River Area Variation of Euphrates near Abbassia reach

The river's area variations of Abbasia reach were extracted from the satellite images and plotted as bar charts as shown in Figure 13. In the study domain, river area oscillation occurred from 1976 to 2022 on both the upstream and downstream sides of the river. In the Pre-installation period (1976) area downstream in the river was more than the area upstream.

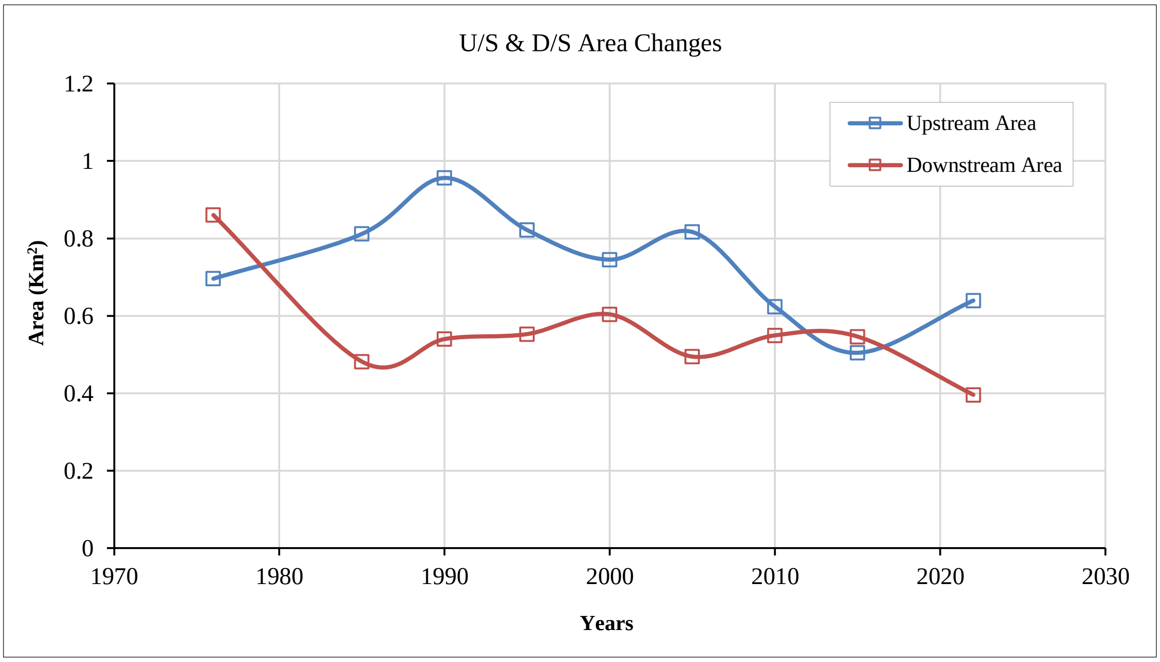


Figure 13. River Area during Pre-and-Post Installation Periods of Abbassia Barrage

In 1985, when the barrage was constructed on the river reach, the case was inversed since the area upstream became larger than that downstream. Once the barrage was operational (1989), The upstream and downstream areas increased both upstream and downstream Abbassia's reach. Thereafter, fluctuation in river area was observed in the years 1995, 2000, 2005, 2010, 2015, and 2022, where a reduction rate in the area of 33% and 26% was recorded in the upstream and downstream of the barrage, respectively, concerning the operation year. Area fluctuation took place where a reduction in the rate of 33% in the upstream part and 26% in the downstream was calculated from the barrage operated year (1989).

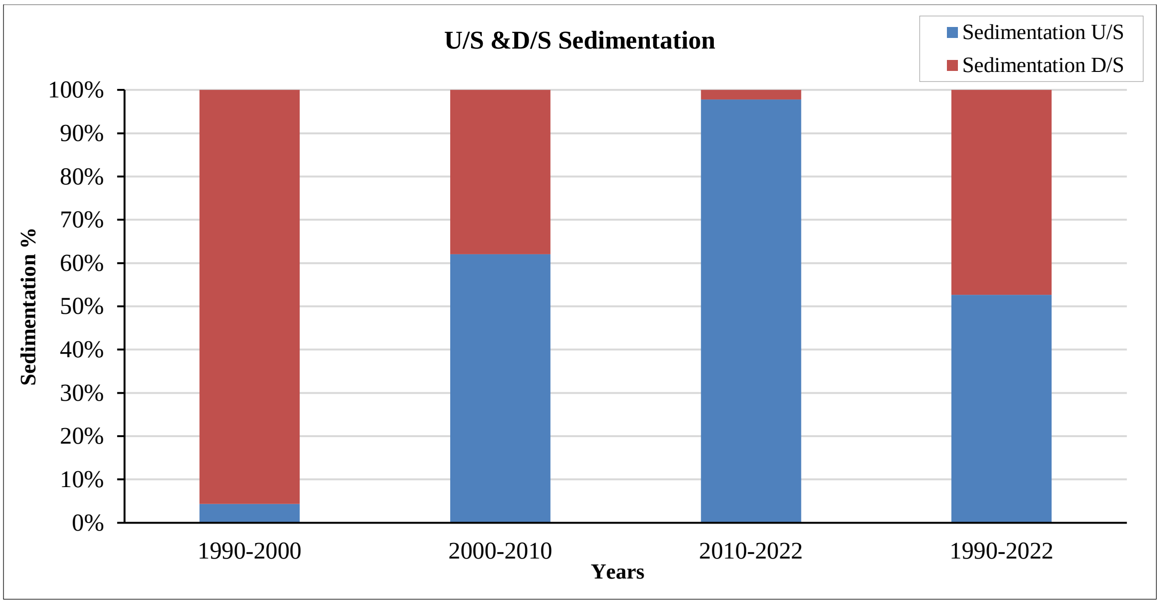


Figure 14. Sediment Deposit in u/s and d/s of Abbassia Barrage

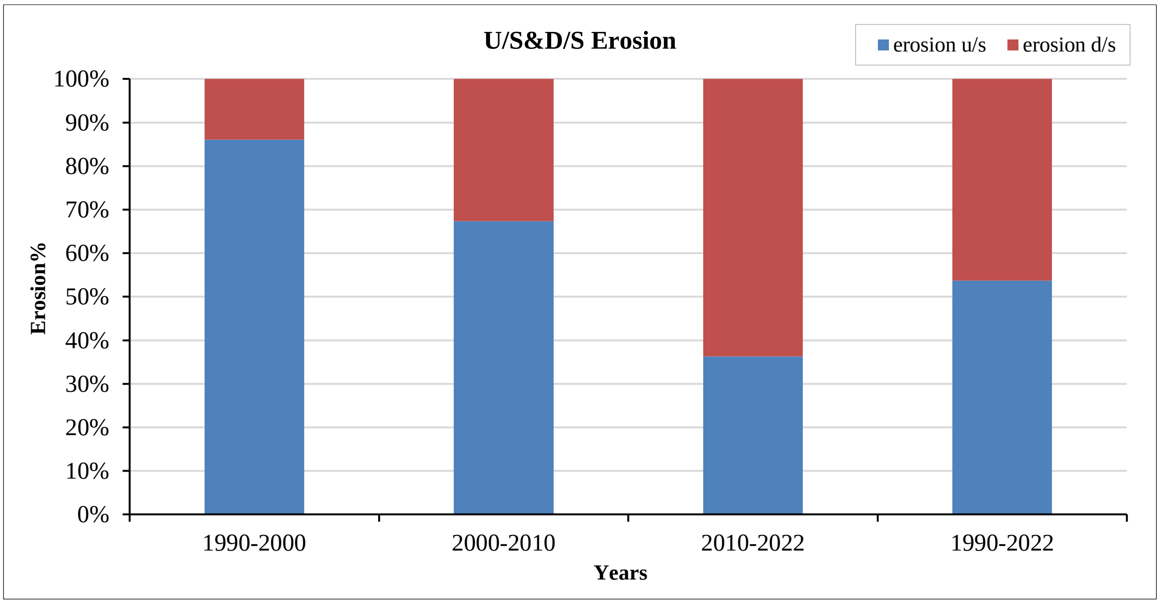


Figure 15. Erosion rate in u/s and d/s of Abbassia Barrage

3.5. Erosion and Deposition Mapping of Euphrates River near Abbassia Reach

Erosion and deposition are the two main phenomena considered in river sediment transport. In the study domain, both erosion and deposition developed from 1990 to 2022. Both the upstream and downstream parts of the river have experienced river erosion as well as accretion or deposition. During this period, the river continued to fluctuate its course. Figures 14 and 15 depict disposition and erosion rates upstream and downstream of the barrage, respectively. The upstream and downstream areas of the river Abbassia reach exposed to erosion at a rate of 85% and 15%, respectively. Whereas, a percentage of 3% and 97% of the land were deposited in these sections from 1990 to 2000. It can be concluded that the upstream river part of Abbassia's reach is not stable. However, some of the areas downstream and upstream of the river experienced erosion rates from 2000 to 2010, with a rate of 20% incremental and reduction, respectively. While this process is inversed at the upstream part of the river with a deposition rate of

37% incremental in the deposited area and 57% reduction downstream in the same period. Lastly, in 2010–2022, the erosion process was continued in the same way through a reduction in the rate at the upstream part and an increase in the rate at the downstream part of the river by 30% and 70%, respectively, while the deposition occurred at a rate of 97% in the upstream and 3% in the downstream. Finally, this process led to what is called the equilibrium state upstream and downstream of the Abbassia River reach 32 years in the period 1990–2022. Change detection for the period 1985–2022 is shown in Figures 16a and 16b.

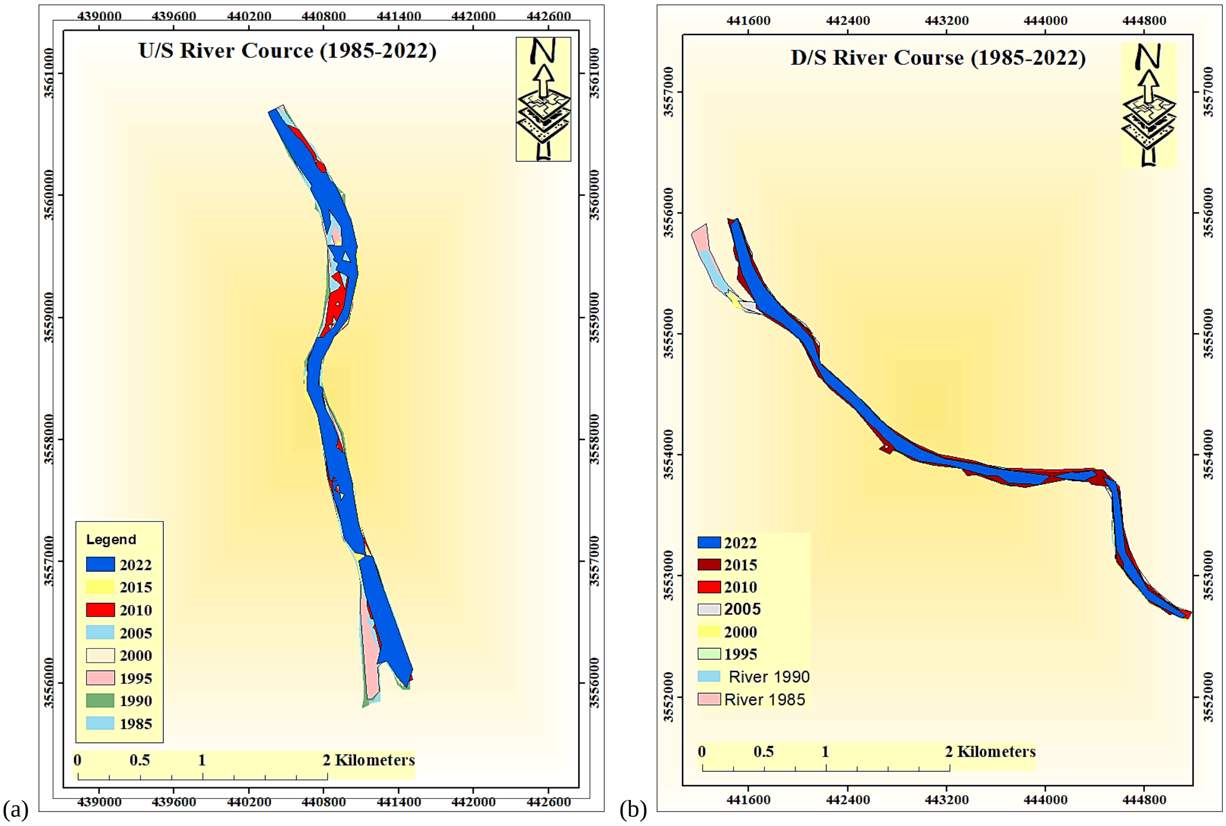


Figure 16. Change detection processes for (a) upstream and (b) downstream of the study area (1985-2022)

4. Conclusions

The utilisation of further detecting information arrangements Landsat images give an effective strategy for identifying changes in the quantity of water within the think about region as well as low costs. In this article, the formal aspects of the Abbassia reach in the Euphrates River were monitored, where a mechanism was designed to identify and evaluate the topographical characteristics and the shape of the plan for this reach. Remote sensing methods are employed to prepare the layout and analyze the planform, with the possibility of detecting the change in the reach through the use of the application of supervised satellite image classification of the land cover from satellite images for the years 1976, 1985, 1990, 1995, 2000, 2005, 2010, 2015, 2020, and 2022.

This article concluded that there is a large and apparent discrepancy in the geometry of the river along its reach. Moreover, a short-term shift of the route of the central channel before construction and after the barrage operation shows some change in the course of the central channel, shift, variation in width, area, and rate of erosion and deposition in this investigation. Nevertheless, the long-term comparison for the period 1976–2022 denotes the continuation of changes in some parts with a rate of approximately 56%, 33%, 97%, and 55% for upstream and 19%, 26%, 3%, and 45% for downstream in terms of width, area, deposition, and erosion, respectively. Furthermore, it is observed that there was a shift in river course downstream during the period 1985–1990.

Also, it was concluded that the Euphrates River has been very dynamic in the study domain over the past 46 years by measuring the rate of erosion in the same area. In other words, the dynamics of this river were a significant point in the occurrence of large amounts of damage to the banks of the rivers adjacent to it. Mainly, the river's dynamism is related to changes in erosion and sedimentation patterns. So, the spatial distribution and temporal variability of erosion and deposition were determined. In general, there is a need to do more literature that focuses on the appropriate management and utilization of the lands deposited by the Euphrates River, and the results of this article can be used for such planning. The outcomes show that the river flow of the Euphrates River in the study domain is very complicated. It should take into account the study of the behavior of some parameters, such as river braiding index, percentage of the island formed, sinuosity index, and vegetation coverage, for further understanding of the river morphology in order to reach valuable outcomes.

River management authorities may evaluate the outcomes of the study before initiating development programs along the river. Therefore, the results might be helpful for understanding future channel behavior to face the challenges generated by these critical issues. Lastly, the accomplished work and the involved methodology contribute to supporting actions to add facts worldwide about uninvestigated rivers and use them as a flexible strategy in any river planning and management.

5. Declarations

5.1. Author Contributions

Conceptualization, Z.D.A. and J.S.M.; methodology, Z.D.A. and J.S.M.; software, Z.D.A.; validation, Z.D.A., and J.S.M.; formal analysis, Z.D.A.; investigation, Z.D.A. and J.S.M.; resources, Z.D.A.; data curation, Z.D.A.; writing—original draft preparation, Z.D.A.; writing—review and editing, J.S.M. and M.M.A; visualization, Z.D.A.; supervision J.S.M. and M.M.A.; funding acquisition, Z.D.A. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Acknowledgements

The authors would like to thank the technical and faculty staff of the Civil Engineering Department at the University of Technology, Baghdad, Iraq, for their valuable support and scientific assistance.

5.5. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Bollati, I. M., Pellegrini, L., Rinaldi, M., Duci, G., & Pelfini, M. (2014). Reach-scale morphological adjustments and stages of channel evolution: The case of the Trebbia River (Northern Italy). Geomorphology, 221, 176–186. doi:10.1016/j.geomorph.2014.06.007.

[2] Abidin, R. Z., Sulaiman, M. S., & Yusoff, N. (2017). Erosion risk assessment: A case study of the Langat River bank in Malaysia. International Soil and Water Conservation Research, 5(1), 26–35. doi:10.1016/j.iswcr.2017.01.002.

[3] Laha, C. (2015). Changing course of the river Ganga in Malda district West Bengal-Damage assessment and risk zone management. PhD Thesis, University of Calcutta, Kolkata, India.

[4] Alam, J. B., Uddin, M., Ahmed, J. U., Cacovean, H., Rahman, H. M., Banik, B. K., & Yesmin, N. (2007). Study of morphological change of river old Brahmaputra and its social impacts by remote sensing. Geographia Technica, 2, 1-11.

[5] Mazumder, S. K. (2004). River behaviour upstream and downstream of hydraulic structures. International Conference on Hydraulic Engineering: Research and Practice (ICONHERP-2004), 26-28 October, 2004, Roorkee, India.

[6] Al-Ansari, N., Adamo, N., Sissakian, V. K., Knutsson, S., & Laue, J. (2018). Water Resources of the Tigris River Catchment. Journal of Earth Sciences and Geotechnical Engineering, 8(3), 1792–9660.

[7] Abed, K. R., Hobi, M. H., & Jihad, A. J. (2014). Numerical modeling of sediment transport upstream of Al-Ghammas barrage. International Journal of Scientific & Engineering Research, 5(11), 469-477.

[8] Hobi, H. M. (2013). Predication of Sediment Transport in Al- Abbasyia Barrage Using the Inverse Monitoring. Kufa Journal of Engineering, 5(1).

[9] Hobi, M. H. (2014). Analytical Study of Haditha Reservoir Sedimentation by CFD Model. Journal of Babylon University / Engineering Sciences, 22(2), 2014.

[10] Mahmood, M. S., Almurshedi, K. R., & Hashim, Z. N. (2017). Non-linear regression models for hydraulic geometry relationships in Al-Abbasia meandering reach in Euphrates River. Jordan Journal of Civil Engineering, 11(4), 549–556.

[11] Hobi, M. H., Khassaf, S. I., & Al-Kizwini, M. M. (2011). Three-Dimensional Flow Model for the Downstream of Kuffa Barrage. Engineering, 29(3), 434–441.

[12] Mohammed, H. S., Alturfi, U. A. M., & Shlash, M. A. (2018). Sediment transport capacity in Euphrates River at al-Abbasia reach using HEC-RAS model. International Journal of Civil Engineering and Technology, 9(5), 919–929.

[13] Nama, A. H., Abbas, A. S., & Maatooq, J. S. (2022). Field and Satellite Images-Based Investigation of Rivers Morphological Aspects. Civil Engineering Journal (Iran), 8(7), 1339–1357. doi:10.28991/CEJ-2022-08-07-03.

[14] Elnashar, A., Zeng, H., Wu, B., Fenta, A. A., Nabil, M., & Duerler, R. (2021). Soil erosion assessment in the Blue Nile Basin driven by a novel RUSLE-GEE framework. Science of the Total Environment, 793, 148466. doi:10.1016/j.scitotenv.2021.148466.

[15] Ibitoye, M. O. (2021). A remote sensing-based evaluation of channel morphological characteristics of part of lower river Niger, Nigeria. SN Applied Sciences, 3(3). doi:10.1007/s42452-021-04215-1.

[16] Boota, M. W., Yan, C., Idrees, M. B., Li, Z., Soomro, S. E. H., Dou, M., Zohaib, M., & Yousaf, A. (2021). Assessment of the morphological trends and sediment dynamics in the Indus River, Pakistan. Journal of Water and Climate Change, 12(7), 3082–3098. doi:10.2166/wcc.2021.125.

[17] Boothroyd, R. J., Nones, M., & Guerrero, M. (2021). Deriving Planform Morphology and Vegetation Coverage from Remote Sensing to Support River Management Applications. Frontiers in Environmental Science, 9(657354). doi:10.3389/fenvs.2021.657354.

[18] Pareta, K. (2020). Effect of Laxmanpur Barrage on the River System-A Case Study through Multi-Temporal Satellite Remote Sensing Data. Indian Journal of Engineering, 17(48), 443-449.

[19] Bato, V. A., Paningbatan, E. P., & Bartolome, B. J. (2011). High resolution satellite data for comprehensive land-use planning. Journal of Environmental Science and Management, 14(1), 12–23.

[20] Seker, D. Z., Goksel, C., Kabdasli, S., Musaoglu, N., & Kaya, S. (2003). Investigation of coastal morphological changes due to river basin characteristics by means of remote sensing and GIS techniques. Water Science and Technology, 48(10), 135–142. doi:10.2166/wst.2003.0558.

[21] Abd El-Kawy, O. R., Rød, J. K., Ismail, H. A., & Suliman, A. S. (2011). Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data. Applied Geography, 31(2), 483–494. doi:10.1016/j.apgeog.2010.10.012.

[22] Masria, A., Nadaoka, K., Negm, A., & Iskander, M. (2015). Detection of shoreline and land cover changes around Rosetta Promontory, Egypt, based on remote sensing analysis. Land, 4(1), 216–230. doi:10.3390/land4010216.

[23] USGS. (2023) Science for a Changing World. U. S. Department of Interior, Washington, United States. Available online: https://earthexplorer.usgs.gov/ (accessed on January 2023).

[24] Gurnell, A. M., Morrissey, I. P., Boitsidis, A. J., Bark, T., Clifford, N. J., Petts, G. E., & Thompson, K. (2006). Initial adjustments within a new river channel: Interactions between fluvial processes, colonizing vegetation, and bank profile development. Environmental Management, 38(4), 580–596. doi:10.1007/s00267-005-0190-6.

[25] Allmendinger, N. E., Pizzuto, J. E., Potter, N., Johnson, T. E., & Hession, W. C. (2005). The influence of riparian vegetation on stream width, eastern Pennsylvania, USA. Bulletin of the Geological Society of America, 117(1–2), 229–243. doi:10.1130/B25447.1.