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Utilization of Stream Power as a Scale to Detect the Deposition and Erosion Processes in Euphrates River, Iraq

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ABSTRACT

Stream Power is characterized as one of the principle forces driving the formation of river pattern. It's effectively used as an indicator to identify channel behavior in terms of its stability and potential for morphological modification. Therefore, the aim of this research is to examine and analyze the effect of Stream Power on instability and morphologically dominant processes within a part of the Euphrates River, and to assess the erosion and deposition processes using the Annual Geomorphic Energy Index (AGE). Several investigations were set up in ten river reaches to collect basic information for calculating parameters using principal hydraulic methods. These parameters include dominant and bankfull discharges, total and specific Stream Power (TSP and SSP) and the change in Annual Energy Balance (ΔAGE). Furthermore,to identify depositional and erosional processes, the results of AGE are compared with the Rapid Geomorphic Assessments (RGA) index, which includes indicators such as Channel Stability Indicators (CSI) and the Oklahoma Ozark Stream Bank Erosion Potential Index (OSEPI). The principle finding has clarified that the river is considered a low-energy stream and that stability is not viable. Also, the comparison of results shows that variations in discharge amounts are significant factors impacting the variance in energy balance and altering the depositional or erosional status; these factors are morphometric parameters (e.g., depth, width, slope of a reach, and channel formation). In addition, regions identified with active erosion phenomena coincide with lateral migration rates and landslides, which are closely linked with human activity, sediment texture, and riparian vegetation. The analysis have indicated that the areas most "sensitive" to variation are crucially subject to instability phenomena as a result of fluvial dynamics. Comparing the results of ΔAGE with the Rapid Geomorphic Assessments OSEP is more consistent with the depositional or erosional status. This confirms that the stability is not applicable for this low-energy stream and characterizing sediment prosesses conditions in terms of energy balance is an innovative technique that conceptually focuses on fluvial drivers. This work can provide useful indications to river dynamics processes and prepare a vision to the sensitive reaches conteroled by low-energy.

1. INTRODUCTION

Rivers are principal geomorphic agents shaping the Earth's surface. They can alter their forms, dimensions, directions, and patterns due to their capabilities for sediment transport and their dynamic features [1, 2]. The equilibrium of a river system is disturbed by the effects of variables such as water discharge, channel slope, and bed material size, producing new conditions that can impact channel morphology [3]. The evaluation and analysis of river long profiles is a recurring topic in fluvial geomorphology [4]. According to research studies by Schumm [5] and Knighton [6], there was consensus that the long profile serves as a diagnostic characteristic of the equilibrium condition between bed material, slope, and transport processes. They precisely defined the equilibrium as a balance between deposition and erosion processes, which later known as negative feedback [5-7].

In 2016, Bledsoe et al. [8] provided an influential paper that described an approach to amend the formation of alluvial channels. However, less attention was paid to the role of channel gradient in sediment transport, a process accomplished through repetitive adjustments to the channel's cross-sectional dimensions and geometry along a long profile [9-11]. Subsequent research studies focused on using sediment transport equations that link discharge, particle size, and slope, providing a more analytical approach [12-14]. More recently, studies have tended to focus on processes and formation at the reach scale, while a conceptual framework has emerged at the basin scale, where high-order channels deposit, low-order channels erode, and middle-order channels transport sediment [3-15].

There is a lack of studies distinguishing the parameters driving sediment transport to explain changes in the formation of fluvial channel systems. Variations in external and internal factors can impact the equilibrium of river systems and sediment transport. Channel sensitivity to erosion and deposition is crucial for river management [16].

Stream Power (SP) is widely applied as a key indicator in morphological evaluations and sediment transport studies [11]. Stream Power represents the primary driving force acting within a channel and its ability to perform geomorphic work [17]. Variations in Stream Power can affect channel stability, sediment transport capacity, and the development of new morphological features. Therefore, it is widely used to assess river pattern evolution [18, 19]. Stream Power is often expressed as Total Stream Power (TSP) or Specific Stream Power (SSP) [20].

Prior studies have used Stream Power to identify dominant river processes and determine threshold limits required for channel adjustments [21-24]. Bull [25] linked Stream Power and geomorphological performance with aggradation and degradation, referring to sustained periods of Stream Power above or below the critical threshold required for bedload transport. This serves as an indicator of channel conditions [26]. Additionally, Stream Power has been successfully used by Cao et al. [27] to quantify sediment transport rates in both perennial and ephemeral rivers by incorporating sediment particle size with stream energy. Recent studies, such as study [28], have explored the applicability of Stream Power as a predictor of channel adjustments. Peak unit Stream Power values are often used to determine various categories of geomorphic changes in unconfined and confined stream channels. Bizzi and Lerner [20] utilized total and specific Stream Power to identify the sensitivity of channels to deposition and erosion dominance, computed both at and upstream of specific locations.

Soar et al. [29] applied the River Energy Audit Scheme (REAS) to integrate flow duration curves and determine the Annual Geomorphic Energy (AGE) for certain reaches in the UK. Changes in AGE indicate the likelihood of erosion and deposition. Similarly, Hosseinzadeh et al. [2] investigated morphometric changes, instability, and Stream Power using the AGE index in the Haji Arab River in Qazvin Province. AGE is determined by integrating the relationship between discharge variations and the excess specific Stream Power associated with the flow duration curve. The calculated AGE values at different cross-sections reflect characteristic local changes in bed slope, channel geometry, and bed composition.

The recent water resources management strategies in Iraq emphasize the need to evaluate morphological changes in river systems to understand channel behavior in terms of erosion, sediment transport, and deposition. This research aim is to use Stream Power to analyze dominant channel processes and morphometric changes in specific reaches of the Euphrates River. Utilizing field datasets, Stream Power concepts (TSP and SSP), and Annual Geomorphic Energy (AGE) as criteria, the study identifies areas prone to erosion or deposition. The findings provide valuable insights for future river management and hydrological studies in Iraq.

2. MATERIALS AND METHODS

2.1 Regional setting

A section of the Euphrates River is selected for examination. The study area extends from station 606+00 km, located downstream of the Al-Hindiya Barrage, at geographic coordinates latitude 32°42'3"N and longitude 44°15'53"E, to station 630+00 km at Aifar Village, with geographic coordinates latitude 32°30'53"N and longitude 44°14'44"E. This section of the river spans 24 km and flows through sedimentary plains within the administrative boundaries of Babylon Province and partially into the borders of the Karbala Governorate (Figure 1).

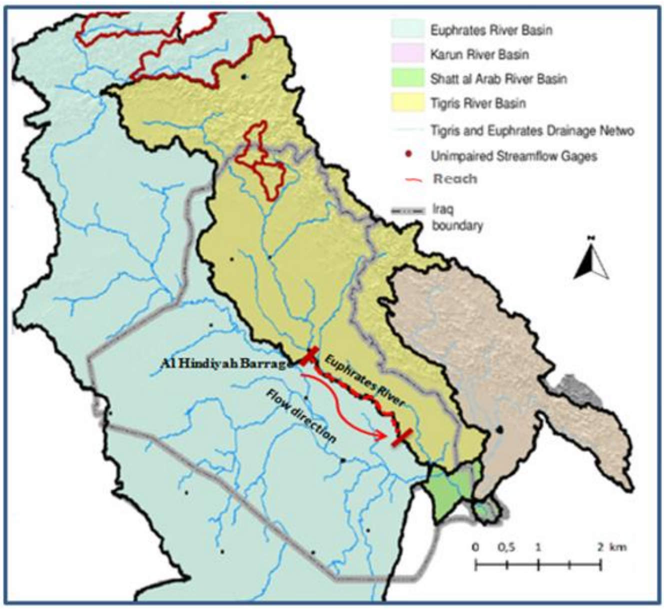

Figure 1. Location map of the studied reaches within Euphrates River

The geomorphic processes of the river in this region are closely correlated with velocity, discharge, runoff speed, sediment transport, and erosion. The selected section of the river has an average flow rate of approximately 135 m^3/s, and variations in discharge significantly influence the development of landforms within the channel. The geomorphic landforms and sedimentary processes vary from one location to another due to the activities of local populations, agricultural areas, and industrial facilities situated along both sides of the river. Specific properties of the river system also vary depending on local factors [30].

As the river flows through a sedimentary plain, it is generally characterized by flat terrain and a low slope gradient, with an average slope of 1 m per 7.5 km from north to south. Despite this overall flatness, the surface is not free from natural manifestations that have formed due to fluctuations in hydrological conditions or human activities.

Different features presented such as bends, meanders and straight reaches [30]. The available of bends are causing significant alteration in velocity. Also,there are a lot of bars and islands insides some reaches and some of them is colonized by vegetation. The nature of variation in sediment accumulation is one of the most key factors that influence and varied geomorphological manifestations. Most of sediment accumulations developed from sequence aggradations of the Tigris and Euphrates Rivers dating back to the modern era, which consists of mud, silt, and sand. Erosion features like vertical or undercut banks are presented as level of lateral mobility of sediment and bank failures [31]. Bed change has forced destabilize toes of bank and trigger bank failures. The instability of river activity from one side to another caused differences in cross sections areas, shapes, and deposition regions.

Geomorphologic processes are principally correlated with the climatic features. Whereas, the effect of climatic elements are connected with each other, which consequently lead to the activation of the geomorphological processes accomplished by the river such as erosion and sedimentation process.One of the most important of these elements is the temperature which characterized by fluctuation in the region between 45℃ in summer and 5℃ in winter. While the rainfall is fluctuating as follow the Mediterranean system. The intensity of rainfall in cold season with about 120 mm / year and zero in hot season Another feature is the present of natural plant which engaged a great role in prvided protection to the banks of channel through its ability to stabilize the river cliff by its roots and increase strengthen of cohesion of the soil of banks and the bottom. besides its role in decreasing the speed of water flow and its effectiveness. This is an important section due to activities of population, the majority of liquefied water stations and a presence of a lot of industrial facilities and urban activities on both sides of the river.

2.2 Data collection

In order to achieve research objectives, the investigation are set up in each reach of studied channel of Euphrates River. The data of morphological and physical features are collected by surveying a within apart of river of 24-km. This a part of river is divided into ten reaches, the length and slope and geomorphological properties are indicated in Table 1.

Table 1. Morphometric characteristics of river reaches

Reach No.	Length (km)	Discharge Class (Dominant)			Discharge Class (Bankfull)			Slope (m/m)	d_{50} (mm)	Roughness Coefficient (n)	Pattern
		Q (m^3/s)	Width (m)	Depth (m)	Q (m^3/s)	Width (m)	Depth (m)				
R1	1	407.960	248.715	4.943	1310.632	373.073	7.857	0.000617	2.044	0.0169	Straight
R2	3.86	372.984	124.000	5.769	1384.617	386.000	9.923	0.000696	0.213	0.0116	East Bend
R3	2.14	270.000	130.000	4.286	1064.418	195.000	8.432	0.000589	0.297	0.0123	Braided
R4	2.0	207.980	87.000	4.487	988.660	188.000	8.522	0.000136	0.264	0.0120	West Bend
R5	2.0	309.000	165.000	3.433	1070.296	247.500	8.268	0.000179	0.637	0.0139	West Bend
R6	4.0	342.275	155.403	5.152	1144.452	217.310	7.480	0.000354	0.586	0.0138	Meander
R7	3.24	279.705	134.523	4.147	1237.736	233.105	7.834	0.000317	0.270	0.0121	East Bend
R8	1.76	352.926	129.447	4.722	1238.181	201.785	8.090	0.000392	0.037	0.0087	Bend
R9	3.0	299.665	132.765	5.983	905.9701	175.940	6.41	0.000697	0.557	0.0136	Straight
R10	2.0	407.960	248.715	4.928	810.550	155.456	5.467	0.000467	0.480	0.0133	Straight

This research assesses the change in discharge by using two period; first period by using dominant discharge (during September, 2023), and second period by using bankfull discharge period (during January, 2024). The Acoustic Doppler Current Profiler (ADCP) technique is used for measurements (Rio Grande 600 kHz and Win River II software version 2.04). ADCP is a device uses sound waves to measure the speed and direction of currents throughout the water column. The device is automated from a small boat on river channel. Normally deployed on its own floating platform which can be towed by boat, from a cableway into opposite banks. The ADCP will be being transported from one site of interest to others and the process of measuring by this device is illustrated in Figure 2. A kinematic GPS is used for positioning ADCP surveyor device, they are linked with a laptop to collect the data by a software system. These data are included hydraulic and geometric data such as flow velocity, geometry of cross-sections, water surface width, and water level during period of time. To conduct uniformity of each cross section, form additional sites between any sequent kilometers. These additional sites were determined by direct depth measurement using ADCP depending on depth of river. The results of measurement are elucidated that some zones of river warped with high materials, many samples are collected where invert action of dynamic stream boundary system and local activities can emerge and entire soil to stream flow or around study area such as: falling banks, banks cavity, steep banks, native vegetation, agriculture farms, alternative bars, aggradation and degradation of channel, and urban areas, which create sediments, and the deposits change is eminent as a source. This work is composed many campaigns with using some devices and tools to gather collect samples from each reach.

Figure 2. The ADCP device sampler and downward facing water in each section

Figure 3. Collection bed material by (Van-Veen) grab from river bed

The bed materials are measured by using Van-Veen grab device with capacity size 5 kg to extract bed load sediment as indicated in Figure 3. A Van-Veen device is forming of two levers and two pails which are spread like an open scissor opened with lowering sampler into water. The levers are locked by pulling a lift chain and unlocked when putting down, then collected samples and brought up for weighting. With about 15 samples are collected from each reach and mixed fully to obtain homogenous sample and to minimize the error of measurements. After samples collected in the field, they were treated with 1 mL of 0.4 g/L copper sulphate solution to slow the growth of organic material. This step has done if samples could not process promptly. The test of bed materials is possessed depend on the length of channel for calculating various classes of particles sizes. Then, samples are transported to the laboratory for analysis. The extract samples individually conserved in class bowls and marked with stickers including all information about the time, date and location. Then, they transported to the laboratory by box covering with ice to prevent of organic growth. Then, according to (ASTM D854-92), samples are dried in an oven under 70°C for 48 hours. Then weighted for obtaining particles distribution which is essentially separation into a number of size classes The soil was broken as small sizes as possible, then sieving it through a set of sieves meshes by a mechanical shaker and weight of sediment kept in every sieve was recorded. The portion of the fine particles 0.075 mm to 0.0002 mm are further analyzed using (Hydrometer-151H) and according to (ASTM D422-63). The sieving results and hydrometer analyses presented as cumulative size – frequency curves.

2.3 Methods

Bagnold [32] introduced the concept of Stream Power as an equation for the Stream Power needed to initiate the movement of grain particles, as follows:

$$TSP = \rho g Q S_x \tag{1}$$

where,

TSP = Total Stream Power in stream channel (W/ m)

ρ = Density of the water 1000 (kg/m^3)

g = Acceleration due to gravity = 9.8 (m^2/s)

Q = Discharge (m^3/s) and

S_x = Slope (m/m).

Specific Stream Power SSP is represented to the equation is further modified for Stream Power per unit bed area of a stream reach of river bed [32, 33]. It's used or for comparison between river beds with different size [34] as indicated in Eq. (2):

$$SSP = TSP / Wr \tag{2}$$

where,

SSP = Specific Stream Power (W/m^2)

Wr = Width of channel bed (m)

The parameters in intermediate level of these concept are estimated depend on individual field observation. This research is examining the dominant discharge and bankfull discharge, the first one managed the river dimensions, while the last one controls stability flow. Basically, high precision is necessary to calculate the discharge, as they are influential in defining the river. For calculation hydraulic parameters for geometry of cross sections, the bankfull discharge is obtained by using Manning-Strickler formula as indicate in Eq. (3):

$$Q = \left(\frac{1}{n}\right)(A)R^{2/3}\left(S^{\frac{1}{2}}\right) \tag{3}$$

where,

A = Cross section area (m^2)

S = Channel slope (m/m)

R = Hydraulic radius (m)

n = Manning's roughness coefficient

The Manning roughness coefficient (n) has been calculated based on the grain size d_{50} obtained for each reach as indicate in Eq. (4):

$$n = \frac{{d_{50}}^{\frac{1}{6}}}{21.1} \tag{4}$$

where,

n = Sticklers roughness coefficient

d_{50} = Medium grain size (m)

In brief, the data that documented by Wallerstein et al. [35] and Thorne et al. [36] about the conceptual index of a River Energy Audit Scheme (REAS) for practical prospective to describe river instability at any basin. This concept constitute question whether the 'stream energy balance' can be an beneficial index of channel un equilibrium. In general, objective of REAS index is not to examine main region of river that suffer from instability locally, scale, intra-reach, but to supply an indicator of probable imbalances in accessible energy to implement morphological action between reaches.

The concept of critical Stream Power is presented to consider some classes of particles sizes transport according to the same hypothesis. The Excess specific Stream Power, SSP_e (W/m^2) is calculated by subtracting a measure of the critical specific Stream Power, SSP_{ci} is needed for introduce materials transport from the TSP as expressed in Eq. (5):

$$SSP_e = SSP - SSP_{ci} \tag{5}$$

The concept SSP_{ci} is developed in river energy to calculate classes of particles sizes available on the bed. This is brought off according to ($SSP - SSP_{ci}$) for the d_{50} of each size class, present on the bed by apply the standard Krumbein phi scale multiplied by its decimal frequency of occurrence, Pi. Therefore, SSP_e for a grain size distribution of 'n' classes is indicated by Soar et al. [29] as shown in Eq. (6):

$$SSP_e = \sum_{i=1}^{n} pi\ (SSP - SSP_{ci}) \tag{6}$$

In light of research by Parker et al. [1], an equation for SSP_{ci} has been proposed, as follows:

$$SSP_{ci} = 0.1\ p\ [(Sp - 1)\ g\ d_{50})]^{3/2} \tag{7}$$

which it is based on sediment specific gravity Sp (~2.65) and medium grain size d_{50}.

In another case, the Annual Geomorphic Energy (AGE) can be estimated by integrating the relationship between discharge and excess SSP through the application of magnitude–frequency analysis to calculate the effective discharge. Before estimating the change in AGE within river reaches, first one should delineate the boundaries of each reach, as each reach has an AGE value that differs from others based on the average of the cross-sections located within it. The excess SSP is used to establish the stream energy value over a reach to implement morphological effort, once threshold particle entrainment has been exceeded. Subsequently, any additional SSP for each reach has a different d_{50} established in the flow frequency histogram and is then multiplied by the water surface width to yield the TSP for each class. These results are multiplied by their respective discharge decimal frequencies and finally summed, as expressed in Eq. (8), to produce TSP as indicated below:

$$SSP_e = \sum_{i=1}^{m} F_j W_j [\sum_{i=1}^{n} Pi(\omega i - \omega ci)] \quad (8)$$

where, Wj is the width for each discharge class j; Fj is the decimal frequency of occurrence of each discharge, and ωj is related SSP (W/m^2).

The parameter is in units of watts per unit length, which can be converted into the excess energy by multiplying by the number of seconds in a year. Results values are indicated in units of kilowatt-hours (Kwh) per unit length [29]. The change in AGE between successive reaches is obtained by Eq. (9):

$$\Delta AGE(\mathrm{r}) = AGE(\mathrm{r-1}) - AGE(\mathrm{r}) \quad (9)$$

The results may be positive or negative; a positive value indicates that the reach is in a depositional state and has less energy (energy deficit), while a negative value indicates that the reach is in an erosional state and has greater energy (energy surplus). The first reach does not achieve equilibrium, as it is not possible to compare AGE values with those of an upper reach. Furthermore, in identifying depositional and erosional processes, the results of AGE are compared with the Rapid Geomorphic Assessments (RGA) index, which includes indicators such as Channel Stability Indicators (CSI) and the Oklahoma Ozark Stream Bank Erosion Potential Index (OSEPI).

3. RESULTS AND DISCUSSION

3.1 Characteristic of studied reaches

In order to achieve research objectives with the hypothesis linking morphological forms within studied river and Stream Power, a well-established protocol of investigation was set up in river sections based on field data. Morphological properties and physical features for each reach channel are described in Table 1.

Usually, it is preferable to show the sediment percent diameter as the median sediment diameter d_{50} as the size for which 50% by weight. For precise details, the average size distribution for particles is described in Table 1. Based on the results, in the reaches 2, 3, 4, and 7, the d_{50} are small with average 0.258 mm to relate medium sand. Meanwhile, reach 8 has d_{50} less than others reaches with particles diameter 0.0237 mm for fine silt. In the reach 1 the greatest quantity of particles frequency was correlated fine gravel due to d_{50} of larger than 2 mm and reach 5, 6, 9 and 10 have an average d_{50} of 0.904 mm to represent of dominant coarse sand.

3.2 Calculating Total Stream Power and Specific Stream Power

There are practically useful parameters TSP and SSP for predicting alluvial channel adjustment at the catchment scale. The both of TSP and SSP engage as the energy required to prompt erosion processes, to transport sediment, and stimulate bank erosion or prompt lateral channel migration. In a case of a sediment supply deficit, this energy condition can trigger crevice of the river bed. Reaches with TSP or SSP or lower than these thresholds tend to be stable and have limited ability to activate those geomorphic processes. The analysis of SP is performed for both types of discharge to calculate TSP and SSP by using Bagnold's equations. TSP is a more acceptable index for transition of channel patterns and analysis of sediment budget. It is recognized that the probability of low sinuosity channel increases with TSP and laterally unstable with fully braided channels [21]. Whereas SSP is connected TSP as in Eq. (2), but it used to describe the entrainment and unit bed load flux, the SSP is an indicator of a 'stability' profiles.

Box plots in Figures 4 and 5 report TSP and SSP for each river reach. The plots at bankfull discharge present considerable variation in SP. The data show whiskers from each end of the box. The values of SP display significant variation due to inconsistency in morphological conditions, channel alignment, grain size distribution, and characteristics of river sections. These factors vary along the river reach, producing fluctuations in the behavior of Stream Power. The profiles illustrate that SP is not a smooth function, with decreases in slope values and grain sizes potentially leading to local deposition and erosion.

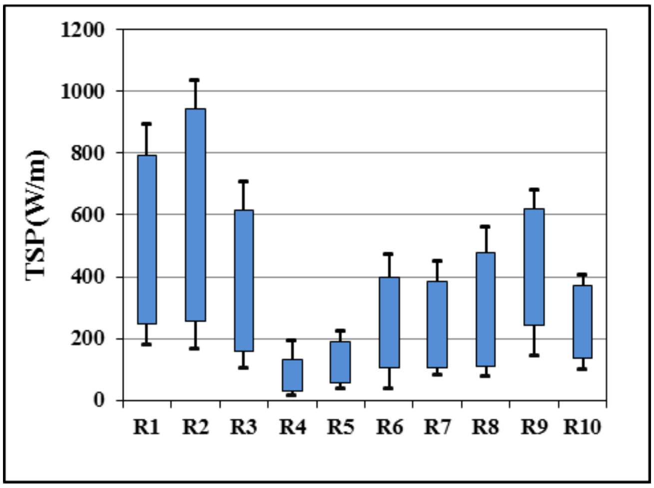

Figure 4. Total Stream Power distributions along the study stem of the river

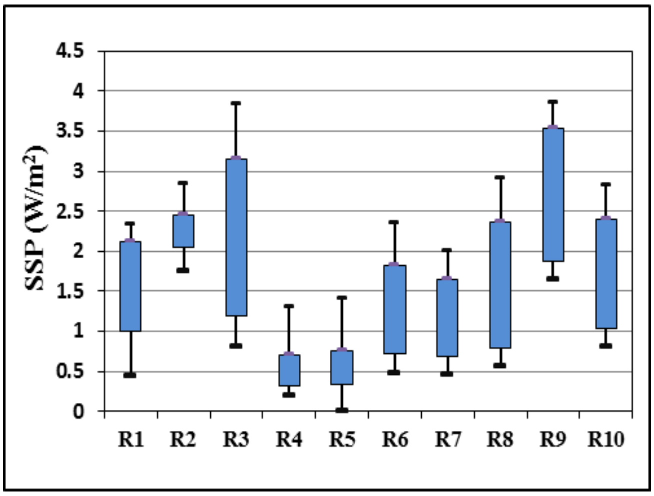

Figure 5. Specific Stream Power distributions along the study stem of the river

From the graph in Figure 4, a rise to values of 944.419 W/m and 614.403 W/m for dominant and bankfull discharge, respectively, is observed in reaches 2 and 3. In reaches 4 and 5, they declined to 131.768 W/m and 187.751 W/m, respectively. Then, it gradually increased to about 241.069 W/m and 618.831 W/m in reach 9. This indicates that TSP drives geomorphic processes shaping the channel. The case study describes unconfined channels as low energy, characterized by the presence of smaller sand particles in the river bed compared to higher energy reaches. The differences in SP in each reach depend on the conditions in the longitudinal profile. Consequently, the difference in slope has different meanings when comparing reaches with varying discharges. However, for the same change in channel slope, the change in discharge will be disproportionately larger, affecting the behavior between slopes, as calculated by Eq. (3).

Regarding special variation of the Stream Power, Figure 5 refers that SSP of studied reaches having a value lower than 10 W/m^2, with general variation in channel width and channel discharge. Two higher Stream Power classes mainly are dominated in reaches 3 and 9 as represented in Figure 5.

In reach 3, the SSP is superior between 1.198 W/m^2 to 3.150 W/m^2 and reach 9 between 1.858 W/m^2 to 3.536 W/m^2 respectively. Streams are classified with high bankfull discharge, gently sloped and widths with dominant bed material of coarse sand. while experienced a lowest value of SSP in reach 4 as ranged from 0.318 to 0.7 W/m^2 and reach 5 ranged from 0.328 W/m^2 to 0.758 W/m^2 for dominant and bankfull discharge respectively. The remaining reaches is majority laying within the range between 1.287 W/m^2 to 2.446 W/m^2.

In general, the graphs shows that SSP and TSP, the stable state does not take place for SSP lower than 10 W/m^2. The SSP values is provided a transition zone between unstable and deposition or erosion. The results tend lead to probability of some hypotheses: (i) a decrease in both SSP and TSP leads to deposition dominance; and ii) local SSP and TSP drives local processes of more erosion. The classes of unstable have extensive deposition state [24].

Our research highlights contrasts in SP between two discharges and looked to account events based upon timescales of years of the recurrence of the bankfull discharge and has not considered flooding conditions as that may increase velocities and discharge

Nanson and Huang [37] described some systems of rivers as being overpowered where water has excess energy that lessens the stream gradient as meanders develop. They are described the converse position where a river has inadequate energy. The case of underpowered is marked by a river having inadequate energy to move its materials and this can lead to aggradation and procreation.

The patterns are shown in Figure 4 indicate that TSP carries out geomorphic work, generates channel geometry, and estimates sediment budgets for reaches. The rate of energy disbursement explains the behavior of a meandering, unbraided channel, which may take one of three forms: bends, straight, or meandering. Since a straight channel has the shortest length, the Specific Power (SP) for a straight channel is the highest among the possible forms, such as reach 9. The law of least time regarding the rate of energy disbursement can be applied to channels to clarify the variations in channel features caused by changes in sediment concentration, water discharge, channel geometry, channel slope, geological constraints, and slope.

3.3 The annual geomorphic energy

In addition, this research is identified Annual Geomorphic Energy AGE as a more useful indicator affecting the deposition and erosion of sediments and evaluated the potential sediment supply as proper parameter for reach distance sediment budget. The annual geomorphic energy AGE is estimated for dominant and bankfull discharge in kilowatt hours per length. The values of energy are indication to examine the variation of TSP compared to the subsequent reach in state of depositional or erosional and this case can be notices from the AGE of each reach. According to the previous information, the “Critical Specific Power” and “excess amount” of Stream Power was estimated for each reach for different d_{50} particle size in different dominant discharge and bankfull discharge.

Spatial Critical Stream Power is required to account movement of particle, was calculated using Eq. (7). The variability between the Critical Stream Power and d_{50} is applied to address deposition, and erosion phenomenon. The concentration of existing sediment in the river in combination with the sediment transport capacity did not examine in this assumption.

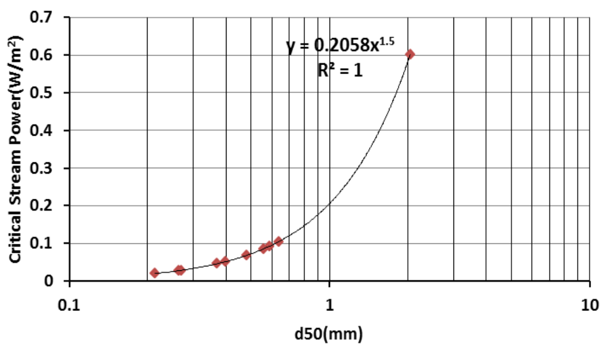

Figure 6. The variation of Critical Stream Power with medium particles size d_{50}

The lower /higher of Stream Power than critical threshold only desired sediment transport capacity. The distribution of critical Stream Power is illustrated in Figure 6. The variation in Annual Geomorphic Energy (AGE) values for each reach of the studied stem of River is displayed in Table 2. The fluctuation in the bed slope is one of the significant factors contributing to the energy variation. It is observed in interesting details that geomorphic energy peaks are generally linked to slope, pattern, and morphometry of the reach. The AGE in the reach 2 is 892.876 Kwh and 3328.372 Kwh per length for dominant and bankfull discharge respectively. Therefore, reach 2 has a maximum AGE compared to other reaches because the change from straight to bending pattern the channel width 186 m increased discharge 1384.617 m^3/s, and slope of the riverbed 6.96 E-05. The minimum AGE is presented in reach 4 with about 93.454 Kwh and 460.674 Kwh respectively. This reach has less geomorphic energy than other because channel pattern has changed from bend to the braided and the width, flow velocity and the slope than other reaches. Also, the riparian vegetation is dense which has minimized the flow velocity.

A channel bend is recognized during the field survey, and visual signs of erosion and sedimentation were found. There are deposits of sediment in point bars in the inner bends, indicating that there are active morphological processes.

Table 2. Annual Geomorphic Energy (AGE) along the main stem of the river

Reach No.	Discharge Class(Dominant)						Discharge Class (Bankfull)					
	Q (m^3/s)	Width (m)	TSS (W/m)	SSP (W/m^2)	SSPe (W/m^2)	AGE Kwh	Q (m^3/s)	Width (m)	TSS (W/m)	SSP (W/m^2)	SSPe (W/m^2)	AGE Kwh
R1	407.960	248.715	246.677	0.992	0.887	794.350	1310.632	373.073	792.487	2.124	2.020	2712.422
R2	372.984	124.000	254.405	2.052	2.000	892.876	1384.617	386.000	944.420	2.447	2.395	3328.372
R3	270.000	130.000	155.849	1.199	1.199	561.058	1064.418	195.000	614.403	3.151	3.151	2211.852
R4	207.980	87.000	27.720	0.319	0.298	93.454	988.660	188.000	131.769	0.701	0.681	460.674
R5	309.000	165.000	54.205	0.329	0.329	195.137	1070.296	247.500	187.751	0.759	0.759	675.905
R6	297.765	144.873	103.301	0.713	0.684	356.823	1144.452	217.310	397.033	1.827	1.798	1406.731
R7	342.275	155.403	106.331	0.684	0.592	331.141	1237.736	233.105	384.515	1.650	1.557	1306.778
R8	279.705	134.523	107.451	0.799	0.713	345.392	1238.181	201.785	475.659	2.357	2.272	1650.224
R9	352.926	129.447	241.069	1.868	1.800	836.065	905.9701	175.940	618.832	3.536	3.467	2184.676
R10	299.665	132.765	137.144	1.038	1.038	493.720	810.550	155.456	370.956	2.393	2.393	1335.443

Table 3. Annual Geomorphic Energy balance in Euphrates River

Reach No.	ΔAGE of Dominant Discharge			ΔAGE of Bankfull Discharge		
	AGE (R)	AGE (R-1)	ΔAGE (R)	AGE (R)	AGE (R-1)	ΔAGE (R)
R1	794.350	--	--	2712.422	---	--
R2	892.876	794.350	-98.526	3328.372	2712.422	-615.950
R3	561.057	892.876	331.818	2211.852	3328.372	1116.519
R4	93.453	561.057	467.604	460.674	2211.852	1751.178
R5	195.137	93.453	-101.683	675.905	460.674	-215.231
R6	356.823	195.137	-161.686	1406.731	675.905	-730.826
R7	331.141	356.823	25.681	1306.778	1406.731	99.952
R8	345.392	331.141	-14.250	1650.224	1306.778	-343.446
R9	836.065	345.392	-490.674	2184.676	1650.224	-534.452
R10	493.720	836.065	342.344	1335.443	2184.676	849.233

3.4 AGE balance

The changes in Annual Geomorphic Energy (ΔAGE) along the studied sections of the Euphrates River channel are presented in Table 3 and Figure 7.

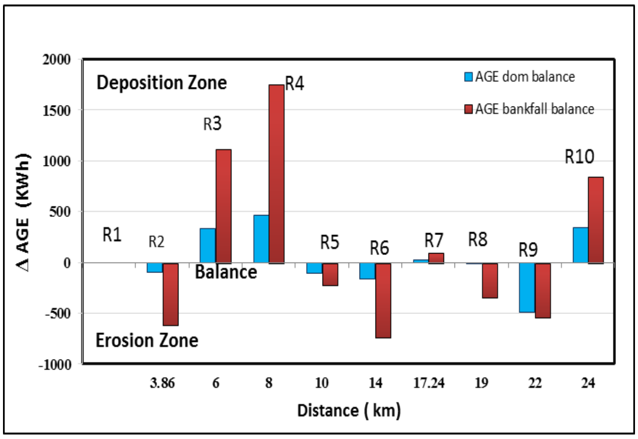

Figure 7. The AGE balances along studied reaches of Euphrates River

The energy balance for each reach is compared with previous reach, and from the second reach onwards, it is necessary to estimate the differences between successive reaches, as these differences determine whether a reach is subject to erosion or deposition conditions. It is interesting to note that the first reach will not have a balance because it cannot be compared with the AGE values of an upstream reach. A negative value of AGE indicates that the reach has higher energy compared to the previous reach (erosional reach). Conversely, a positive value of AGE indicates that the reach has lower energy than the upstream reach (depositional reach); therefore, based on the differentials in values, erosional and depositional reaches are established. According to available findings, ΔAGE in reach 2 has more than its previous reach due to its action speed and as in a state of erosion. The morphometric features of the river in reach 2 caused an increase in ΔAGE and as indicated values the energy balance is also negative -98.526 Kwh and -615.950 Kwh for dominant and bankfull discharge, respectively. So, sedimentation have reduced, and the size of bed sediments has increased, and an erosional state has dominated. In this section, the residence of ticked marl and calcareous sandstone on the right bank have caused confined area, because a slope of channel is mild the river form is transition to the next braided reach. The conditions present above have get larger and the geomorphic energy of this section be as erosion stage. The ΔAGE in reach 3 has maximal value than its subsequent reach, the geometry of reach is braided and display flattening of bed slope toward sediment trap. A positive value of reach 3 present that this section in a depositional state and accumulate sediment on the bed. The ΔAGE to reach 3 are 331.818 Kwh and 1116.519 Kwh for dominant and bankfull discharge, respectively as indicated in Table 3 and Figure 7. Its lower than previous reach because of the decrease in slope, increase in a width. In this reach, the type of bed materials is coarser –grains and bars are formed inside bends as results of low level of flow and low shear stress.

In reach 4, the term of morphological conditions, is more than reach 3 and the depositional state continues in maximal value, with the difference that the energy in this reach is less than the previous reach. The ΔAGE balance of reach 4 is 467.604 Kwh and 1751.178 Kwh increased compared to former distance which in turn produced maximum deposition of the channel. Additionally, the presence of riparian vegetation is greater than in other reaches, which has slowed the velocity of the flow, changed the channel pattern, and decreased the slope, thereby altering the flow.

Vegetal growth in some of regions preserving banks and its roots supply more strengthens of bottom soil. Besides, it has reason of reducing the speed of water flow that in turn decrease influence of wind and water erosion as well. The most common plants that are spread in the regions are aquatic plants and marshlands plants.

Also, the erosional situation in reaches 5 and 6, the erosion is focused downstream deposition reaches. Interesting geological characteristics is presented of ΔAGE peak in the reaches 5 and 6 which have steeper slope than neighboring reaches with small prospective for either progressive erosion or deposition. ΔAGE balance for dominant discharge to the reaches 5 and 6 are -101.683 Kwh, -161.686 Kwh, and for bankfull discharge -215.231 Kwh, -730.826 Kwh, respectively. In these channels, as a result of sequence sedimentation activities could led to develop formation of bends as procedure of remediating river balance. This is also reflected capability of water to hold load with increase current power and the level of surface slope. As well as to the lateral motion of water, it has described by the creeping of the river intersections towards the outlet as results of deposition in the convex sides. and erosion of the concave sides. In another case, local activities such as sand quarries in reach 5 have impacted the river stream with distortions and pits, which in turn have significantly influenced the geometry of the channel, as indicated in Table 3 and Figure 7.

In reach 6, the strength of ΔAGE changes due to erosion at a certain degree of Stream Power (SP). When the flow is less than the average Stream Power, it results in the erosion of the concave bank. However, as the water level rises, the stream cuts through the bar and redirects its energy against the concave bank at the apex bend. This process causes the bends to shift position, leading to areas of significant erosion, often found downstream, due to excessive water energy. Additionally, failures in the banks are observed due to the prevalence of loose materials on both sides. It has been noted that erosion occurs as a result of weak energy, which tends to decrease the slope. A common feature observed in riverbanks is "Local Instability", which is part of the bending process.

While the distance of reach 7 was assumed the minimal ΔAGE by 25.681 Kwh and 99.952 Kwh in the case study area because of presence of agriculture's areas in two sides of river and classifies the stream as "Lateral Immobile" to be semi stable channel. The reach is underpowered as it cannot transport sediment or erode materials for much of its distance. The reach is influenced by river storage and the impact of its low power. The deposition is happened on the bed of river, and slowly replacing to the erosion form while cross section is filling up and the width is increased. The sudden separation of land from one property and its attachment to another, especially by flooding capacity or a change in the course of a river.

Furthermore, it is observed that the ΔAGE in reaches 8 and 9 has worsened significantly due to agricultural activities and bank failures. The changes in AGE for dominant discharge in reaches 8 and 9 are -14.250 Kwh and -490.674 Kwh, respectively. For the bankfull discharge, the values are -343.446 Kwh and -534.452 Kwh, as indicated in Table 3 and Figure 7. Reach 8 is a peaty channel with high organic materials. The Erosion in a reach has a peaty and clayey deposits were considerably less than in sand deposits. This is indicated that the reach which cover with sandy materials is less resistance to erosion than the reach cover with organic materials. Consequently, a significant factor in managing lateral migration in the case of the Euphrates River is observed. The nature of heterogeneous erosion indicates that lateral activity is influenced by local conditions, which scour the banks and widen the cross-section. This process occurs intensely where the materials originate from floodplains, as waterways tend to curve the river course due to the water's energy focusing more on maintaining the motion of materials than on transportation. This observation aligns with findings from various researchers who have explained that the composition and texture of the riverbanks, as well as the organic matter content, are influential factors on energy and erosion rates [1, 35, 36]. In this reach, the river tends to be more laterally active in sandy deposits, particularly where the stream adheres to sandy banks or aeolian dunes fixed in the peat fill [29].

The influences of the water vortexes at Towirij Bridge and the effect of the Karbala Water Project intake RWI in reach 9 are significant due to the spiral movement of the water stream, which acts as a collecting mechanism. This phenomenon occurs when the rapidly moving main water current collides with the concave area, causing the water current to move downward and slowly interact with the sediments that have accumulated.

In reach 10, there is a variation in morphometric, decreasing in a slope can vary the channel situation. The placement as straight channel has decreased the geomorphic energy compared to the previous reaches present of flood plains into sides of river. Reach 10 is located at the end of studied section with a length of 2 km from previous reach. The result is showed that the ΔAGE in reach 10 with about 342.345 Kwh for dominant discharge and 849.233 Kwh bankfull discharge. A slowness in slope of the stream is main reason has caused attributed.

Sedimentation builds up, reducing the river's ability to transport its load directly to the downstream end. Additionally, natural plants growing along the bottom and sides of the river act as natural obstacles to sediment movement. Their roots and stems function as filters, trapping particles and increasing sediment accumulation over time.

It is also important to highlight the impact of human activities and land use, which exacerbate these conditions. The large-scale disposal of sewage and industrial waste into the river poses significant problems, contributing to sedimentation and erosion damage. Local land use practices, such as land cultivation, bank sliding, and construction activities, can lead to increased river deposition. Alternatively, these effects may also result from natural processes related to the watershed's characteristics.

The comparison of AGE results with the rapid geomorphic REAS and CSI index shows that the instability of banks in the Euphrates River is significantly impacted by bank erosion, bed material, and vegetation, as indicated in Table 4. So, the scores for the RGAS are classified the stability of the banks. CSI indices are indicated that all reaches are moderately unstable with larger relation to lateral retreat consisted bank instability and the intense of riparian woody vegetative cover While the results of OSEPI indicate that stream bank instability, characterized by long-term bank retreat, may be better represented by metrics reflecting the frequency of bank failures rather than by metrics that capture instability at a single point in time.

Additionally, the results of the OSEPI indicate that the effective factors in estimating the stability of the left bank are the vegetation of the bank and the bend of the river. Furthermore, it has the ability to reduce the speed of water flow, which consequently minimizes the impact of water and wind erosion. Evaluation indices show that the results of the OSEPI are consistent with the depositional or erosional status according to the AGE, indicating that aggregation reaches have reached a semi-stable state, while erosional reaches remain unstable. The practical value of this study provides an index for comparing river reaches; however, this method cannot replace geomorphic field studies [29]. The studied river section lacks sufficient power to transport sediment or erode the maximum amount for much of its length. The course is a stagnant zone with insufficient flow, leading to significant accumulation. This zone is characterized by in-channel storage due to its low power.

Table 4. Comparison of results of AGE with Channel Stability Index (CSI) and Ozark Stream Bank Erosion Potential Index (OSEPI) at studied reaches of Euphrates River field evidence

Reach No.	AGE	CSI Index[a]		OSEPI Index[b]		Geomorphic Evidence
		Score	Category	Score	Category	
R1			Moderately Unstable		Unstable	Large size of bed sediment, bank instability
R2	Erosion	21	Highly Unstable	54.5	Unstable	Calcareous sandstone and marl on the right bank transition to the next braided reach
R3	Deposition	19.5	Moderately Unstable	49.5	Unstable	Coarse grains points bars are formed inside bends (braided)
R4	Deposition	23.0	Highly Unstable	69.0	Highly Unstable	Maximum deposition,woody plants
R5	Erosion	13.5	Moderately Unstable	48.5	Unstable	Local activities, pasture vegetation
R6	Erosion	15.5	Moderately Unstable	64.5	Moderately Unstable	Bank failure, loose soil
R7	Deposition	12.0	Moderately Unstable	33.5	Moderately Stable	Limited deposition, confined zone
R8	Erosion	14.0	Moderately Unstable	62.0	Moderately Unstable	Loose textures nd Bank failure, lack of vegetation
R9	Erosion	16.5	Moderately Unstable	58.0	Moderately Unstable	Extended erosion feature, armoring bed, wide channel
R10	Deposition	18.5	Moderately Unstable	66.0	Highly Unstable	Local land use processes, tree and shrub vegetation growth

Note: *[a] 0-10 = Stable, 10-20 = Moderately Unstable, And >20 = Highly Unstable.
*[b] 0-25 = Highly Stable, 26-35 = Moderately Stable, 36-45 = Stable, 46-55 = Unstable, 56-65 = Moderately Unstable, And 66-85 = Highly Unstable.

In general, this work is provided a conceptual platform for development and testing, beside made perceptive contribution to the drive towards integrating fluvial geomorphology with river management. Characterizing morphometric features in terms of energy budgeting is an innovative technique, which principally focuses on fluvial drivers. This application in Euphrates River suggests that the methodology should be treated as a complementary mode of analysis to be performed alongside field-based methods of geomorphological responses.

4. CONCLUSIONS

This research sought to examine of using Stream Power as indicator to characterize the differences in morphological features at ten reaches along Euphrates River for bankfull and dominant discharges and the results are indicated as:

1. The studied stream is regarded as a low-energy case and classified as a river having insufficient energy to transport its materials, and phenomenon of deposition is leading to aggradation and procreation. While the sinuosity does not denote that the studied sections is more actively.
2. Bare vertical cut-banks and fresh point bars in the channel is given active signs of erosion. Moreover, it shows the situation of active erosion correspond to significant higher lateral migration rates than locations where no or little active erosion. This denote that in spite of the river is characterized as a low-energy stream, but does not denote to a non-dynamic stream.
3. The comparison of the results of AGE for all reaches are presented that the most principal factors influencing the alteration of energy balance and variable in the depositional or erosional process are the channel morphometry (e.g, depth, width of reach, the slope, and pattern of channel) which has an impact on the hydrological conditions, such as, Stream Power, shear stress, and velocity of flow.
4. The direct and indirect human action and hydrological condition has an effect on sedimentation rates and the lateral migration in some reaches of Euphrates River is caused by local factors and soil textures. The composition of heterogenic deposits in each reach is more dominant in the river with other factors such as specific water energy, slope, and bed load grain size.
5. AGE is compared with rapid geomorphic assessment indices, and the results indicate that OSEP is more consistent with the depositional or erosional status. The practical value and interpretation of the results suggest that the energy of the river plays a key role in morphometric activities by providing an index for each reach. AGE is an innovative system that focuses on drivers applicable to the management of the river channel and the conditions of sediment processes in terms of energy balance.

6. The river can be classed as underpowered which means that deposition would be possible. For sediment there will be long sections which act to modify formation particulates (e.g., organic matter, POM) into autochthonous POM.

Overall, this research display how determination of Stream Power values can prepare useful reference on river dynamics processes. It can possible to highlight how the process of erosion, solid transport and deposition circumstance occurring along fluvial reaches, and the geomorphological problems that connection precisely to sudden alteration of the "power" available. It is clear that the analysis in large-scale within a river system could provide preventive and forecasting way, the zones of most "sensitive" to alteration as they are subjected as instability occurrence caused by the fluvial dynamics.

It can be mentioned to some limitations like sediment transport controllers are not used in Stream Power estimations. This research has supposed that bed load transport is not the mechanism which is directing the river morphology of the major part of the river course. In addition, the channel banks are highly sensitive to variation, and the present study is not particularly considered the sensitivity between the bank and riverbed.

These results have characterized Euphrates River in a small-scale. Therefore, additional studies are needed to focus on application these methods in large -scale taking in account sediment transport. This will potentially paradigm-shifting in wide geomorphological evaluation.

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