Morphotectonics of Shatt Al-Arab River Southern Iraq

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Abstract
A morphotectonic analysis is conducted on Shatt Al-Arab drainage basin. This study aims to analysis of the river patterns of Shatt Al-Arab channel and their relationship with the development of subsurface geological structures and the neotectonic activity, as well as an attempt to determine the relative amount to this activity.
Transverse river profile analysis is derived quantifiable and comparable parameters such as neotectonic index ($Eh*L_n$), Eh, Ch, and B_s. These parameters are useful to detect the morphotectonic indicators of Shatt Al-Arab basin. The analysis showed the role of the subsurface structures that affecting the river cross sections shape, through channel incision, as in (Dair and NuhrUmr) cross sections, while in the others the increasing in neotectonic index interpreted by the geomorphic features such as sudden changes or diversion in river course and river pattern changes.

Keywords: Neotectonicy index, Shatt Al-Arab river, Transverse profile, thalweg, basin Symmetry, incision

مورفوتكتونية نهر شط العرب- جنوب العراق

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الخلاصة
تهدف هذه الدراسة الى اجراء تحليل مورفوتكتوني لحوض شط العرب من خلال تحليل انماط التصريف لنهر شط العرب وعلاقتها بالتراكيب الجيولوجية تحت السطحية والفعاليات النيوتكتونية، بالاضافة الى محاولة تحديد المقدار النسبي لهذه الفعالية.
اجري تحليل للمقاطع العرضية المقاسة في شط العرب من خلال اشتقاق معاملات ممكن حسابها ومقارنتها ضمن المجرى النهري لشط العرب. هذه المعاملات مفيدة لتحديد الشواهد المورفوتكتونية لحوض شط العرب.
اظهر تحليل المقطع العرضي دور التراكيب تحت السطحية بالتأثير على شكل المقطع العرضي من خلال التعرية في مجرى النهر كما هو الحال في مقطع الداير ومقطع نهر عمر، والتغيرات في النمط النهري والتغيرات المفاجئة في مجرى النهر في بقية المقاطع العرضية

Introduction:
The study area is located at the southernmost part of the Mesopotamian Plain. It represents Shatt AL-Arab channel course from Al-Qurna town (about 70 Km north the city of Basra) where the Tigris and Euphrates rivers meet to Al-Fao town (about 90 Km south of Basra city) where the Shatt Al-Arab

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debouches onto Arabian Gulf. Shatt Al-Arab basin is located on the unstable shelf, particularly in the Mesopotamian zone, according to the tectonic division of Buday and Jassim [1]. This part is characterized by thick sedimentary cover and the subsurface structures are not reflected to the surface [1,2].

Shatt Al-Arab drainage basin is represented by very lowland area where the topographic gradient is about (1 cm/km). Its channel also displays different patterns varies between (straight, sinus, meandering, and braiding) [3] here we discuss these patterns in terms of their relationships to the neotectonic movements of the region.

The main objective of this research is to analyze the river patterns of Shatt Al-Arab channel and their relationship to the subsurface geological structures and the neotectonic activity, as well as an attempt to determine the relative amount to this activity.

Method and Material:

Studying of river profiles can provide significant information on both hydrodynamic factors and geomorphic features of drainage basins [4]. Most of river profiles studies emphasize the longitudinal profiles that comprises more analytical methods such as the geomorphic approach and the field evidence [5] , the scale models of Ouchi [6], and the numerical methods of Snow and Slingerland [7,8] and Ohmori [9]. These approaches tend to discover the reach-scale response of rivers to tectonic deformation. Furthermore, the long profile of the river is linked with many factors, such as riverbed sediment, erosion power, bedrock lithology, sea level changes, tectonic activities, and climate [10]. On contrary, the transverse river valley profiles (TRPs) have not received much attention, except that these generally used to ascertain the channel symmetry such as the work of Leopold and Wolman [11]; and Knighton [12, 13]. Sinha, [4] summarizes the drawbacks that make transverse river profile difficult to interpret and analyze. First, such TRPs are difficult to use to compare different TRPs across the same basin and also those across different basins, because of variable valley elevations and profile lengths. Second, the shape of such TRPs is scale-dependent, and hence, fixing of horizontal and vertical scales of the TRPs, particularly for the long ones across basins having highly contrasting altimetric, frequency is problematic and subjective. These aspects restrict the usefulness of the conventional TRPs. These problems can be circumvented to a large extent by normalizing the two variables, namely the elevation and the distance.

The present study derives the data of cross-sectional profiles from different sources. Cross section profile (A-A') is obtained from the previous bathymetric surveys of Shatt AL-Arab channel, carried out by the Marine Science Center [14]. Other cross-sectional profiles are taken during the fieldwork that was carried out in March\ April 2010 in the area of Shatt Al-Arab. Channel depths of the course of Shatt Al-Arab cross section profiles are made using precision Echo-Sounder instrument model (PS 10E). Starting and ending measurements of each section are recorded using the (GPS). Another instrument was used is the Acoustic Doppler Current Profiler (ADCP) type Rio Grande 600 Hz to illustrate the channel morphology against some hydraulic characteristics such as (velocity and discharge). In total, the study comprises analysis of five cross sectional profiles, covering Shatt AL-Arab channel from Al-Qurna to Um Al-Rusas Island, figure-1. Unfortunately, no bathymetrical survey exists for the areas below Um Al-Rusas Island because the river shared between Iraq and Iran, so cannot complete cross sections. It is noteworthy that the cross sections arranged facing downstream of the trunk stream. All of them are selected which individually have a tectonic, morphological, significance (Figure 2).

An analysis TRPs of Shatt AL-Arab has been performed according to the study of Sinha [4].This study provides a new approach of analysis of TRPs using several TRP parameters that are quantifiable and comparable.

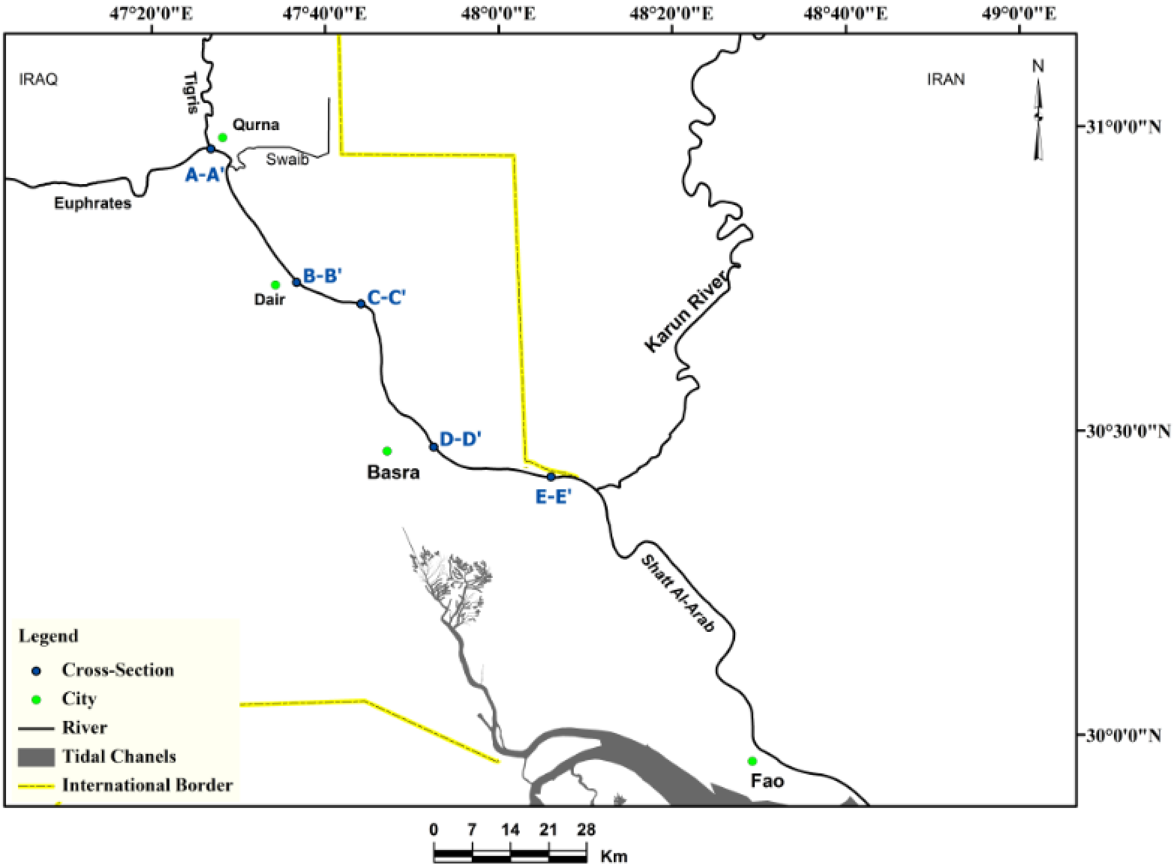

Figure 1- Location map of the TRPs of Shatt Al-Arab River

In order to extract the quantified and comparable parameters a hypothetical analysis to each cross-section should be performed. The conceptual normalized steps of TRPs follow these points:

1. A simple modification of a given cross-sections is performed by making their values vary between (0-1), representing the high and low values in the TRP curve, figure-3.

- The X coordinate represents the ratio L_i/L, where L is the profile length and L_i is the distance of the individual data point (breaks in slopes) from the channel at one end of the profile.

- The Y coordinate represents the ratio $\Delta H_i/\Delta H$, where ΔH is the difference between the maximum and the minimum elevations of the profile, ΔH_i is the difference in elevation between the individual data points.

- The area (Ea) between the profile curve and the H_1-H_2 Line joining the two opposite side of the channel bank is defined as the total valley erosion in the given TRP. It is expressed as percentage of the area ABH_1H_2. It is an approximate two-dimension measure of the total channel erosion in the given TRP as shown in figure (3).

2. In order to assess the incision at each channel site the following procedure should be made:

- Smoothening process of TRP curve is carried out as shown in figure (4).

The Thalweg (Th) of the main river being located at the minimum height in the TRP where the $\Delta H_i/\Delta H$ equal to zero, is plotted by line to join M at the line H_1 H_2, to define (Ch) i.e.; the maximum vertical incision at the current channel site (Figure 4). Its value is considered 1 in all analyzed cross-sections, because the cross-sectional measurements restricted to channel perimeter that do not cross the bank.

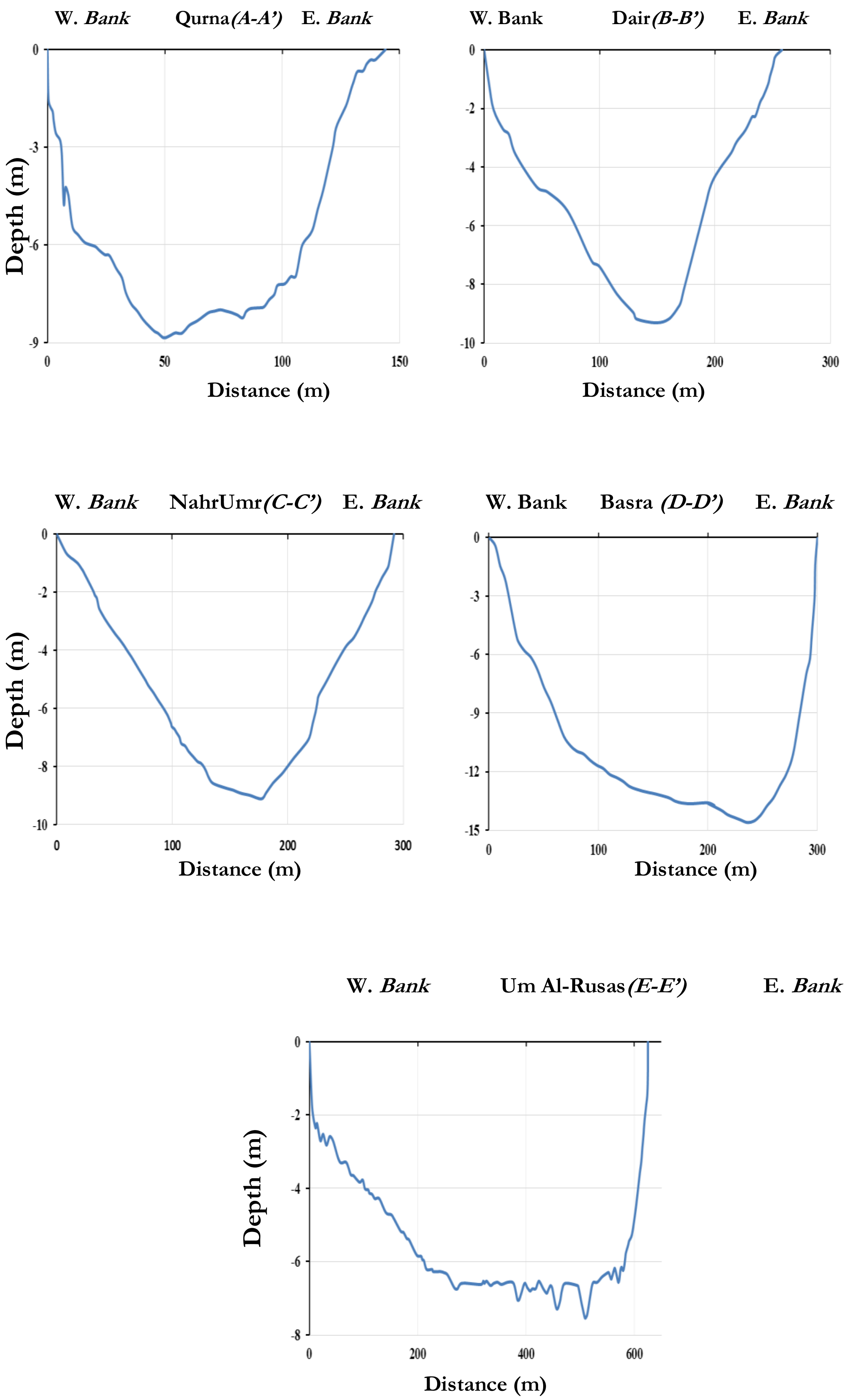

Figure 2-. Transverse River Profiles (TRPs) of Shatt Al-Arab

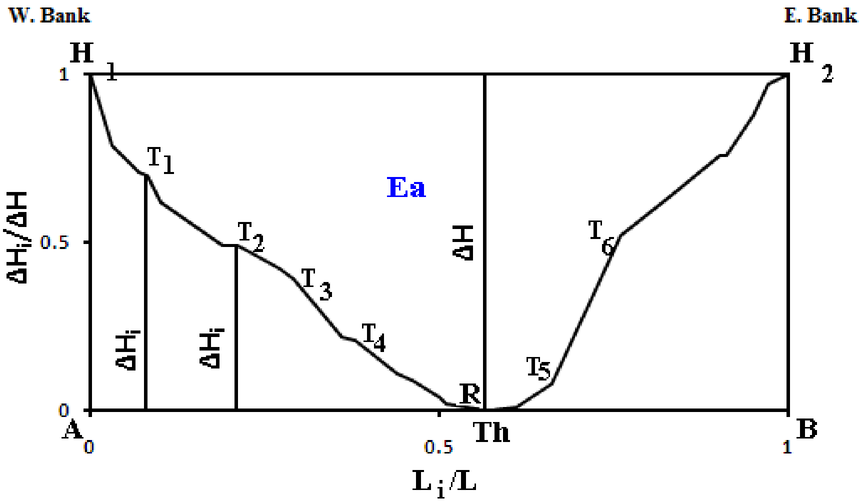

Figure 3-. Normalized transverse river valley profile (TRP) across a hypothetical river valley. $\Delta H_i/\Delta H$ is the individual height data (H_i) normalized against the maximum and the minimum height differential (ΔH), L_i /L is the individual data-point distance (L_i) from one end of TRP normalized against total TRP length (L).Thalweg (Th) of the main river; T_1– T_5, Terrace positions; H_1, H_2, Valley top on the east and west banks, respectively; Ea, Measure of valley erosion.

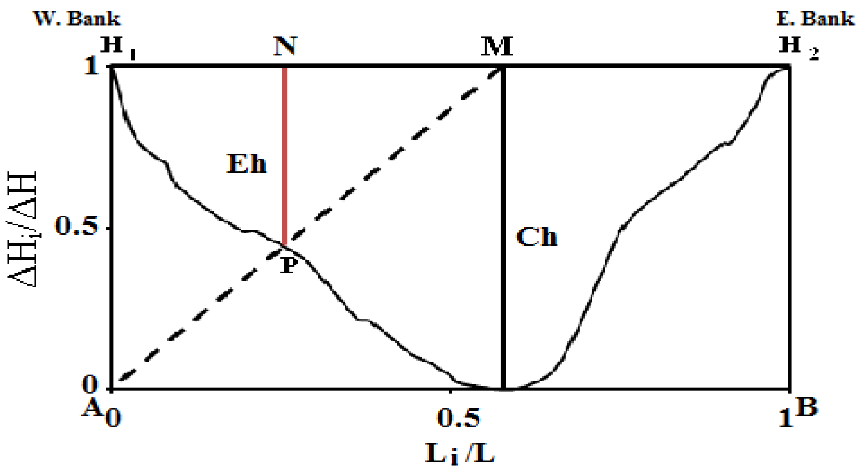

Figure 4- Smoothened hypothetical TRP curve from which Eh and Ch are extracted for one valley side. Th, Thalweg of the main river.

- The point M on H_1-H_2 line is joined with the point A, the line intersects the TRP curve at the point P. The point P joints N on H_1-H_2line to define the normalized expression of average valley-side incision (Eh). Each TRP has two values of Eh; one for the east bank [Eh (EB)] and the other for the west [Eh (WB)].

A key factor in the interpretation of the river incision is the degree of the approach of the Eh or Eh/Ch parameter to Ch parameter. The Eh parameter allows the following interpretation: if its value is close to 1 the lateral incision is greater than vertical incision and allow to determine the tributaries and masswasting, and where the values tend to decrease relatively, then can interpret that the vertical incision tends to increase and allow to identify the neotectonic factors or lithological contrast.

3. The geometry of the transverse river profile can be described quantitatively through the parameters channel symmetry (B_s) and valley symmetry (V_a), and the channel side slopes (V_s). The river cross section curve is shown in figure-5.

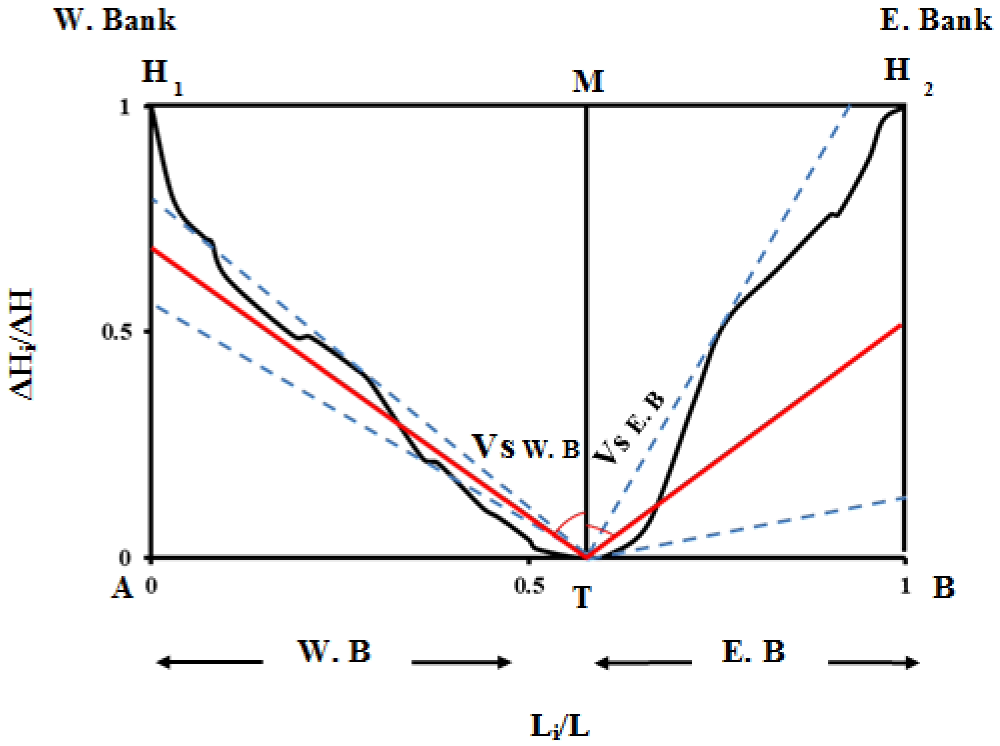

Figure 5-Method of computation of basin symmetry (B_s) and valley symmetry (V_a). Dotted lines are form surfaces of profile curves originating from T (thalweg of the main river). The angles between the bisectors of the form surface angles at T and the line TM give the generalized valley slope on each valley side. This is not the actual gradient but WTM – ETM gives the valley symmetry (V_a) and AT – 0.5 gives the basin symmetry (B_s). West bank WB, East bank EB.

- In order to get more realistic measures of the channel side slope (V_s) from TRP curves, the form surfaces of TRP curves are obtained by joining the maximum deflection points on the concave and convex sides of the profile curve for each bank with T the Thalweg Broken lines in (Figure 5). The form surface angles for both EB and WB curves arebisected. The angles between the bisectors and the line TM give the V_s value. It is noteworthy that the channel side slopes (V_s) thus computed do not give the actual channel-side slope angle.

- The difference in the channel side slopes values for the east bank and the west bank is a measure of the valley symmetry (V_a).

The Important parameter in this study is the parameter Eh* Ln where the (L_n) is the normalized profile length derived from the ratio L_p/L_{max}, where the L_p is the length of the individual TRP i.e.… the valley width at each TRP location. L_{max} is the maximum valley width of the study TRPs, while Eh is the mean Eh value of the given TRP. Such parameter is important for expressing valley incision on two counts. First it is a 2D.parameter and second, it is an incorporates an element of linkage throw (L_n) in the study of TRPs channels, in both these counts Eh*Ln parameter is better than Eh used alone for TRP comparison. Generally, Eh*Ln is influenced largely by non-hydrologic factors. For example, higher value of this parameter would indicate greater valley erosion in response to either neotectonically controlled uplift of blocks or the presence of easily erodible bedrocks [4].

The procedure has been successfully tested in the study of Shatt AL-Arab channel after asking the author Mr. Sinha-Roy about the validity and possibility of his approach to apply in the case study of Shatt AL-Arab.

Results and Discussion:

The different parameters defined above are calculated for the five cross sections (table 1).These cross sections are compared on the light of the known geologic characteristics of the area. At the end possible tectonic influence on the river cross section shape can be assessed.

Table 1- Computed parameters of the TRPs of the Shatt Al-Arab channel.

Profile ID	*Lp (m)*	*Lmax (m)*	*Ln= Lp/ Lmax*	Ea%	West Bank		East Bank		Eh	L_n*Eh	Bs= AT-0.5	Vs (degree)		V_a
					$Eh_{(WB)}$	$Eh_{(WB)}/Ch$	$Eh_{(EB)}$	$Eh_{(EB)}/Ch$				W. B.	E. B.	
1. Qurna (A-A')	144	625	0.23	64.1	0.657	0.657	0.648	0.648	0.653	0.15	-0.16	53	71	18
2. Dair (B-B')	258	625	0.413	57.1	0.563	0.563	0.462	0.462	0.513	0.212	0.07	57	41	-16
3. Nuhr Umr (C-C')	292	625	0467	57.3	0.564	0.564	0.531	0.531	0.547	0.256	0.11	48	68	20
4. Basra (D-D')	300	625	0.48	72.75	0.703	0.703	0.667	0.667	0.685	0.329	0.30	75	41	-34
5. Um AL-Rusas (E-E')	625	625	1	73.6	0.673	0.673	0.705	0.705	0.689	0.689	0.31	75	40	35

1. Qurna Reach (A-A'):

The current reach reveals lower values of the parameters of the (Eh*Ln= 0.15) or as can be termed neotectonic index as compared with those in the other cross sections in the area. However, the other parameters such as E_a, Eh, Eh/Ch, with values 64.1%, 0.648, 0.648, respectively are relatively high. High values of these parameters reflect the role of the tributaries that enabled the river to cut broad channel floor where the lateral erosion exceed the incision or down-cutting. It is noteworthy the current cross section site is bounded by the Tigris and Euphrates rivers.

2. Dair Reach (B-B'):

The cross section in this reach appears the increasing of the parameter of Eh*Ln =0.212 than the previous reach associated with decreasing in the parameters E_a, Eh, and Eh/Ch (57.1, 0.513, 0.513 respectively). The river in this site is able to incise into the riverbed and create approximately V-shaped channel in response to neotectonic uplift of the subsurface anticlinal structure that called NahrUmr structure (Figure 6), this structure is inferred from many geophysical studies such as Al-Johar [16]Karim [17]andKarim, et al., [18] which generally confirmed the origin and type of neotectonic movement in this area. The current transverse profile located upstream from the axis of uplift of the above subsurface structure.

The geomorphic response of the river observed in this site is the deflection or diversion in its course where it crosses the actively uplifting structure above. Deflection of the streams by tectonic warping has been studied by Holbrook and Schumm [19], Keller and Pinter [20], Della Seta et. al [21].

Keller and Pinter [20] outline three possible causes to deflection of the streams that cross an actively uplifting morpho-structures. They are:

1. The stream will continue to flow in spite of the deformation, but its path will be deflected by the deformation: or
2. The fluvial system will have enough power to maintain itself through downward incision; or
3. Uplift will defeat the steam, forcing drainage to flow by some other route.

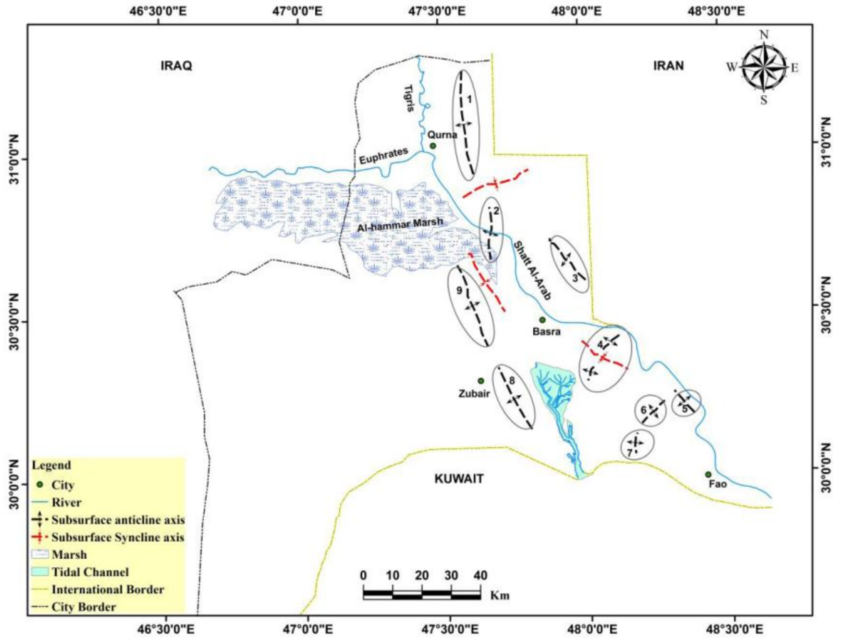

Figure 6- Structural subsurface anticline and syncline of Shatt Al-Arab Basin [15]

3. NahrUmr Reach (C-C'):

This reach reveals considerable increase in $Eh*L_n$= 0.265, than the former reach. The other parameters E_a, Eh, Eh/Ch (57.3, 0.547, and 0.547 respectively) are low values. This means that the channel in this site is able to downcut into the riverbed and it create V-shaped channel (Figure 2). This cross section is located downstream from the axis of actively NahrUmr subsurface structure (Figure 6). This reach exhibits significant sudden deflection where the channel course has been shifted eastward approximately in E-W direction rather than the former path of NW-SE direction. However, it is associated with abrupt increase in sinuosity index reaching (1.1) indicating local change in gradient caused by neotectonic activity of above subsurface structure.

4. Basra Reach (D-D'):

All channel cross section parameters are increasing more than the previous reaches where the lateral erosion exceeds the vertical erosion (table 1). In this reach, the significant geomorphic feature is the frequencies of the island that elongated the east bank of Shatt Al-Arab. These islands extend about 20-30 km. The geomorphic process responsible for the formation of these islands is avulsion [22]. Avulsion is the relatively abrupt shift of an entire channel belt from one location to another on the floodplain [23, 24, 25]. Regional long-term factors controlling avulsion include: base level change, climatic change, tectonic movements and discharge variation [23].

In the study of Shatt Al-Arab drainage basin all the factors above are expected, but can be accentuated by the neotectonic movements for two reasons. First is that these movements are still continuing up to now, and second is that the late geological event has influenced the landscape in the area, as mentioned in many geological studies [2, 26, 27 and 28].

The other hand, avulsing channels concentrate in areas of tectonic subsidence, and avoid areas of tectonic uplift. However, if channels occupying subsided areas have a high aggradation rate, subsequent river diversions may be directed away from the zone of maximum subsidence [29]. Tectonically, Basra area act as depression (subsided zone) where the geophysical data gives negative anomalies to magnetic and gravity that mean deep-seated light core of probably salt beds [18].

5. Um Al-Rusas Reach (E-E')

Within this reach, All the cross section profile parameters are relatively more than all analyzed profiles, especially the neotectonic index or ($Eh*L_n$= 0.689). The main river tends to have a cross-sectional morphology that reflects involvement of many factors. The maximum values of ($Eh*L_n$) reflect possibly neotectonic movement of the subsurface structures that called Siba Structure. The geological studies are pointed out its responsibility for deposition of series of Um Al-Rusas Islands [17, 30, 31], as well as sudden channel diversion exists downstream of uplift axis where the course trends approximately N-S.

Conclusions:

1. Shatt Al-Arab drainage basin have responded and adjusted to neotectonic movements by uplifted and subsided subsurface structures. These adjustments can be recognized using geomorphic analysis.

2. The TRPs is an affective reconnaissance tool for areas that experiencing neotectonic elements.

3. The Analysis of transverse river profile method showed that the neotectonic index increased relatively downstream along the main stream channel of Shatt Al-Arab for the analyzed cross-sections.

4. The geomorphic response in Shatt Al-Arab drainage basin that attributed to the neotectonic uplift of the subsurface structures include incision in the river bed through developed (V-shape) of the cross-section at Dair and NahrUmr reaches, as well as sudden change in river course (deflection).

5. The geomorphic response in Shatt Al-Arab drainage basin that attributed to the neotectonic subsidence include channel avulsion at Basra reach.

6. The eastward preferred increasing of Basin symmetry (B_s) parameter in the studied cross sections may be revealed eastward migration of Shatt Al-Arab river course that may be related to the eastward migration of the paleochannels that located in the west side of Shatt Al-Arab river present course.

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