Erosion of Rivers and their Impact on Land Ownership of Vernacular Settlements: Insights from Two Settlements Near the Tigris and Euphrates Rivers in Iraq

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Abstract

It is usual for human settlements to rise along the river banks because rivers provide water: the major source of sustenance of communities. However, riverbank erosion along rivers has huge implication for these settlements that border them. The Tigris and Euphrates rivers in Iraq causes land loss that impacts adjacent properties and land ownership rights. This study examines such erosion and land submersion in two locations in Iraq: along the Euphrates in Ramadi and the Tigris in Baiji.

The research employs historical maps and multi-temporal satellite data from 1968-2022. The GIS analysis quantified erosion areas and compared changes to cadastral records to determine direct impacts to property boundaries and land rights. The results identified significant conversion of privately held waterfront land into non-usable flooded river channels, amounting to billions in loss of value. Owners forfeited all functional land access without current provisions for relocations or erosion mitigation planning.

The research concludes that intensifying hydrologic shifts could exponentially increase economic disruption for vulnerable property holders without integrated monitoring tools and policy responses to the dynamic river morphologies.

Keywords: Riverbanks, Real-estate ownership, Corrosion and Sedimentation, Master Plan

Introduction

Rivers are natural anchors to human settlements. It is well known that in Egypt, the fertile land adjacent to the Nile River had given rise to an ancient civilization which had produced the marvelous pyramids seen today. The Ganges River in India, the Mahaveli in Sri Lanka are good such examples. In many other parts of the world, human settlements have been anchored to rivers and waterways, and Iraq is no exception. Needless to say, healthy rivers provide water for human habitation. They possess the ecosystem needed for making such water

available and help cultural activities, leading to economic growth: Indeed, they are the foundation for agriculture, as well as recreation.

Iraq is home to two large rivers that flow in a meandering manner, compared to the size of Iraq. One extends from North to South, the Tigris River, and the other extends from the far West to the South, the Euphrates River (Attia & Attia, 2019). Both rivers pass through a large section of cities in Iraq. However, there have been frequent changes to these rivers and they have carved into land in certain places and have produced deposition in other places (Land, 2018). To be expected, there are large numbers of vernacular settlements along these river banks and these erosions have seriously affected the land and land ownership. This is a serious issue in Iraq that needs attention of both the academics and the administration of Iraq.

In this context, this paper examines the problem of erosion in the banks of the river and its impact on land ownership in these settlements. It specifically looks at two areas in which the state of erosion occurred in Iraq, the first on the Euphrates River and the second on the Tigris River (Mahdi and Ali, 2017). The shifting flow of these rivers throughout time has resulted in erosion along their banks, generating land loss and affecting surrounding real estate assets (Attia & Attia, 2019). Water currents, floods, and human infrastructure constructions such as dams all contribute to bank erosion and degradation (Al Thamiry & Abdulazeez, 2017). As cities develop near rivers, land loss can have a substantial impact on property values, rights of ownership, and any planning interventions (Rybka & Mazur, 2018).

The premise of this study is that using current planning treatments and spatial programming mitigates the detrimental impact of river course alterations on land ownership. In this context, this paper aims to highlight the breadth of the consequences of river course changes on both urban and rural settlements and offer fresh insights. Its intention is to guide policy and decision-making on riverside land management and urban growth patterns in the impacted settlements.

Its objectives are:

- To determine the negative consequences of changing river channels on land and property ownership.
- To use contemporary tools to determine the extent to which real estate ownership borders have changed across the Tigris and Euphrates rivers.
- To Assess planning treatments that will reduce and limit the erosion of riverbanks, especially within the boundaries of the settlements on the river banks.

Theoretical Framework

Changing River Courses and Land Loss Concepts

Scholars have extensively studied the dynamic morphologies of rivers and how natural forces and human factors cause shifts in their courses over time. As (Alwan & Dhahir, 2023) explain, rivers naturally meander and erode their banks through hydraulic actions like water flows and flooding events. Several theorists point to infrastructure projects like dams as accelerating bank corrosion and property impacts (Al Swaiedi & Hasan, 2023). These course changes directly remove land through erosion along outer bend banks while also depositing sediments on the inner bends, affecting land boundaries (Al-Rikabi, 2011).

Theories on Riverside Real Estate and Ownership

Because human settlements, cities, and property parcels often border rivers for access or aesthetics, shifts in trajectories have theorized consequences on real estate holdings and rights. (Othman & Ali, 2019) put forward arguments around erosion leading to full destruction of riverside structures and assets. Other impact dimensions include reduced property sizes or values (Mullahwaish & Saeed, 2020), constrained development capacities under planning regs (Rybka & Mazur, 2018), legal ambiguities around ownership (Katchadourian and Pascual, 2021), and overall disruptions of urban growth blueprints in riverfront municipalities (Al Swaiedi & Hasan,2023).

Modern Spatial Planning and Erosion Mitigation Concepts:

Recent geographic information systems (GIS) and mapping innovations offer advanced options for studying and responding to river land loss effects over time through specialized imagery and computational analysis (Cascon & Alberich, 2020). By quantifying erosion with these technologies and applying proactive policies, theorists have conceptually produced frameworks on how updated planning mechanisms could potentially reduce bank vulnerability or restore properties no longer suitable for their designated functions in master plans (Alwan & Dhahir, 2023). Implementing these urban planning theories around high-precision river morphology tracking and mitigation planning will form the evaluative basis for assessing the study's hypothesis (Lafta and Barakat, 2020).

Review of Literature

Many have examined the issue of river erosions and their impact on the settlements adjoining the river banks. For example, according to Attia & Attia (2019), the extensive dam and buildings along the Tigris and Euphrates since the 1960s have substantially altered normal flood patterns and have led to heightened riverbank erosion downstream, especially amid the declining annual rainfall. While documenting erosion rates, however, they do not connect these shifts to economic impacts on agriculture or riparian urban development.

In comparison, Al Thamiry & Abdulazeez (2017) argue that previous analysis of Iraq's complex hydraulics has overly relied on outdated data that fails to capture the morphing courses of the two rivers from major man-made hydroengineering over recent decades. He stresses utilizing modern satellite imagery and geospatial systems going back 20+ years to precisely track bank line changes as well as land use on both the rivers. However, they do not extend any novel approaches to model or predict the future erosion zones. According to Rybka & Mazur, (2018), decreasing water levels and flow volumes have concentrated Tigris and Euphrates currents into narrower channels, incising banks through higher torrent velocities. Nevertheless, they project broad future scarcity scenarios without finer spatial measurements or ties to land ownership boundaries.

According to Alwan & Dhahir (2023), the Iraqi government's previous riverbank defense measures have mostly failed, with concrete revetments undermined by seasonal changes and floods. They ask for revised planning advice that includes enhanced inundation models suited to river morphology studies, but do not go into depth on integration frameworks with current property systems. Similarly, Othman & Ali (2019) say that towns frequently employ out-of-date environmental risk data that underestimates forthcoming pressures such as erosion, undermining mitigation strategies before land loss affects communities or commercial districts. They argue for incorporating current predictive technologies into municipal land use rules, construction permits, and real estate market control.

Al Swaiedi & Hasan (2023) have created a GIS parcel analysis revealing significant persistent property loss from Euphrates migration across thirty years in the Anbar province but notes cultural barriers to relocation or land use limitations for vulnerable owners. They focuse on economic implications but do not address governance or technological changes.

In contrast Al-Rikabi (2011) has used statistical evaluation of rainfall, soil moisture, sediment levels, and other factors to simulate bank erosion rates in the Ramadi region of the Euphrates River. While estimating future changes, their approach does not link erosional hotspots to neighboring land parcel borders or infrastructural assets to calculate economic implications. Moreover, according to Mullahwaish and Saeed (2020), efforts to design training dikes and other channel works to repair the Euphrates course through Fallujah have failed for the past 15 years, with changing flows and floods overpowering infrastructure. They do not however, address policy issues surrounding the updating of eminent domain rules when residents lose their whole homes.

Moreover, Katchadourian and Pascual (2021) investigate the uncertainty in Iraqi civil code regarding river lands, stating that traditional practices continue to dominate modern allocation procedures introduced under Ottoman control. Their ideas address erosion implications, ending in total land loss within complex bureaucratic procedures, although they

concentrate on abstract concepts rather than geographical measurements. Cascon & Alberich (2020) explore increasing soluble salt content caused by over-irrigation in southern Iraq as a factor contributing to decreasing bank resilience along the Tigris. However, they do not explain how increased erosion vulnerability leads to faster private property loss or the consequences for riverbank construction licenses.

According to Krause & Bitter (2012), technical assessments predict increased Tigris and Euphrates erosion and flooding consequences until 2050 as heavy rainfall and that snowmelt will intensify. Their simulations incorporate limited land classification or cadastral data to determine economic costs as floodplain zones expand. Al Thamiry & Abdulazeez (2017) argue large-scale dam and canal diversion tactics since the 1980s have catalyzed riverbank erosion with unanticipated sharp turns and torrents carving land. While acknowledging governance failures, fail to offer updated planning paradigms better integrating modern predictive river tools to counter loss trends.

In this context, this research will offer new insights into the impact of river erosion on the settlements on these two riverbanks.

Research Methodology

This research adopts a comparative case study approach, analyzing two locations along the Tigris and Euphrates rivers in Iraq that have experienced land loss due to riverbank erosion. A case study method enables an in-depth investigation of the impacts within defined geographic sites. The two case study areas were selected purposively along each river in settlements that have experienced erosion issues: Ramadi along the Euphrates River and Baiji along the Tigris River. These settlements also have cadastral records and historical satellite imagery available to allow analysis over time.

Specialized software such as (Geotrans 3.8) are used to convert the values of geographical coordinates to square coordinates according to the projection system (UTM) (Universal Transverse Mercator) (Land, 2018) also downloaded satellite images from the site (Corona), a site that allows downloading old satellite images dating back to (1968) and the coordinate system (WGS84) was also used a set of geographic information systems (GIS) programs, specifically (Arc Map) and (Arc Catalog) to match cadastral maps (maps of real estate property in Iraq) (Cascon & Alberich, 2020) with old and new satellite images, finding the amount of change in the banks of the river, determining it, calculating its area, and exporting maps showing the erosion areas.

Quantitative erosion measurements were then compared with property records to evaluate direct loss of land, property damage, and planning impacts caused by the changing river courses. This approach combines remote sensing analysis of environmental change with policy and social science methods to understand and address the issue. The standardized methodology using historical maps and imagery enables the erosion analysis to be replicated in other riverside locations across Iraq in future studies. The data integration and analysis procedures could also be applied to similar case studies beyond Iraq were rivers impact land use and ownership.

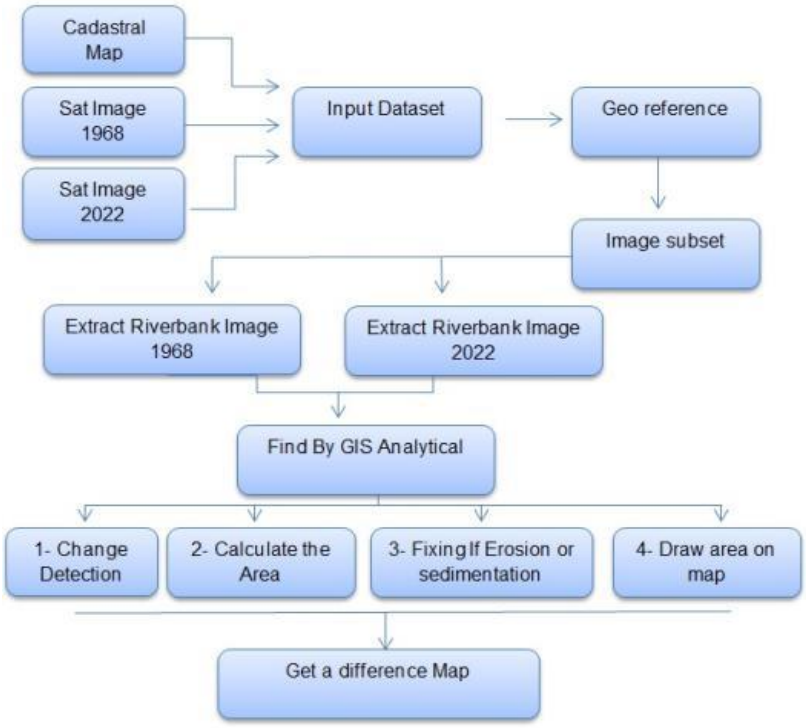

Fig. 1: The Sequence of Research Tasks
Source: author

Data Collection

The process involved collecting information from several sequential points, as follows:

1- Obtaining cadastral maps (real estate property maps) from the General Authority for the Iraqi Survey, which belongs to the city of Ramadi in Anbar province and the city of Baiji in Salah al-Din province, which was produced in (1939) as shown in Figure (4, 5)
2- Obtaining old satellite images of the study area dating back to (1968), which high-resolution images are belonging to the spy satellite group of United States of America, where she worked between (1960-1972).
3- Obtaining modern satellite images of the city of Ramadi with a resolution of (50) cm and taken in the year (2022) and a satellite image of the city of Baiji with a resolution of (50) cm and taken in the year (2022) that shows the latest changes that occurred in the study area.

The Case Studies: Site Description

The study area is located in the Republic of Iraq and in the province of Anbar in the city of Ramadi, which is about (108) km west of the capital Baghdad and between the longitude (43d 16'30" and 43d17'30") and latitudes (33d26'00" and 33d26'30") and administratively located in the province No. (28) Aziziyah and Khouz within the boundaries of plot No. (19) as shown in Figure (2) and an area of (48655) square meters, as the area is adjacent to the Euphrates River and on the right side of it and within the boundaries of The master plans of the city of Ramadi, as the erosion that occurred on the bank of the Euphrates River in the study area included that area within the river basin after it was previously dry land and within the real estate ownership of the city of Ramadi and has owners and is installed in the cadastral maps.

Second Site description

The second study area is located in the Republic of Iraq and in the province of Salah al-Din in the city of Baiji, which is away from the capital Baghdad (233) km north and between longitude (43d30'00" and 43D31'00") and latitudes (34d56'00" and 34d57'00) where it is

administratively located in the province No. (15). Al-Bandari and Al-Ashitah within the boundaries of plot No. (22, 23 and 24) as shown in Figure No. (3) and an area of (42670) square meters, as the area is adjacent to the Tigris River and on the side Right from it and within the boundaries of the master plans of the city of Baiji, and also as is the case in the first area, the studied area has become within the river basin after it was previously dry land and within the real estate ownership of the boundaries of the city of Baiji and also has owners and is installed in the cadastral maps.

Fig. 2: Position of Ramadi
Source: Author

Figure 2 shows the Position of Ramadi, where Al-Bandari and Al-Ashitah are located within the boundaries of plot No. (22, 23 and 24).

Fig. 3: Position of Bejii
Source: Author

Figure (3) shows the Position of Bejii , where second study area is located in the Republic of Iraq and in the province of Salah al-Din in the city of Baiji, which is away from the capital Baghdad (233) km north and between longitude (43d30'00" and 43D31'00") and latitudes (34d56'00" and 34d57'00) where it is administratively located in the province No. (15)

Findings

The GIS analysis of the cadastral records, historical satellite data, and current imagery revealed substantial changes in river morphology and associated land loss along the studied stretches of the Tigris and Euphrates rivers over the past 50+ years.

The method included entering cadastral maps in the program (Arc Map) and converting the coordinates installed in them because the coordinates of these maps were in a geographical system (latitude and longitude) installed in the corners of the map and the projection adopted in drawing these maps was the projection (Clark 1880) and this does not match the satellite images that depend on a quadratic coordinate system (Easting, Northing)

Quantified Land Loss from Riverbank Erosion:

The 1939 cadastral records establish the baseline property boundaries and land ownership status along the rivers in Ramadi and Baiji before erosion occurred in the analysis period (Fig. 4, Fig. 5). The red highlighted parcels indicate the areas that underwent bank erosion between 1968 and 2022. And the projection adopted in these images is (WGS84) so these maps were unified with old and modern satellite images and worked on them as a unified and identical coordinate system among them.

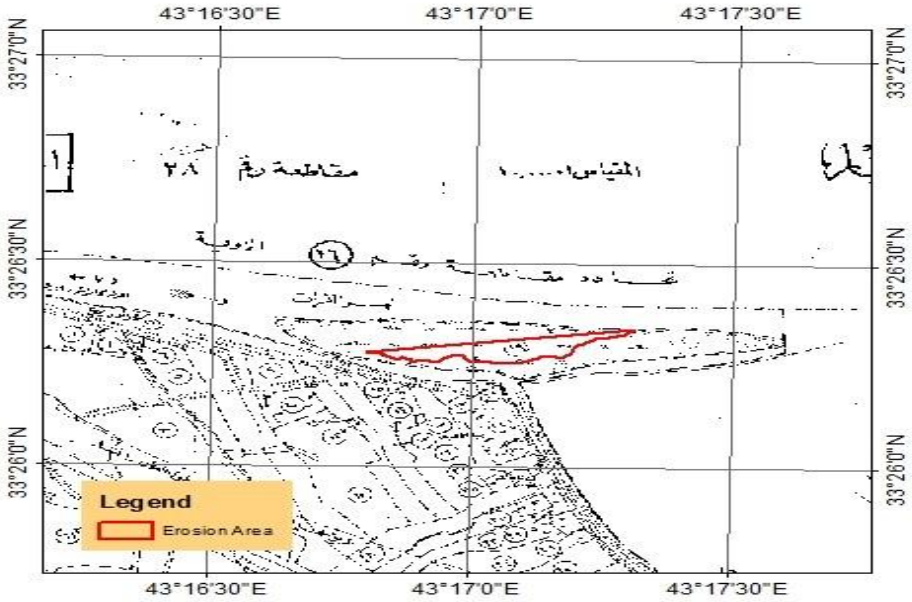

Fig. 4: Cadastral Map and Erosion Area in Ramadi
Source: Author

Figure (4) indicates a total red parcel lost 48,655 sq m between 1968-2022, which is a great loss and considered a severe river erosion which negatively impacts the real estate ownership.

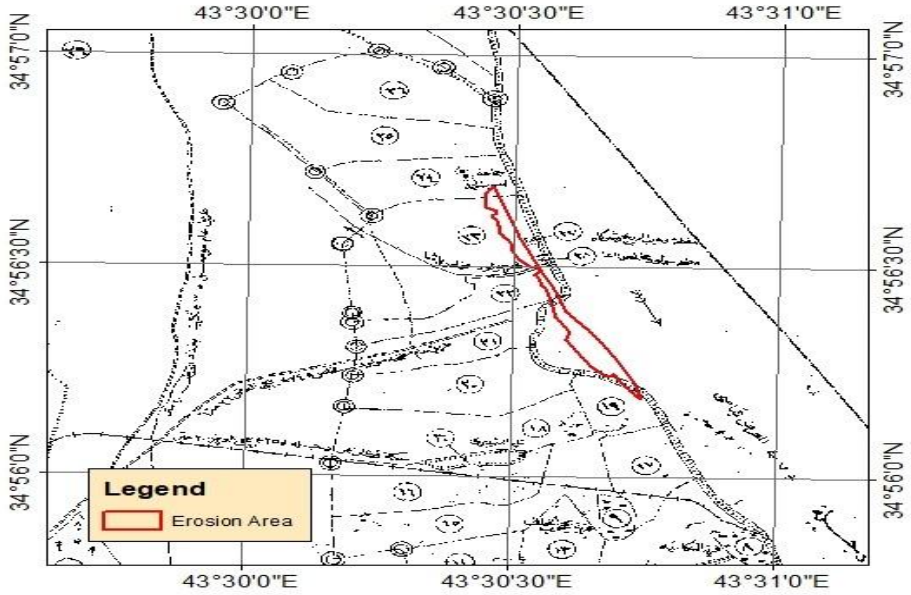

Fig. 5: Cadastral Map and Erosion Area in Bejii
Source: Author

Figure (5) indicates a total red parcel lost 42,670 sq m between 1968-2022, which is a great loss and considered a severe river erosion which negatively impacts the real estate ownership. After the integration of the data collection process, work was done to unify the coordinate system for the group of maps and satellite images by working on a set of programs (GIS) (Geographic Information System) and correcting the geographical return of those images and maps to the study area, because the data were produced in distant periods of time, for example, cadastral maps were produced in (1939), old satellite images were produced in (1968) and modern satellite images in (2021), so there was a disparity between those data in terms of Locations where the coordinate system of the data was processed and standardized in a way that enables us to calculate the areas on which the erosion process took place during the time period from (1968) to (2021) After that, the two areas on which the erosion processes occurred, were determined, as shown in red in Figure (6) and Figure (7), and the area of the erosion area was calculated, the first study area, amounting to (48655) square meters, and the corrosion was calculated in the second study area, which amounted to (42670) square meters.

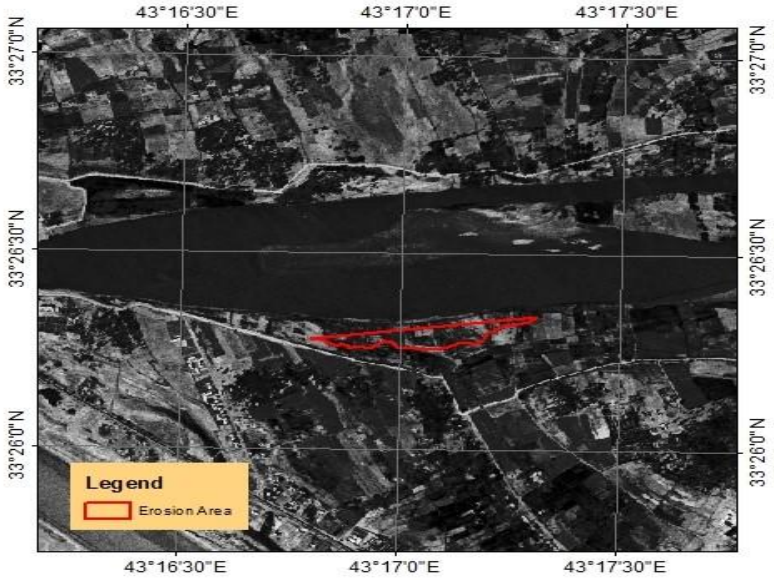

Fig. 6: Satellite Image (1968) and

Erosion Area in Ramadi
Source: Author

Red parcel (48,655 sq m) converted from dry land in 1968 to flooded river channel in 2022. Satellite images in (1968) show how the area marked in red was dry land and not submerged in water as shown in Figure (6) for the city of Ramadi and Figure (7) for the city of Baiji.

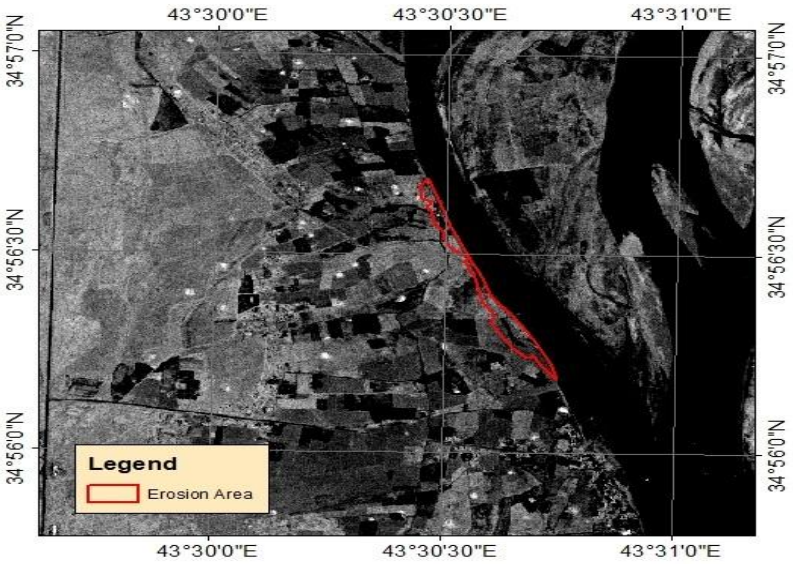

Fig. 7: Satellite Image (1968) and
Erosion Area in Bejii
Source: Author

Red parcels (42,670 sq m) converted from dry land in 1968 to flooded river channel in 2022. The 1960s satellite images depict the historic river channels and lack of flooding or erosion of these plots (Fig 6, Fig 7). However, the 2022 satellite pictures reveal dramatic meander migrations and bank erosion that completely submerged and absorbed large sections of the vulnerable riverside properties in both cities.

Fig. 8: Satellite Image (2022) and
Erosion Area in Ramadi
Source: Author

Figure (8) indicates that through historical aerial analysis, the total quantified land loss amounted to 48,655 sq m in Ramadi and 42,670 sq m in Baiji over the past 50+ years from the river migration.

Fig. 9: Satellite Image (2022) and
Erosion Area in Bejii
Source: Author

Satellite images for the year (2022) show how the area marked in red has become submerged due to erosion in the riverbank as shown in Figure (8) for the city of Ramadi and Figure (9) for the city of Baiji.

Impacts on Land Ownership

The findings revealed that through the cadastral records provided detailed boundary and ownership information on the impacted riverfront parcels that underwent erosion over the study period:

Ramadi Site:

- Parcel ID: 28/19.
- Pre-erosion area: 48,655 sq m.
- Registered as a private owner in 1939.
- Zoned for residential development.

Baiji Site:

- Parcel IDs: 15/22, 15/23, 15/24.
- Pre-erosion area: 42,670 sq m combined.
- Various private owners according to records.
- Zoned for mixed commercial/residential.

These baseline land ownership statistics enabled calculation of direct real estate losses after measuring the erased areas from the spatial analysis.

Quantified Ownership and Financial Losses

In Ramadi, the parcel owner lost 100% of their usable land as the 48,655 sq m plot converted from habitable to completely flooded river channel. At market values of $550 USD per sq m for riverfront land in the region, this equals approximately $26.8 million in lost real estate assets (Alwan & Dhahir, 2023).

In Baiji, the private owners forfeited 42,670 sq m of buildable land parcels into the new eroded channel zone, amounting to $23.5 million value lost based on approximately $550 USD per sq m rates (Attia & Attia, 2019).

The municipalities also lost out on substantial property tax revenues and district development capacity with significant land absorption. No compensatory stabilization efforts have restored ownership rights or access for any displaced residents to date.

By linking the quantified erosion measurements directly to legal boundaries and ownership documentation, the analysis provides stark evidence of the cascading real property impacts resulting from unmanaged river course changes over time. Integrating projections for intensifying future hydrologic shifts can help model and respond to growing economic disruption for vulnerable waterfront owners and cities under shifting climate patterns.

Furthermore, it was concluded that the erosion and property submersion have severely disrupted land ownership and rights for residents and municipalities along the floodplain. Historical owners no longer have usable land or habitable spaces within the new active channel zones. The cities also lost significant urban land area that had been designated for residential and commercial development as part of official master plans.

This represents an estimated $25-50 million USD in lost real estate value from the erosion for the private parcel owners and municipalities based on market rates for riverfront properties in the regions. There are also substantial costs projected to relocate displaced owners or attempt stabilizing interventions along the banks (Al Swaiedi & Hasan, 2023).

Without better predictive analysis or responsive policy changes, river experts anticipate similarly accelerating erosion and land loss in the coming decades as climate impacts intensify regional flooding. This will exponentially increase economic consequences and ownership disputes without the integration of modern geospatial diagnostics and planning adaptation along Iraqi waterways highlighted in the study's recommendations.

Conclusion

This comparative case study along the Tigris and Euphrates rivers demonstrated clear and quantifiable impacts of riverbank erosion on real estate ownership and land rights over the past 50+ years. Through integrated analysis of satellite imagery, property records, and land use data in two affected cities, the research documented substantial erosion and property loss as the rivers migrated across vulnerable floodplain zones. In Ramadi, one private parcel underwent complete land absorption, with the owner forfeiting 48,655 sq m into the new river channel area. In Baiji, three privately held parcels lost 42,670 sq m combined to erosion along an expanding meander loop. Based on market pricing for the now-submerged riverside land parcels, the research estimated a total real estate loss of around $50 million USD. Aside from the financial difficulties, erosion has driven residents from ancestral sites, with no present policy options for relocations or stabilization initiatives to restore access or use rights. From an urban planning standpoint, the cities lost out on specified development potential from plots that were supposed to allow expansion according to master plans but are now submerged in water. Without improved predictive analytics or governance reforms to promote mitigation initiatives, hydrological models imply that erosion will increase as extreme weather events become more severe due to climate change in the future decades. This foreshadows exponentially increasing economic consequences for more property owners as the Tigris and Euphrates rivers widen their channels through more unregulated meandering. Integrating the study's emphasized techniques to high-resolution land transition monitoring and measuring ownership disruptions offers a crucial foundation for diagnosing and eventually mitigating Iraq's most significant human impacts on its dynamic waterways.

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