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Morphological Evolution of Euphrates River Cross-Sections in Central Iraq: Response to Streamflow and Sediment Load Variability

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ABSTRACT

In recent years, the Euphrates River in Iraq has experienced a noticeable change in its morphological system. The presence of sediment has created some problems in spite of rehabilitation and maintenance process have been put into practice. Therefore, the aim of this research is identifying the morphological evolution in a part of Euphrates River as response to streamflow and sediment load variability due to climate change. To this end, a field survey was conducted along a part of Euphrates River in center of Iraq start from station 605+554 km northern Al Hindiyah Barrage and extend about 25 km downstream until station 630+00 km. Approximately 40 cross-sections were surveyed along river reach with distance between one cross section and another from 0.4 to 2 km. The meandering changes and river migration were estimated with support of Satellite images, besides provided maps and aerial photographs to investigate which river segments that remained steady or changed between 2019 and 2022. The field surveying was included of explore morphologic manifestations of channel such as; meanders, bends, bars and islands and measured the change in geometry shape of selected cross sections. For analysis, a comparison was done with historical field data approved in 2019. The results have indicated that the channel has multiple morphology course of river consists of straight, curved and braided parts and the curvature occur according to the stage of the flow. The average width of displacement is changed between 130 m and 930 m and the variation in centerline distance due to variations in the radius of curvature caused by the internal arc's reduction 880 m and 2035 m. The river is varied in the ratio of sinuosity SI between 1.005 and 1.149 "straight" and "winding" sections; and there is one meander formation the maximum percentage of sinuosity 1.62. The geometry of cross sections, sediment and water conditions are mightily connected and varied relatively over the time scale. The variation in shape has associated with constructing floodplains, riparian vegetation, and boundary conditions. Besides, the quantity of sediment that input river reach. Several factors have helped to widen floodplains over along time of centuries like; flood deposition, river flow, presence of plants, branching, bends and meanders, and the presence of river islands. The results of survey can have important effects on the development, operation, and maintenance of river basin for sustainable use in an environmentally and economically sound manner.

1. INTRODUCTION

Euphrates River is one of the main rivers in Iraq and major water resource to the life of country. Its origin from springs in mountains of Turkey and keep flowing through Syria, Iraq, and join Tigris River at Shatt al Arab and then pour into the Arab Gulf [1]. From last century, the river has experienced radical reductions in water flow due to Turkish hydro-engineering structures and regional droughts [2, 3]. Turkey and the Syrian have construction many dams at Euphrates River stream, these dams are caused a sharp decrease in downstream flow, and the quantity of water entering Iraq fell by 25% causing acute tension between the countries [4, 5]. The level of water is fluctuation in this river at lowest level from September to December, and high level in spring season through months March, April, and May, also may cause a flood in this time [6]. Otherwise, one season's flood may be ten or more times as great as that in another year [7]. This fluctuation in water flow due to fluctuation in flood and drought has induced erosion and deposition of sediment, beside evolution of bars and islands to extent that classified as an unstable river [7]. The presence of sediment created some problems in Euphrates River system, in spite of a great improvement in river basin restoration [8-10]. Some of these problems are the change the regime and stability of river, variable in inflow and lateral feeding of sediment, sequences of fixed and mobile beds. Besides reduce river flooding and decrease the sufficient amount of water that arrive tributaries

[11]. Problems of sediment are not equally likely at all points along river channels, its varied with several factors such as; sediment sources, mode of sediment deposition, the way of sediment transport, sediment characteristics, and stream flow variability [12]. Furthermore, the progress rate in field of sediment management is limited and the impaction is very clear [13]. The Hydraulic maintenance or any type of management have not efficient enough, as result of large amount of sediment deposit in the bed and river banks [9, 14]. Also in some years, when heavy rain raised the water level could lead to some damage in the floodplains areas and hydraulic structures [15-17]. Thus, it is very essential to control sediment accumulation in such projects. In view of this crisis and from reviewing previous studies, there is a lack in information considered the alteration in morphology of Euphrates River and the severity of sedimentation processes, with regard that the region has experienced of dry periods which affected the hydraulic and morphological characteristics of river regime from the shape, direction, and depths of flow. The risk of increasing sedimentation causes significant variation in channel landforms and led to build up a major central and side points bars. However, the aim of this study is identified alteration the morphological characteristics in a part of Euphrates River as response to the Streamflow and Sediment Load variability especially the region has experienced dry periods because of climate change. Achievement of river morphological assessment is required of conduct a survey to explore morphologic manifestations of channel such as; meanders, bends, bars and islands and measured the change in geometry of cross section pattern.

Therefore, this work will answer these questions: 1) What is the effect of moving flow on developing sedimentation areas? and 2) How can evaluate the persistence of cross section forms in a morphologic timescale with the hydrologic conditions? So, this work will be useful for water resources planners as significant baseline for consideration future sediments management strategies to reduce the change in hydraulic and morphologic river regime which caused high threat to the natural river cycle.

2. SITE DESCRIPTION

The stream has selected for examination is a part of Euphrates River located in center of Iraq. The field survey was started from a distance 554 m north Al Hindiyah Barrage from station 605+554 km within geographic coordinates of latitude “32°42'3" N” and longitude “44°15'53" E”, and extended 25 km downstream until station 630+00 km at Aifar Village located within geographic coordinates of latitude “32°30'53" N” and longitude “44°14'44" E”. The river is running through alluvial plains areas as represented in Figure 1. There is some of natural constituents have influenced river reach like; morphological characteristics (e.g. climate change, geological features, land use, and natural plants), as well as the characteristics of water drainage system. This reach is only and most important resource of water where passes within wide areas to supply water to the agricultural lands and civilian uses. The river flows through riparian deposits with elevation ranging between 40 and 50 m asl., also there is a difference in geological pattern of Euphrates River flow between upstream and downstream basin. As with slope of 5-15 cm/km [18, 19]. The mean annual rainfall in the area is 98-110 mm that occurs mainly in winter season between November and March [12, 15]. The rainfall is not reliable with a large fluctuation from year to year [15]. The summer in this region is very hot and dry with day shade temperature frequently reached a maximum 48.0°C in July and August.

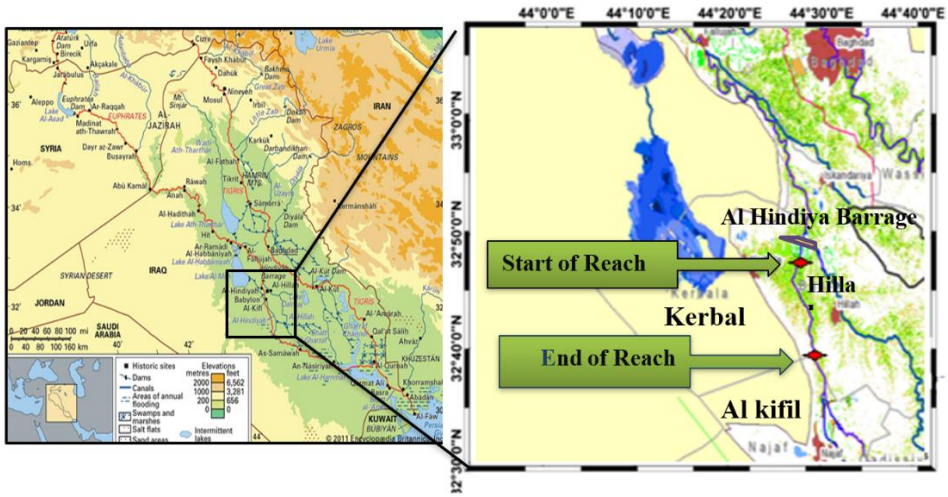


Figure 1. Map of Iraq and the location of studied reach of Euphrates River (Encyclopaedia Britannica, 2023)

Geologically, the river is feeding with sediment from upstream natural sources at flooding period (e.g. hill slope, gullies, and tributaries) which contributed of increase sediment yield and suspension flux [4]. In addition, the erosion of sediment from river bed and bank erosion are associated with rainfall season and the flood in each year [7]. The surface runoff from agricultural lands and urban areas, banks slip, and the amount of dust come with high winds other natural sources of sediment pour into river [4].

The excessive amounts of sediment load a rise in some locations lead to build up a major alternative side and central point bars. In addition, a lot of environmental problems have risen as a result of installation a wide open drainage network and/or field drains spread in both sides of channel designed to reduce salinization problems on thousands hectares of agricultural lands, beside to transport drainage water of excess irrigation to the river stream. Some of riparian regions are utilized for high intensity of agriculture practice, while others have riverbank sloping covered with wild reeds plants which in common an herbaceous and perennial plant. Also, a major effect to the local people which are taken some advantages of riparian regions relative riverbanks for planting farmland.

These consecutive agricultural activities have been imposed on riverbanks over centuries. In another way, the riverbanks are deterioration from direct disturbance, but floods events have a significant impact because sediments transported with river flow affect the Physical and chemical properties of riparian soils. Subsequently, bottom layers of riverbanks sediments closed river were often saturated by water most of time, and some zones along the river were levelled or backfilled using various river sediments from elsewhere.

3. METHODOLOGY

3.1 Data collection

The Approximately 40 cross-sections were surveyed along rive reach. These sites are represented various forms such as straight, curved and branched parts. The distance has ranged between one cross section and another from 0.4 to 2 km. Consider in a study, the lowest value of contour line with closest to the river course as represented in Figure 2. The bank level has fixed at each section by relying on settlement number that available by the Ministry of Water Resources. The meandering changes and river migration were estimated with support of satellite imagery to follow the shifting of river bank lines, besides provided maps and aerial photographs indicating primary changing in channel morphology to investigate which river segments that remained stable or changed between 2019 and 2022. The flow within bends and meanders when river eroded and deposit sand and silt along their banks which resulting course shift.

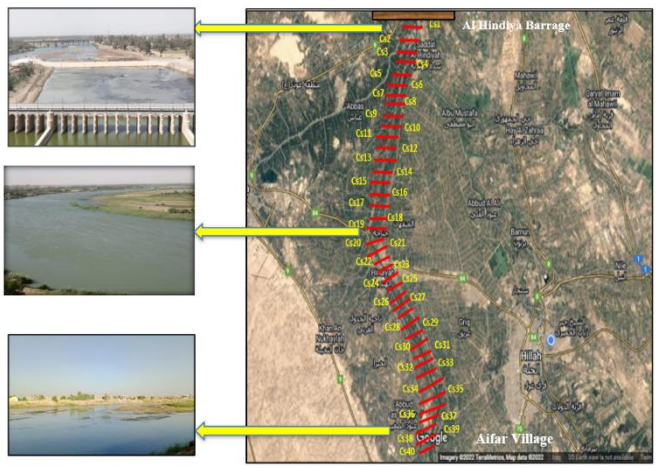


Figure 2. Locations of cross sections along studied reach of Euphrates River and aerial photos to stations 605+554 km, 620+240 km and 625+300 m

During field survey, its noticed phenomena that could not been seen throughout the year except on some days, for example; the appearance of many small islands and bars in form of longitudinal strips with the extension of the course when the level of Euphrates River decreases to the lowest possible extent. The discharge was in short supply because of drought condition in the center and south of Iraq. In addition, it was noticed some aspects such as; construction of some earthen embankment on the natural banks, and how selected their locations, besides of exploring the recent history of the region and how it was before construction New Al Hindiyah Barrage. In all cases the straight sections, bends and meanders have investigated. Other factors of major consideration also governed selected sites were locations relative Al Hindiyah Barrage that might cause alteration in studied river section.

The field surveying was included two main parts; the first part includes morphologic manifestations of channel such as meanders, bends, bars and islands. The second part includes river stream geometry where water level, bed depth and width of river at specific cross sections were measured. The fieldwork was has done by using of both Electronic Theodolite and Total Station instruments for integrating an electronic distance measurement EDM to collect data and performed advance coordinate based on calculations and other devices.

In addition, historical data related conditions of river reach were collected from some Ministries, especially the climate parameters, hydrological and hydraulic data, besides flow condition within past fifty years. For analysis, details of historical morphological data were collected from (Ministry of Water Resources / State Commission of Survey) to the field survey approved in 2019 for comparison.

Therefore, before demonstrate the results of surveying, it is important to explore river natural constituents because it is one of the main factors influencing the geomorphologic and sedimentation characteristics of Euphrates channel.

3.2 The natural constituents of river

There are natural constituent's elements influenced the morphological characteristics such as; flow, land surface, climate change, soil and natural plant, as well as the characteristics of the water drainage system [17]. These elements have caused a clear change in the geomorphologic processes in the study area.

3.2.1 Flow conditions

Due to a large area of the Euphrates basin in Iraq, there have been variety in water feeding sources, and the rainfall is the first source of feeding [20]. As for the percentages of water supplied to the river that 82% comes from Turkey, 9% from Syria, 8.97% comes from the seasonal desert valleys in Iraq, and 0.3% comes from Saudi Arabia [7, 21]. It is noted that Iraq is contributed by very few and fluctuating proportions of their imports due to their exposure to seepage and evaporation because of its arid climate. The feeding is concentrated during the winter and spring seasons ranging between 3.49% and 6.41%. Despite the high percentage of rain feeding, the discharges during this period are unstable and fluctuated according to the fluctuation of rain falling on the whole river basin.

The second source of feeding water is the melted snow, and its nutrition concentrated in the spring. It occupies the second place in the nutrition ratios as ranged between 26.2% and 41.1% of the total expenditures. As for the third source is the groundwater which is related the amounts of rain and melted snow that seep into the ground, and the groundwater recharge of river occurs in the summer due to the interruption of other sources of nutrition [21]. It occupies the last rank in the nutrition ratios, which ranged between 14% and 27.4%. However, one should not lose sight of the annual variation of these ratios in relation to their rates depending on the characteristics of the water year, whether it is dry, medium or humid [22].

From previous published studies and historical documents issued by (Ministry of Water Resources / General Directorate of Water Resources Management), there is a variation in rate

of flow at gaging station of Al Hindiyah Barrage as shown in Figure 3. In 2009, a UNESCO report formed that the level of water in the Euphrates River have retraction by more than two-thirds and premonitory these vital lifelines could dry up completely by 2040.

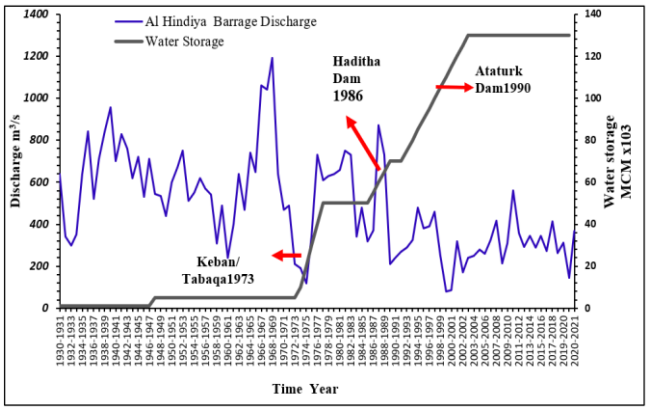


Figure 3. Hydrological changes in the Euphrates River from 1930 to 2022; and accumulated reservoir storage in the basin plotted with mean annual flow at station Al Hindiyah Barrage

The discharges rates are changed monthly and annually and appeared a significant reduction in main rainy season, where the average monthly discharge dropped from 595.10 m^3/s for the period between 1930 and 1989 to about 257.13 m^3/s for the years between 1990 and 2022. While, there are several fluctuations in discharge data in a period between 1930 and 1989. there was a sudden increase in annual average discharge causing a flood with 1272.3 m^3/s and 888.44 m^3/s recorded in 1969 and 1988 respectively, while there is a sharp fell for a level 98.85 m^3/sec in 1974. After 1990 s, the fluctuation in annual discharge data is continued with a significant fell trend in level of records compared to the last periods until the end of measurement years. The decline in outcome discharge rate in period 1990- 2022 year is because construction and operation of the Keban dam in Turkey and the Tabqa dam in Syria led to a shift the Euphrates flow regime. The increased regulation of the naturally flow regime of the Euphrates resulted in less powerful seasonal flow variation with higher dry season flows and lower wet season flows. The impact of dry years is more pronounced, with release rates approximately 1/3 rd of the normal rates. Under the current water management regime, droughts form a major natural hazard that affect water supplies in the basin, as witnessed in recent decades in Iraq [6, 16].

Another case can be considered about storage in the basin during year 1970 to 1990, the flow data of river regime can reflect the limited in water regulation of the runoff-generating area in Turkey. The natural flow regime is represented with a high-flow season for a period between Oct to April and a low-flow season for a period between June to September. This is a regular feature in hydrological of arid regions where no /or few tributary rivers discharge within the area. The discharge is increased during the flood season because the high flow generated upstream highlands and such regime was typical for year of record 1970. While the decline in outcome from Al Hindiyah discharge rate between 1990 and 2022, because construction and operation of the Keban dam in Turkey and the Tabqa dam in Syria led to a shift the Euphrates flow regime. The increased regulation of the naturally flow regime of the Euphrates resulted in less powerful seasonal flow variation with higher dry season flows and lower wet season flows [2, 15, 16].

It was consistent with the climatic data that recorded a decrease in the amount of rain and an increase in temperature for the same period. The amount of rainfall also decreased in the same year, which reached its peak in year 2000, especially in the years 2007 and 2008, this clearly shows the impact of climate change on water scarcity, especially since rain occupied the first place in water nutrition ratios as well as its impact on other sources of feeding. Figure 3 is shown the variation of flow at AL Hindiyah site with data into separated as “natural” or “pre-1971” and as “regulated” or “post-1971” periods. In particular, the year of 1974 marked in which Keban and Tabqa dams have operated for upper Euphrates basin, and these alterations resulted in decreased flow and reduced flood peaks due to regulation. The data indicating that 24% of area weighted basin area precipitation has recognized as flow at the site and recorded mean annual flow of 638 m^3/s at Al Hindiyah Barrage site. In different, the relation between precipitation and flow in the regulated period “post-1971”, indicating a vast reduction in water transportation and utmost shift in the Euphrates River flow system. While, mean annual flow at Al Hindiyah in regulated period were 330 m^3/s, respectively [7].

In this research, it is important to mention old Al Hindiyah Barrage and New Al Hindiyah Barrage are located at upstream river reach. From last century, the sediment accumulation was threating the downstream Al Hindiyah Barrage in spite of efforts to maintain processes to remove excess of sedimentation [3, 4]. This issue has led to reduce the capacity of river basin, river depth and change the cross sections patterns of river. Besides, minimize the amount of the discharge and block water streams by fluvial sediment.

Iraq also constructed a complex network of canals on the Euphrates River, diverting Euphrates water to the dam lakes such as "Al -Habbaniyah" lake and "Al Tharthar" lake which store overflow flood water, but recently these lakes suffer from shortage of water. These structures have also suffered from a large accumulation of sediment which caused a serious flood in upstream tributaries were featured to concern that reservoirs have become a reason for trapping sediments. The sediment augmentation was threated Euphrates River downstream Al Hindiyah Barrage in spite of efforts to maintain processes to remove excess of sedimentation [5]. This issue has led to reduce the capacity of river, river depth and change the cross sections patterns of river. Besides, minimize the amount of the discharge and block water streams by fluvial sediment.

3.2.2 Land surface

Another element is the land surface which affected on the velocity of water and the discharge. The Euphrates River is capable of transporting a certain quantity of sediment depending on some factors like surface slope, the current power, cross section formation, and size of sediment [18]. Since the study river channel is flowing across a Mesopotamia plain, it was characterized by general mild slope from north to south, where the degree of trend 5-12 cm/km [11]. In turn, this is led to the activation of the geomorphological processes carried out by the river like erosion and sedimentation process. Moreover, the different in geological pattern of river between upstream and downstream [10, 15] caused soil erosion mainly took place on the plateaus and valley slopes contribution of increase sediment yield and suspended flux, and supply excess of sediment accumulated in downstream. Besides, to the lateral movement, it has characterized by the creeping of the river intersections constantly towards the outlet due to the

erosion of the concave sides and deposition in the convex sides.

The natural banks of rivers are usually higher than the neighboring and far areas by 1.5 to 2.5 m with lateral steep slope in most areas. While areas adjacent to the banks are river basins, besides some areas are located a far from the river and which covered by swamp water, besides some landforms are constructed due to man-made, which is represented by the dredging operation resulting from irrigation and clearing irrigation channels [11, 16].

3.2.3 Climate

Regarding morphologic, processes are associated with the climatic features and the change is depending on nature of the Earth's surface landforms. The extent is being to which these processes respond to each of the different climate elements. In addition, the impact of these elements combined with each other.

The temperature has a direct effect on atmospheric pressure, and then on wind movement, rainfall and the amount of evaporation, whose rates rise with the rise of temperature [21]. The temperature range above 45℃ in June, July and August to lower than 8℃ in December and January. The study river reach is classed within (arid – desert) hot region according to Koppen's climate classification and sub arid – moist according to climate classification [21, 22]. In area around river reach, the temperature and the evaporation rates are higher with hot summer months. The mean annual evaporation values are between 300 to 450 mm per month and average annual value about 2416 mm per year. This has a significant impact on increase water losses by evaporation. The average monthly evaporation rates are ranged with about 375 mm in July, unlike winter months which record with about 52 mm [10].

Another effective element is the rainfall, it is not reliable into the region and data have shown large fluctuations from year to year. The characteristics of topographical area and climate behavior play important roles in this variation [15]. According to the monthly data collected from (Iraqi Meteorological Organization, 2022) for period between 1970 to 2022 indicated the rainfall is sparse in Iraqi lowlands of Mesopotamian Plain, short duration high-intensity rainstorms account for the dominant contribution to low annual total rainfall [15]. The extreme yearly variability in the wet and dry periods between 43 and 167 mm /year on the rain gauge measure and the mount can drop to minimum value as 43 mm in dry water years.

In general, it is noted that the trend is toward a decline in the amount of rain, especially during the decade of the 2000s due to growing repercussions of global warming and climate change are increasing day after day. Consequently, limited rainfall may expect deterioration of Euphrates water discharge with the flow direction in terms of salinity and sediment accumulation because of high evaporation process, leading to decline renewal water rates with rainwater and runoff [10, 22]. While high intensity rainfall has a great influence on groundwater replenishment and on leaching of soluble salts from soil profiles the shallow groundwater and then to the river waterway. In view of impact the climate with its multiple elements like the temperature, rainfall, and evaporation as the most important factors directly affecting the Euphrates water feeding and as basic components effect on water resources and type of sedimentation.

Consequently, limited rainfall may expect deterioration of Euphrates water discharge with the flow direction in terms of salinity and sediment accumulation because of high evaporation process, leading to decline renewal water rates with rainwater and runoff. While high intensity rainfall has a great influence on groundwater replenishment and on leaching of soluble salts from soil profiles the shallow groundwater and then to the river waterway.

3.2.4 Soil feature and natural plant

On the subject of watershed, soil around the channel has characterized as a movable soil formed because of accumulation various sediments texture brought by the river water. These sediments are resulted from sequence aggradations of the Tigris and Euphrates rivers dating back to the modern era, which consists of clay, silt, sand and gravel they do not contain any rock formations [16, 19]. As for the tectonic status of the region, it is located within the unstable pavement units within the sedimentary plain. Moreover, some of sediments brought by the wind from areas outside the region and this made area soils characterized by the stratification.

The most important types of soils in the region are basin soil of poor river discharge, and marsh and swamps soils that covered with slits. Some of areas covered by natural plants engage a great role in preserving banks through its ability to stabilize the river cliff by its roots and increase strengthen of cohesion of the soil of banks and the bottom [12, 14]. As well as its role in blocking the speed of water flow which in turn reduce the effectiveness of water and wind erosion as well. One of the most important plants that are spread in the area riverside plants, aquatic plants, desert plants and marshlands plants.

4. RESULTS AND DISCUSSION

The findings of field surveying are introduced in details as following including the change in river morphology system and sedimentation phenomena particular the change in bends characteristics, as well as the impact of bars and islands formation.

4.1 Morphologic manifestations of channel

The natural activities of river migration have played a significant role in creating a set of geomorphologic features that classified according to different processes causing their formation. However, these features have identified, studied and distributed based on study these features and used space visualization in their identification and topographic maps.

4.1.1 Changes in meanders and bends

The studied Euphrates reach is situated in a low sedimentary land and the variation in flow velocity controlling sedimentation process, it could lead to an irregularity in cross sections of the river channel. It is a great significance to note that most of sediments transported since earlier time to river course with current flow has been trapped in the upstream impoundments (e.g. Al Hindiyah Barrage). Therefore, the river is attempting to achieve a new regime for more stability. The decline in regional rainfall and decrease in annual discharges diverted from Turkey is leading to lower water levels downstream, and the flow is eroding only below basis levels of protection banks than given to the upper level.

The river reach consists of nine bends and one meander. The sediment is dominant by lateral induction more than the vertical direction. The details in Table 1 are described these

bends according to the morphometric characteristics of field investigation and Satellite Images. The presence of bends causing potential changes in the velocity of flow, and this led to increase sediment in one side and erosion in the other on.

The results of investigation are presented that the channel has multiple morphology, for example the course of river consists of straight section between 608+00 km and 609+520 km, and from 616+600 km to 619+530 km. While, its curved in section from 608+840 to 612+340 km and between 613+700 km to 615+440 km, besides constructed braided part at sites 616+650 km. The curvatures occur according to the stage of the flow and spread widely when the river is in the old age. The bends formed when the flow decreases to the point where the activity of the river turns from the lower side to the lateral side and the least obstacles may affect the running flow.

Table 1. The Morph-Metric characteristics of bends and meanders along Euphrates River reach from station 605+500 km to station 630+00 km

ID	Starting of Curvature at, km	Ending of Curvature at, km	Length of Curvature, m	Ideal Straight Line Dist., m	Sinuo-Sity, SI%	Ave. Stream width, m	Width of Curve Displacement, m	Direction of Curvature
1	605+635	607+772	2137	2035	1.051	281	204	Westerly-Bend
2	608+050	609+170	1120	1050	1.066	210	90	Westerly-Bend
3	609+790	611+02	2230	2220	1.005	280	290	Easterly-Bend
4	611+830	612+870	2040	1860	1.097	260	250	Westerly-Bend
5	612+780	614+340	1560	1410	1.106	250	390	North-East Bend
6	614+460	615+540	1380	1290	1.070	190	503	North-West Bend
7	615+630	617+720	2090	1830	1.149	240	310	North-East Easterly Bend
8	620+640	624+090	3450	2130	1.620	202	930	North-East Meander
9	624+040	624+995	955	880	1.085	230	165	North-West Bend
10	624+965	626+165	1200	1135	1.057	250	130	East-South Bend

Sources: Maps from General Survey Authority Iraq, Satellite Images Land Sat. 2018, the projection system WGS 84-UTM-Zone 38 N and Field study.

In another case, the bends are formed when the river scouring continuously the area of its course, while deposition occurs in the opposite side. This is happened due to the spiral movement of water current when the main water is rapidly moving and collides with the concave area [23]. A reactionary water current is down warded and works slowly with a quantity of sediments that have been deposited in the convex side [24]. Also the barrier islands are play a large role especially in the straight parts as at sites of the course for generation water stream running towards outer side of meander resulting in the scouring in it as at site 612+730 km [25].

In some cross section a formation of multiple bends as process of maintaining the state of river balance like a distance between 609+00 km to 618+140 km. This is also reflecting the ability of water to carry materials depend on the current power of river and the degree of surface slope. Besides to the lateral movement of the river, it is characterized by the creeping of the river intersections constantly towards the outlet of river due to the erosion of the concave sides and deposition in the convex sides.

The results in Table 1 introduced that the river is varied in the ratio of sinuosity SI. If SI <1.05 is classified almost “straight section”; while if ranged between 1.05 ≤ SI <1.25 is classified by “winding”; whereas 1.25 ≤ SI <1.50 is “Twisty”; and 1.50 ≤ SI is “Meandering”. From surveying, it was notice there is one meander formation was calculated and the sinuosity value of the entire river is equal to 1.62 in sites 620+640 km. While it has ranged for other bends between 1.005 and 1.149. The average width of displacement changed between 130 m and 930 m and the variation in centerline distance due to variations in the radius of curvature caused by the internal arc’s reduction 880 m and 2035 m. While length of curvature m between 955 m and 3450 m.

There is great difference in bends directions change from as 4 bends whose direction toward North-East, 3 bends towards Western while 2 bends of the North -West direction and 1 in the East -South orientation. Therefore, it is possible to refer that most important reasons of formation bend in river section is also comes from firstly; the presence irregularity in the floodplains are led later to form more sinuosity in river section. Secondly; occurrence of slips and fall off more material from the bank inside the stream by erosion currents and scouring is happened in the opposite sides formed more river sinuosity. While, the transition of the river from vertical activity deepening to the horizontal activity expansion leads to get more bends.

4.1.2 River bars

Points bars in Euphrates River are sedimentary phenomena formed in the inner side of bend of river, while central bars in straight reach [25]. The river reach has a lot of bars are observed during field investigation and the details are presented in Table 2. The dimensions of the river bars have varied according to their morphological characteristics. There are bars longer than width, while others have characterized by the opposite of this or in which the length is equal to the width, and the difference in its dimensions varies from time to time according to the activity of deposition and erosion process. The lengths of the bars varied of which the smallest length is 980 m, and the longest bars with a length of 5030 m. River bars are taken different shapes, including irregular and elliptical strip, and Elliptical bar depending on the shape of bars takes with bank close to it (Table 2).

Also, it was noticed that points bars are formed inside bends because of shallow flow and low shear stress which reduce the amount of material that can be carried there [26]. The overflowing falls out of transport and forms the bar, especially in the convex area as a successive arc due to slow water current. It is difficult to the river flow of carry sediments to low level

regions because of spiral movement of water stream which works as collector tool [26].

For specific analysis and accurate explanation of the mechanism that led to the formation of free alternate bars in rivers is described as an imbalance between water weight and bottom drag, which causes reduction near the top of bars and resulting further deposition [27]. The formation of bar is clearly counteracted by the impact of the sideway slope on the sediment transport, which tends to suppress bars [27]. The process of bars formation is occurred as a result of the accumulation of sediments in the banks because of transfer water to the lower portion of river by water currents. Therefore, when sections of water have separated, it will move in small vortexes with transverse motion towards the convex bank, especially in areas of low depth, leading to the formation of riverbanks [25]. The sediment sources may cause a temporary sediment bar until a large-enough flow occurs to mobilize and transport the sediment down-stream.

The river bars are played a large role in formation floodplains as their continued growth which leads to added new lands, which consequently increase the area of the floodplains [24], especially, if their components are cohesive through the natural plant, which will grow over the time [26]. The bars range of channel section consists *of "strip adjacent"* to the bank extending along the length of the bank have formed due to the combination of some reasons, including: Low water level and lack of discharge with the presence of a large load borne by the river water, especially in the summer or drought season and with reduction in longitudinal slope and direction of river stream.

4.1.3 River islands

River islands are formed in studied reach due to several factors including; high river load of sediment during floods, the unexpected reduce in flow rate, decline in velocity due to decline in river bed slope, and widening of stream. The details of island that dominant along studied reach according the field survey are listed in Table 2. Lengths of islands are varied of which smallest island width as 42m and length 111 m, and the big islands with width 110 m and length of 1020 m with depth more than 2 m above surface water. The shapes of river islands and bars can be distinguished according to this Ratio= (width)/length ×100. If the result is less than 15% then the islet is *"strip",* and between 15 and 26% the islet then is *"longitudinal".* While the percentage between 26 and 30% the island or bars is *"arc",* and between 30 and 45% the island is *"irregular "*in shape, but if the result is between 46 and 57% the island is *"round",* and between 60 and 90% sorting as *"semi-regular"* in shape [24, 25]. Different shapes of island have taken in studied reach including *"Oval",* or irregular because of the difference in their dimensions

Table 2. Main observed sides bars and islands along study river reach from station 605+00 km to station 630+00 km

ID	Type of Bar	From, Km	To, Km	Length, m	Max Width, m	r%	Shape of Bar
1	Island	605+000	606+522	522	128	25	Longitudinal
2	Left Bar westerly Bend	605+000	606+590	1590	157	10	Irregular strip
3	Right Bar Westerly Bend	606+300	608+020	2087	178	9	Elliptical strip
4	Left Bar Straight Reach	607+880	609+530	1650	208	13	Elliptical strip
5	Left Bar Easterly Bend	609+500	611+380	2070	193	9	Elliptical strip
6	Right Bar Straight Reach	609+100	609+780	680	160	24	Longitudinal
7	Right Bar Westerly Bend	610 +880	613+550	1990	171	9	Elliptical strip
8	Island Change Reach from Westerly Bend to easterly Bend	612+450	612+980	490	71	14	Elliptical strip
9	Left Bar North –East Bend	613+140	614+450	1310	180	14	Elliptical strip
10	Right Bar North- West Bend	614+200	615+660	1460	240	16	longitudinal strip
11	Island	615+580	616+600	1020	110	11	Elliptical strip
12	Island	616+540	616+880	370	75	20	Longitudinal Oval
13	Left Bar North -East Bend	616+060	617+610	1720	165	10	Elliptical strip separated River into two Branches
14	Left Bar	616+050	621+080	5030	42	1	Thin Rectangular strip
15	Island	617+930	618+730	660	85	13	Oval strip
16	Right BarWesterly Bend	617+860	620+410	1940	132	7	Large Rectangular Bar
17	Island	620+330	620+850	520	87	17	Longitudinal
18	Left Bar Easterly Bend	620+550	623+520	2970	77	3	Elliptical strip
19	Right Bar	623+970	625+102	1132	70	6	Elliptical strip
20	Island	621+450	622+280	830	65	8	Irregular strip
21	Right Bar North -West Bend	624+040	625+020	980	75	8	Elliptical strip
22	Island	625+070	625+450	310	56	18	Longitudinal Oval
23	Left Bar North -East Bend	624+340	625+830	1490	90	6	Elliptical strip
24	Island	626+680	627+790	111	42	38	Irregular
25	Right Bar Straight reach	627+240	630+380	2780	168	6	Rectangular strip
26	Island	628+680	629+350	640	55	9	Strip
27	Left Bar Straight reach	629+470	632+500	2030	120	6	Strip

Islands in studied reach are divided into; "*Permanent islands"* which types of islands surrounded by water from all sides throughout the year, which has been clear morphological features from long time period of time as in sections sites 605+00 km, 609+860 km, 612+620 km, 615+720 km, 616+630 km, and 620+550 km. They covered with natural

plants, some of them are settled and other exploited for agriculture. Second type is *"Merged* islands*"* with the floodplains such as; the island attached with the left bank 607+360 km, 609+860 km, 613+00 km, 616+060 km. These islands have constructed due to persistence of sedimentation, especially in narrow passages. It has often caused by large sediments brought by the river, which deposited in confined area of island and adjacent banks and enclosing island with floodplains. The islands have varied in distance from the nearest bank, some of them are closed only a few meters apart, as the case in the island 616+550 km which is only 3 m apart from the right bank and another far away.

The reasons have led to formation river islands, including the difference of river discharge between one year and another [25].

There is also a direct relationship between components of banks and their susceptibility of islands formation. As a part of expansion by current of flow due to processes of scouring and transportation from banks would provide opportunity to be middle barriers in the river stream. In addition, with the time there is a more increase in river expansion through the decline of the original banks, it will help to increase the growth of the island located in this location of river course [24].

4.2 The impact of sediment processes on channel system

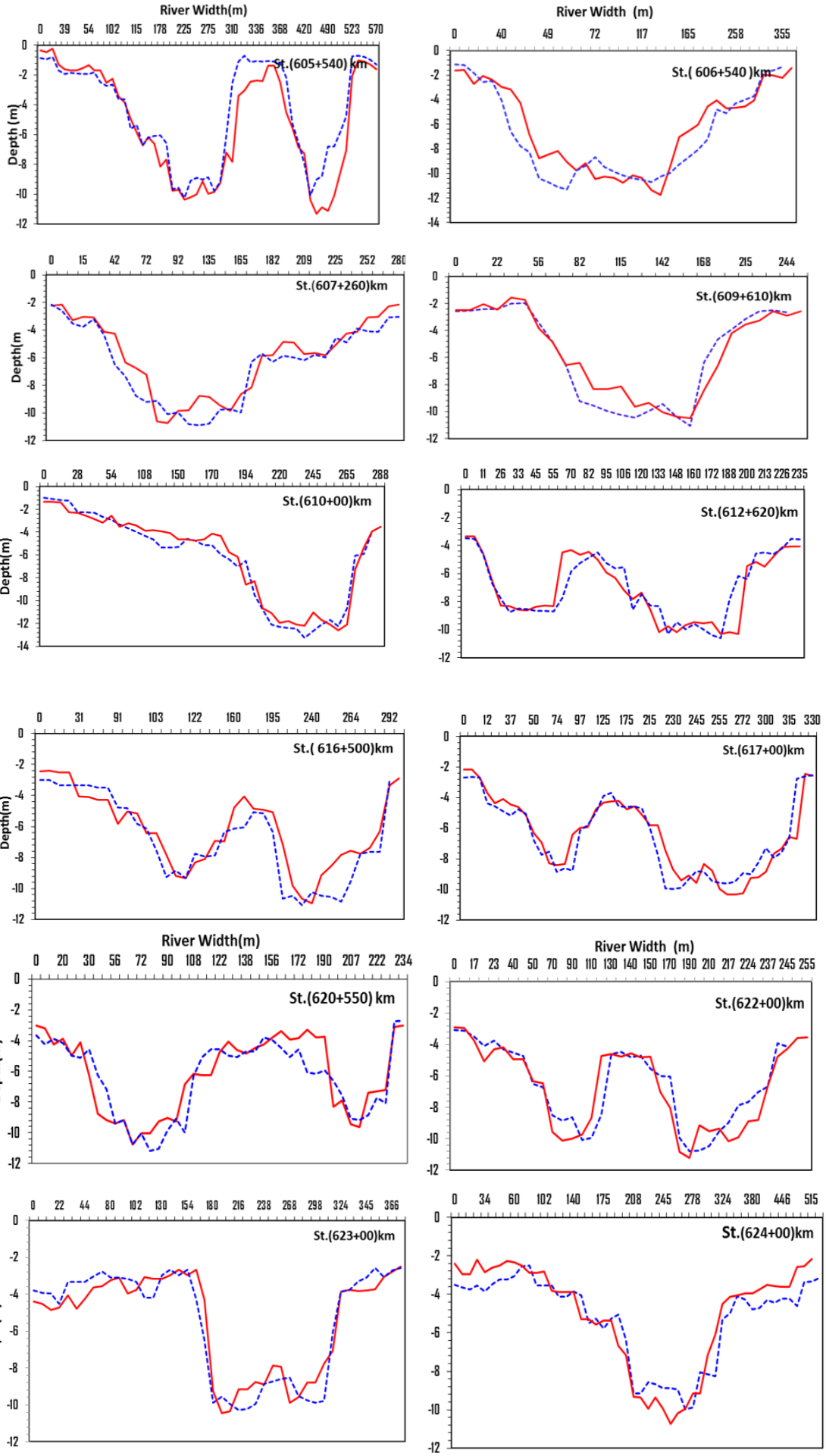
4.2.1 Change of cross section stability

Surveying shapes of cross-sections basically were performed to describe the channel system under which river section alters due to deposition and erosion in banks and beds. Therefore, the field survey was automatically determined by using some devices to measure many variables depth, width, and water level. As all free changed with climate and cross-sections areas are computed by using *"Autocade Civil 3D"* then multiplying by different distance between successive cross sections to produce sequential morphological maps and to better recognize river migration as section-by-section a comparison with cross-sectional shapes were accomplished with records of (State of Survey/Ministry of Water Resources) in 2019. The results are indicated in Table 3 and plotted graphically in Figure 4. The plots are clarified the variation in cross section shape from site to another and presented critical parts of deposition and erosions regions in each site.

Table 3. The differences in the quantity of sedimentation volume between 2019 and 2022

ID	Sites	Section Area m^2, 2019	Section Area m^2, 2022	Variation in Cross Sections, m^2	Length of Section, m	Sediment Volume, m^3
1	605+554	2300.693	2564.192	263.499	----	-----
2	606+000	1562. 307	1853.701	210.324	446	105662.529
3	606+540	1743.768	1653.503	-90.265	460	-27613.570
4	607+000	971.713	1133.079	161.366	460	16353.230
5	607+260	1208.542	1309.586	101.044	740	-97091.700
6	608+000	1111.779	1067.775	-44.004	740	21104.800
7	609+000	1119.709	1103.771	-15.938	1000	-29971.000
8	609+610	857.996	815.056	-42.940	390	11481.210
9	609+860	1331.853	1271.056	-60.797	250	-12967.125
10	610+000	1056.234	1149.09	92.856	140	2244.130
11	611+000	1013.101	937.371	-75.730	1000	8563.000
12	612+000	1029.652	1323.735	294.083	1000	109176.500
13	612+620	839.376	782.113	-57.263	380	-44995.800
14	613+000	1096.230	902.052	-194.178	380	-47773.790
15	614+000	755.030	1020.300	265.270	1000	35546.000
16	615+000	746.741	693.615	-53.126	1000	106072.000
17	615+670	1027.396	1159.924	132.528	330	-13101.330
18	616+000	981.808	909.280	-72.528	330	9900.000
19	616+500	1054.247	964.002	-90.245	500	40693.250
20	617+000	1278.602	1128.74	-149.862	500	-60026.750
21	618+000	1045.863	896.292	-149.571	1000	-149716.500
22	619+000	845.663	779.178	-66.485	1000	-108028.000
23	619+400	1173.291	1136.7	-36.591	600	30922.800
24	620+000	937.648	1085.264	147.616	600	33307.500
25	620+550	835.074	726.839	-108.235	450	-8860.725
26	621+000	969.933	1027.08	57.147	450	-11494.800
27	622+000	933.445	1066.613	133.168	1000	95157.500
28	622+450	1118.015	853.204	-264.811	550	36201.825
29	623+000	1011.192	1142.698	131.506	550	-36658.875
30	623+240	1232.800	1107.615	-125.185	760	-2401.980
31	624+000	1018.508	1380.217	361.709	760	89879.120
32	624+680	1181.339	1151.065	-30.274	320	-53029.600
33	625+000	1331.773	1050.038	-281.735	320	-49921.440
34	625+300	1382.257	1487.107	104.85	700	61909.750
35	626+200	748.074	778.992	30.918	100	-6788.400
36	626+860	691.409	568.532	-122.877	660	-30346.470
37	627+140	1564.957	1765.111	200.154	720	-27819.720
38	628+000	1207.539	942.509	-265.03	860	-27896.680
39	629+ 000	1504.835	1252.156	-252.679	1000	-258854.500
40	630+000	1008.947	980.754	-28.193	1000	-140436.000

Note: The sign- referee to the scouring.


River Width(m)
St.(605+540) km
River Width (m)
St.(606+540)km
St.(607+260)km
St.(609+610)km
St.(610+00)km
St.(612+620)km
St.(616+500)km
St.(617+00)km
River Width(m)
St.(620+550) km
River Width (m)
St.(622+00)km
St.(623+00)km
St.(624+00)km
Depth (m)
Depth(m)

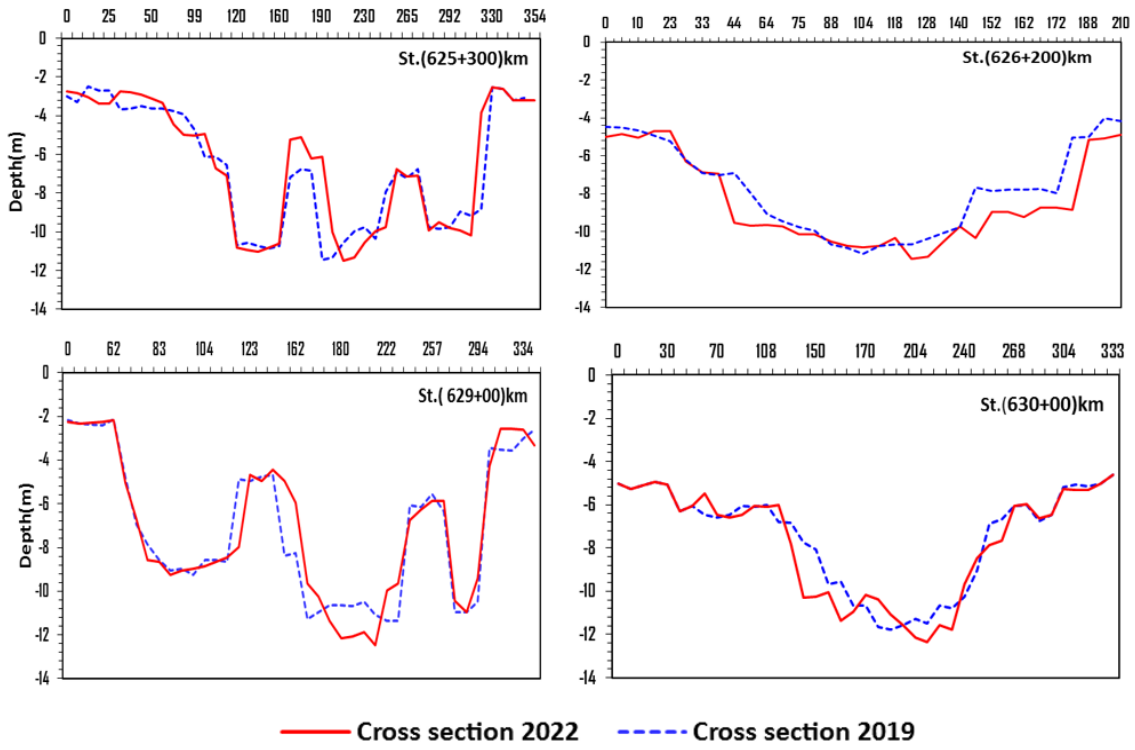


Figure 4. Sequential changes in cross-sections shape of river reach between Jan. 2019 to Dec. 2022

For specific analysis to sites 605+540 km, 607+00 km, 606+540 km, 614+00 km, 613+ 00 km, 620+ 550 km, 622+00 km, 624+00 km, 626+ 850 km, 627+140 km, 628+00 km and 629+000 km were sharply influenced by river migration as deposition or erosion process. The site 624+00 km was the greatest vulnerable of all the sections, as it was found near 361.709 m^2 of alteration in total area (Figure 4). Also, the figure is shown that a part of channel is semi -Stable section with minor adjustment that do not impact function of the watercourse like 609+00 km, 624+680 km and 630+00 km were among the most stable sections where shifting with about -15.938 m^2, 30.918 m^2 and -28.193 m^2 respectively. A channel has considered dynamically in stabilization when the dominant flow and sediment regimes do not lead to long-term degradation and aggradations. The geometry of semi stable cross-sections does not experience changes over the medium to long term and short-term changes in sediment storage, the shape and formation of cross section are both inevitable and adaptation in natural channels because aggradations and degradation pattern may occur on stream over the course of a storm event, but does not necessarily indicate overall instability. While short-term modulation may damage bank structures or bank stabilization [28].

In another case, the cross -sections at sites 606+540 km, 608+000 km, 609+860 km, 611+00 km, 613+00 km, 617+00 km, 619+00 km, 620+550 km, 622+450 km, 623+240 km, 625+00 km, 626+860 km, 628+00 km, and 629+00 km the rate of migration also greatly high when compared to other sections. The cross section 628+00 km has been subjected to significant migration where near –265.03 m^2. As per collective information, due to some issues moving was causing area degradation because the influences water vortexes of Second Towirij Bridge and the effect of Karbala water project intake R.W.I. It is also noted that there are sand "Quarries" on the river bed. These Quarries affected the river area with distortions and pits that greatly affected the pattern and direction of flow in the river as well as the morphology of the river.

In addition, it was observed that a banks near sections 620+550 km, 614+00 km, 616+500 km, 622+00 km and 626+200 km had entirely worsen due to human activity and banks failure. While some sections are suffering from bars development is one factor that makes the area is vulnerable. As a result, determining the tendency of ability region to build more bars or extent floodplains is crucial for river management, especially in this sector of river where the township is close to the floodplains. As a result, the riskiest zone at this section of river due to bars and islands formation if the river has not protected immediately

It is recognized that a lateral or bank erosion are a process occurs as a result of weakness of river which can be attributed to slow of slope, so the river scouring its sides and expansion the cross section. In turn, these phenomena will lead to winding of the course to find a state of balance between the water discharge and the amount of sediment carried by the river. Thus, the occurrence of this phenomenon is concentrated in the areas where the origin of sediment is floodplains, whose river waterway always tend to curving channel because river's energy as concentrated on keeping movement of sediments more than transport, which requires more energy than that [20, 28].

In some cases, the bank erosion has referred by term "*Local instability*", as most common feature in local instability of riverbank may be due to either erosion of stream bank or erosion along concave bank due to meandering. The local instability is occurring as part of the natural torsion process [29]. The transition from deposition to subsequent fluvial erosion associated with structurally driven surface uplift. When long-term sediment deposition occurs on the bed of river channel is gradually changed to the erosion form, the channel cross section is filling up and channels are expansion in width, reduction in flood capacity and avulsions [28].

This work is similar work done by Ali et al. [30] when described a comparison to the bed morphology of the River

Tigris has been surveyed on three occasions (1976, 1991, and 2008) at Sarai gauging station in Baghdad. The changes in elevation in cross section between the 1976, 1991 and 2008 surveys reached up to 4 m.

The comparison shows irregularities in the cross-sections of the river reflect the variations in flow velocity controlling erosion or deposition in new parts of the reach. The 1991 cross-section illustrated the highest changes in bed level. This is believed to be due to the survey having been conducted shortly after the 1988 major floods. The bed level variation in 2008 was the least and may be attributed to the fact that the survey was conducted after 20yr of drought period and after maintains operations were done on this reach od river.

4.2.2 Bank erosion and failure processes

Figure 4 shows that the erosion in bends is generally much greater than in straight reaches when stream flow moves through a bend, the tractive force and velocity along the outer bank increases. The strength of erosion also changes with degree of stream power, when the flow is less than average the stream tends to follow the alignment of concave bank. However, when the flows rise, the water stream tend to cut the convex bar and concentrate the power against the concave bank below the apex of the bend. These processes cause the bends of tend to move downstream, and the region of great erosion which is usually located in the downstream portion of the bend level due to the higher flows [31].

Other phenomenon, it is observed banks collapses because of widespread of sedimentary banks in both sides as in sites 609+610 km, 620+550 km, and 626+200 km. The dominant mechanism of bank failure is planar, rotational, and cantilever. While in some areas, there is no phenomenon of collapsed banks because these banks have to be covered with natural plants or that human being planted some crops to make these areas less scouring.

The collapsed banks can be referred for several factors such as; erosion of wind speed by taking strong water currents, besides the act of gravitation which cause a bank erosion because succession of rising and falling river water [32].

The fall of rain and the rise of humidity between summer and winter play an exponential role in the issue of collapsed banks. As well as flow near the toe of the banks, roughness variability, presence of cohesive sediment materials, turbulence effects, variations in bed particle size, cross-sectional variation, sediment transport rate, vertical stratification and longitudinal variability of the bank materials [29].

4.2.3 The deposition and floodplains evolution

According to river cross section analysis, some sites such as 605+540, 607+000, 612+000, 614+00 km, 620+00 km, 623+00 km and 625+300 Km where the deposition is in higher accumulation over bank sides and most strip sides of channel represents a prevalent component for floodplains expansion. While sites at 610+00 km, 615+670 km, 621+00 km, and 626+200 km the deposition is in lower accumulation, this is because of that Iraq country is located within arid environment areas, when sediment is moved downstream the sediment cannot be moved for spacious distance. The minimum rate of flow, which will decrease the stream guiding downstream and as a result a great amount, will infiltrates into the dry alluvial.

The depositional landforms have constructed at firstly through “Lateral accretion” as a boundary bars formation. Secondly; it’s constructed through “vertical accretion” of fine sediment from over bank deposition. In another case, when a river breaks its banks with and floods, it leaves behind layers of alluvium silt and clay [32]. This sedimentation may be reworked during the subsequent flood events or may remain stored for millennia as the river naturally moved back and forth from one side to the other because of the change in flow hydrodynamics and often the dynamic of floodplains [25]. As a result of the lack of maintenance and dredging, these deposition materials throughout the year gradually harden and are exposed to the growth of plants, which increases their stability and reduces the width of stream and causes of growth new bars.

Several factors have helped to widen floodplains are represented in floods deposition, river streams branching, the bends and meanders, and the presence of river islands has helped river to create floodplains over along time of centuries. Most of which have consequently will join with banks of river with time period and thus will add new lands to the floodplains [28].

The low slope of deposition contains various portions of oxbow lakes, which are irregular manifestation, besides low swamps that are formed due to irregular sedimentation over time scale because of unevenness of sedimentation process. Some areas received large amounts of sediment, while others received a small amount, which resulted in the creation of geomorphic forms included swamp region and undulations at the surface of the earth.

One of the things that it has noticed is the growth of large areas of aquatic plants in the riverbed, especially in the shallow areas, and this in turn affects the river flow in terms of its impact on the value of the roughness factor. In addition, it works to deposit suspended sediments and stabilize the banks of the river in a stronger manner, and leading to a decrease in the width of the river. The decrease in the discharges passing through the river, which leads to a decrease in the depths of the water in the course of the river, which helps in the arrival of sunlight to the bottom of the river, which helps in increasing the growth of these aquatic plants.

5. CONCLUSIONS

A field survey has conducted to a part of Euphrates River to evaluate the alteration in river morphology as response to stream flow and sedimentation change. The results of the survey are indicated significant baseline for consideration such as:

1. Understanding process of control and response natural characteristics is difficult, because of various morphological systems have affected by complex responses to multiple events and climate change. It may more influences in the future, where the sedimentation is characteristically episodic varying with the magnitude and frequency of flow and stream power.
2. The variation in shape of river over time scale has associated with constructing floodplains, riparian vegetation, and boundary conditions. Besides, the qualitative of sediment that input into the river reach and the covariate analysis of geotechnical predictors.
3. Formation multiple bends in some sections as process of maintaining the state of river balance. Besides lateral movement of river, it is characterized by creeping of river intersections constantly towards the outlet due to

the erosion of the concave sides and deposition in the convex sides.

4. The river is in general varied in ratio of sinuosity SI between straight and winding sections, and there is one meander formation.
5. The mechanism has led to formation free consecutive bars in rivers is described as an imbalance between water weight and bottom drag, which causes reduction near the top of bars and resulting further deposition.
6. The geometry shapes of cross sections have varied relatively over the time scale. Some of pervasive features have occurred in river reach like; some of cross sections become deeper, while others have more expansion due to processes of erosion and transportation from original banks which provide opportunity to build more barriers in the river stream.
7. The geometry of semi -stable cross sections does not experience changes over the medium to long -term and short-term changes in sediment storage. The shape and formation of cross section are both inevitable and adaptation in natural channels because aggradations and degradation pattern may occur on stream over the course of flood event, but does not necessarily indicate overall instability. While short-term modulation may damage bank structures or bank stabilization.
8. Several factors have helped to widen floodplains over along time of centuries like; flood deposition, river flow, presence of plants, branching, bends and meanders, and the presence of river islands Most of which have consequently will join with banks of river and thus will add new lands to the floodplains.
9. The sedimentation may be renewed during sequent flood events or may remain stored for millennia where the river naturally moved back and forth from one side to the other because of the change in flow hydrodynamics and often the dynamic of floodplains. If there is a lack of maintenance the deposition materials throughout the year gradually harden and exposed to the growth of plants, which increases their stability and reduces the width of stream and causes of growth new bars.

It is crucial to mention, that the possibility of any future events may occur like, floods, local land use and human activities, banks sliding, excess in drainage water or runoff could cause prospective alteration for any individual section of Euphrates River and more weakness and more degradation.

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