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A Comprehensive Assessment of Sediment Transport in Greater-Zab River, Iraq

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Abstract. The requirement for efficient management of natural resources has recently risen. Consequently, the requirements for a hydrological analysis study is a crucial instrument for managing watershed natural resources-means the region of interest must be thoroughly investigated and evaluated. This study employs morphometric analysis to examine the Greater-Zab watershed in the northeastern part of Iraq. The Greater-Zab River serves as the case study because no sediment observations have been made there at all. Prior investigations have been conducted to gather data on the soil composition and anticipated hydraulic parameters at Km. 73.000 of the Basin, specifically upstream of Ninawa Governorate. These investigations were carried out in relation to the design discharge of 330 m^3/s. The main goal of this research is to employ various widely-used methodologies globally to assess an alluvial channel's capacity to carry the entire bed-material load, using the Greater-Zab River Basin as a case study. There were five different formulas that were utilised in order to get an estimate of the bed's material load. Larsen's Observational Methodology [LOM], Karim and Kennedy's Regression Method [KKRM], Engelund and Hansen's Stream Power Technique [EHSPT], Akers and White Stream Power Technique [AWSPT], and Yang Stream Power Technique with Dimensionless [YSPTD] are the names of these studies. Taking into account Yang's 1973 ruling, the study found that 1)The anticipated bed-material load at the site under consideration is roughly (205000 m^3/Year); 2) Variations in the outcomes of various formulas used to anticipate the amount of sediment in rivers by a certain factor are expected; and 3) It is crucial to measure the amount of sediment load in significant areas, such as those that support property and life in a major metropolis (as in the case study).

Keywords: Sediment transport movement, Greater-Zab River Basin, Bed material load, Sediment Investigation, River basin management.

1. INTRODUCTION

Human beings have been confronted with the challenge of sediment transport since ancient times. As an illustration at the local level, the ancient channel of the Tigris River has been transformed into the present course of the Greater Zab River Basin (GZRB) in the district of Ancient Ninawa City as a result of centuries of continuous scouring and sedimentation. The Upper Zab River region, which flows from the Turkish regions to the Iraqi border, is the most important resource that enters the State of Iraq and contributes to several aspects, including economic, environmentaland social aspects of the neighboring regions. Therefore, the transport of sediment within this river can beimportant, especially to determine its hydrological patterns, which affects the quality of water, the health of theecosystem used and the stability of infrastructure along its banks [2]. Engineers must be comprehensivelyaware of these dynamics because it is of paramount importance for the successful management of waterresources, as well as environmental conservation, and sustainable development project management in theregion [14]. A comprehensive assessment is the investigation of the complex ways in which the components of thesediments that affect the sediment transport of the Great Zab River overlap with each other. A thorough understanding of sediment dynamics in this research is essential within the waterway through the analysis ofgeomorphological and hydrological impacts as well as anthropogenic impacts.

The importance of the Greater Zab River cannot be emphasized, particularly in terms of Iraq's water availability and Turkey's water management measures [17]. With rising demands from urbanization, agriculture, and climate change, making informed decisions about sediment transport patterns becomes increasingly important.The enduring aspiration of humanity in this regard has been and continues to be the desire forwaterways that do not accumulate sediment or erode [26]. In the former Punjab region of India and Pakistan,R. G. Kennedy is generally recognized for their groundbreaking work in this field, which is also known as theregime approach [Kennedy: 1895; Quoted from [8].

The first documented and influential theoretical analysis of the erosion of the channel is attributed to Du Buat in 1786, as cited in reference [4]. Numerous individuals pursue that work, but their names are too multiple to list. Nevertheless, the methods for analyzing sediment transport are typically categorized as follows, according to reference [29]: (1) The method of governance. (2) The method of regression. (3) The strategy is based on probability. (4) The approach that is deterministic, and (5) One technique for assessing a stream's power is the stream power approach.

This assessment uses a multidisciplinary approach that includes hydrological modeling, field measurements, and socioeconomic analysis to clarify the complex dynamics that drive sediment transport processes in the Greater-Zab River [11]. Its goal is to contribute to the development of sustainable management methods and policies aimed at preserving the integrity of this critical river system by synthesizing current knowledge and producing new insights.

2. THE CASE STUDY

The majority of the Greater Zab River Basin is located in southeast Turkey, close to the political boundaries between Turkey and Iran, and in northeastern Iraq, between latitudes 38° 20′ N and 36° 00′ N and longitudes 41° 20′ E and 43° 20′ E [30]. The drainage area of the Greater Zab River at Eski Kelek is approximately 19325.170 km^2 [5]. A significant portion of the catchment region is situated in Iraq, which accounts for around sixty percent of the total area [20]. The remaining portion of the Basin is located in Turkey, as illustrated in Figure 1 [18]. The ground levels vary between 90 m and 3792 m above sea level [9]. Approximately two-thirds of the region is divided between forests comprising a blend of deciduous trees and agricultural zones [3]. The remainder consists of aquatic, urban, and barren regions. The Greater-Zab River gathers water from numerous tributaries. The river and its tributaries are predominantly nourished by precipitation and the melting of snow, leading to significant variations in discharge throughout the year [16]. The discharge rate at its head regulator is currently (250 m^3/s) according to the design. On the other hand, the growth plan that has been approved for Greater-Zab calls for increasing the design discharge to 330 m^3/s [19]:

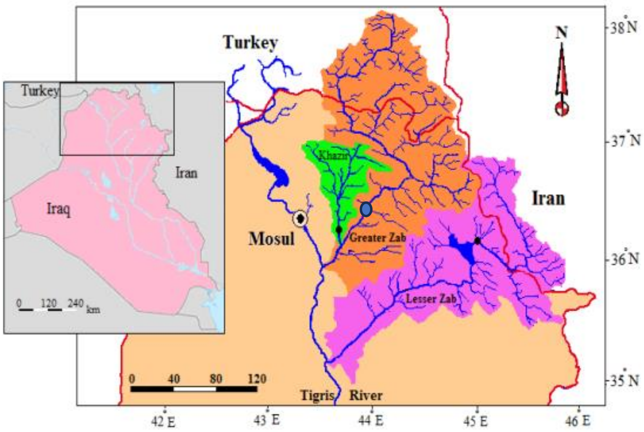

Figure 1: Watershed of Greater-Zab River at Eske Kelek [18].

The Greater Zab River runs through Ninawa City for a distance of 25 to 82 km. A rating curve exists for a stage gauge placed at km. 73.000 [6]. Four branch canals divert water from GZRB, located upstream to Ninawa Governorate that a combined discharge of design is 30.150 m^3/s. The anticipated design discharge of the Greater Zab River is Q = 299.850 m^3/s [22].

Based on the reference [16], GZRB at a Kilometer of 73 might have Z = 0; B = 45 m; n = 0.035; S = 9 cm/km. Based on the reference [21], the material for the bed for (GZRB) has d_{50} = 0.11 mm; d_{35} = 0.04 mm; d_{65} = 0.32 mm; S_S = 2.82.

Where n: manning coefficient; S: longitudinal slope; B: the width of the channel section; Z: side slope; d_{50}: particle size corresponding to the cumulative frequency of 50%; d_{65}: particle size corresponding to the cumulative frequency of 65%; d_{35}: particle size corresponding to the cumulative frequency of 35% and Ss: refer to small solid particles that remain in suspension in water.

3. METHODOLOGY

There are too many methods and models that can be used to guess how much sediment open channels can hold. The following approaches have been picked, taking into account only those who care about the total bed-material load:

A. Larsen's Observational Methodology [LOM]
B. Karim and Kennedy's Regression Method [KKRM]
C. Engelund and Hansen's Stream Power Technique [EHSPT]
D. Akers and White Stream Power Technique [AWSPT]

E. Yang Stream Power Technique with Dimensionless [YSPTD]

3.1 Field Investigation

The canal cross-section was examined in relation to the direction of water flow. The entire width of the channel was divided into many segments. The depth of each segment was then measured. The cross-section was sketched from the depths of the channel, and these sections were then estimated to have a trapezoidal form. The fieldwork was conducted on 1 section. The given data is as follows.
(Q_x = 299.850 m^3/s); (B_x = 45.000 m); (Z_x = 0); (S_x = 0.00009); (n_x = 0.0350); (d_{50} = 0.11 mm); (d_{35} = 0.04 mm); (d_{65} = 0.32 mm); (S_S = 2.82); (**g** = 9.81) m /s^2; (**ρ** = 1000 kg / m^3); (**v** = 0.000001 m^2/s).

3.2 Foundational computations

The preliminary calculations section of this paper is the main pillar on which the following analysis of the dynamics of sediment transport in the Upper Zab River region follows. It is through this initial step that the process of carrying out basic tasks begins, including data collection, factor estimation, and building a mathematical model. From all this we get the hydraulic and sedimentary properties of the area.
This section involves systematic research that begins with the collection and integration of diverse data sets from historical archives, field surveys, and remote sensing techniques. Using accurate data processing and verification methods, we aim to exploit the wealth of information to improve our understanding of the river's complex hydrological distributions.
Emphasis is placed on estimating basic hydraulic parameters, such as flow velocity, channel slope, and cross-section geometry. The goal of using experimental relationships and hydraulic modeling techniques is to develop a hydraulic system that controls sediment transfers within the river channel.The calculation is as follows:

1. Using a trial and error procedure for the equation of Manning with knowing Q_T, Z_x, S_x, n_x, and B_x to calculate: D_x = 7.331 m.
2. $U_i = \left({Q_T}/{A_x}\right)$ = 0.909 m/s.
3. $Re_x = \left({U_i D_x}/{\nu_i}\right)$ = 6 663 333 ; $Fr_x = \left({U_i}/{(gD_x)^{0.5}}\right)$= 0.11
4. $R_x = \left[{A_x}/{P_x}\right]$ = 5.431 m; $\tau_0 = (\gamma_i R_x S_x)$ = 4.795 p a; $U^*{}_i = ({\tau_0}/{\rho_i})^{0.5}$ = 0.0692 m / s.
5. With Rubbey [1965]: {Quoted from [24]}: ω_x = 0.0089 m / s.

3.2.1 The empirical approach of Laursen [LOM]

The empirical methodology of Larsen is predicated on observed data and correlations between hydraulic parameters and sediment transport. Statistical analyses and field measurements are frequently combined in this approach to generate empirical equations that forecast sediment transport rates. Using empirical relations [13], derived the set of calculations provided below to calculate the load of bed material:

i. $$\tau'_{0i} = \left[\left({\rho * U^2}/{58}\right) * \left({d}/{D_x}\right)^{\frac{1}{3}}\right] \quad \ldots (1)$$

ii. $$Re^*{}_x = \left[{(U.d)}/{\nu_i}\right] \quad \ldots (2)$$

Then, using the Shields diagram to estimate (F_S) corresponds to the (Re^*) [24], then:

$$\tau_{0cr} = [F_s * (S_S - 1) * \gamma_i * d] \quad \ldots (3)$$

iii. $F_x = [U^*/\omega_x]$; using the graph of Laursen, as shown in Figure 2, for finding the corresponding of the value ***f (F).***

iv. $$C_m = \left[({d}/{D_x})^{7/6}\right] * \left[\left({\tau^*_{0i}}/{\tau_{0cr}}\right) - 1\right] * f(F) \quad \ldots (4)$$

v. $$QYTS = \left[\left({C_m}/{100}\right) * \left({Q}/{S_S}\right) * 86400 * 365\right] \quad \ldots (5)$$

In the case study, τ'_{0i} is equal to 0.315 Pa, $Re^*{}_x$ is 6.55, and the F_s Calculated using the mathematical relationships proposed in reference [3] to depict the shields' diagram is 0.0347. Consequently, τ_{0cr} is equal to 0.061 Pa; ***f (F)*** = 441, ***F*** = 7.6, C_m = 0.0043105 % by weighting. Then: *QYTS* = 145 667 m^3/Year.

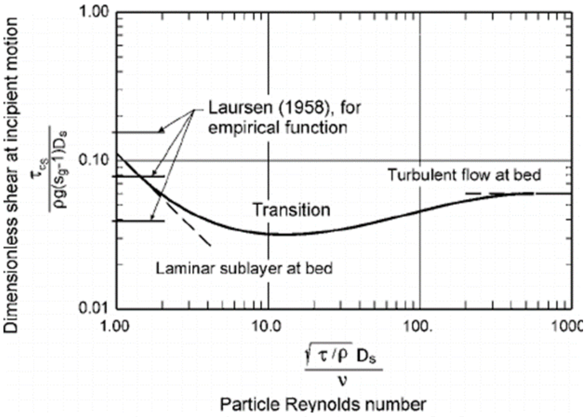

Figure 2: The Graph of Laursen [10]

3.2.2 The regression approach of Karim and Kennedy [KKRM]

The regression strategy devised by Karim and Kennedy likely employs statistical analysis techniques to find correlations between sediment transport and other hydraulic and geomorphological characteristics. Regression models are created using collected data in order to forecast sediment movement rates. By employing nonlinear, multiple regression analysis on a combined dataset of 340 river data sets and 618 flume data sets, the researchers [12] obtained the following results:

$$\log(qTS/(1.65 * g * d^3)^{0.5}) = (-2.279) + \log(U_i/(1.65 * g * d)^{0.5}) + 1.06 * \log(U_i/(1.65 * g * d)^{0.5}) * \log\left[\frac{U^* - U^*_{cr}}{(1.65gd)^{0.5}}\right] + 0.299 * \log(D_x/d) * \log\left[\frac{U^* - U^*_{cr}}{(1.65gd)^{0.5}}\right] \quad \ldots (6)$$

With : $U^*_{cr} = [\tau_{0cr} / \rho]^{0.5}$ … (7)

For (GZRB): τ_{0cr} [According to section (A)] = 0.061 pa; which U^*_{cr}= 0.0089 m/s ; then from Eq.(6): qTS = 5.127432 *10^{-4} m^3 / s.m. then:

$QYTS = qTS * B_x * 86400 * 365$ = 727 644 m^3 / Year …(8)

3.2.3 Stream power approach of Engelund and Hansen [EHSPT]

The stream power concept developed by Engelund and Hansen focuses on the influence of the kinetic energy of flowing water in promoting the movement of silt. This methodology considers the amount of energy present in the stream to facilitate the movement of sediment and is frequently based on theoretical equations derived from hydraulic principles. Using the similarity principle and Bangold's stream power notion, Engelund and Hansen [1967; 1972] [27] produced a series of relationships functionality that may have combined formula of a single as follows:

$qTS = (0.05) * [U_i^2 \quad * (\tau_0 / \gamma)^{1.5}] / [(S_S - 1)^2 * (d\sqrt{g})]$ … (9)

To a GZRB: qTS = 3 660 850 × 10^{-4} m^3/s.m.

Applying Eq. (8): $QYTS$ = 540 634 m^3 / Year.

3.2.4 Stream power approach of Akers and White [AWSPT]

Akers and White, like Engelund and Hansen, employ the notion of stream power to assess the capacity for sediment movement [7]. Their approach probably entails making alterations or expansions to the original stream power notion in order to enhance its applicability or precision. Using dimensional modeling, Ackers and White [1973] were able to describe the rate of transport of sediment by means of devoid of dimensions components as follows [1]:

1. $d_g = d * [(S_S - 1) * g / \nu^2{}_i]^{1/3}$ … (10)
2. $F_g = U_i^{*n} (U_i/\sqrt{32} * \log(\alpha * D_x/d_x))^{1-n} / ((S_S - 1) * g * d)^{0.5}$ … (11)

   Taking α = 10 [1] .
3. $G_g = C * ((F_g / A) - 1)^m$ … (12)
4. $X_T = G_g * S_S * d_x / (D_x * (U_* / U_i)^n)$ … (13)
5. $QYTS = [(X_T/S_S) * Q_x * 86400 * 365]$ … (14)

For particle diameters more than 0.04 mm and Froude numbers less than 0.8, as well as for particle diameters between 1 and 60 mm, which is known as the transition zone, specific correlations for each value of the corresponding sub-parameters *(m)*, *(A)*, *(C)* and *(n)* were proposed by Ackers and White [1973]. HR Wallingford [1990] has changed those values. (Cited from [5]) as stated:

1. $n_i = [1 - (0.56 * \log(d_g))]$ … (15)

2. $\log C = (-3.46 + (2.79 * \log(d_g)) - (0.98) * [\log(d_g)]^2)$ … (16)
3. $A_x = (0.14 + (0.23/\sqrt{d_g}))$ … (17)
4. $m_i = (1.67 + (6.83/d_g))$ … (18)

Then *QYTS*= 697 607 m^3 / Year

3.2.5 Dimensionless unit stream power approach of Yang [YSPTD]

The objective of Yang's dimensionless unit stream power approach is to facilitate comparison and application across various river systems by generalizing the stream power concept into a dimensionless form [31, 25, 28]. One potential strategy is to scale stream power using a variety of hydraulic parameters in order to establish dimensionless relationships that can be utilized to predict sediment transport, as follows:

$$\log C_{TX} = ((5.435) - (0.286) * \log[\omega * d_x/\nu_i] - (0.457) * \log[U_* / \omega] + \{(1.799) - (0.409) * \log[\omega * d_x/\nu_i] - (0.314) * \log[U_*/\omega]\} * \{\log[(S_x/\omega) * (U_x - U_{cr})]\} \quad \ldots (19)$$

Then; if $70 > (d * U_* / \nu) > 1.2$ chose:

$$U_{cr}/\omega = [0.66 + 2.5]/[\log[U_* * d_x/\nu_i] - (0.06)] \quad \ldots(20\ i)$$

But if $(d * U_* / \nu) \geq 70$ chose: $(U_{cr} / \omega) = 2.35$ … (20 ii)

Then: $QYTS = [(C_{Tx}/106) * (Q_x/S_S) * 86400 * 365\ ]$ … (21)

Finally, by using Eq. (21): *QYTS*= 204 130 m^3 / Year.

4. CONCLUSION AND SUMMARY

The findings from the process of calculating the bed-material capacity for transport of the Greater Zab River Basin (GZRB) immediately upstream of Ninawa City using five seemingly separate techniques are provided in Table 1. Sadly, there are no sediment observations recorded at the selected site. As a consequence, the findings that were obtained lack a direct, concrete reference against which they can be evaluated.

Table 1: The summary of findings

No.	Equation	QYTS (m3 / Year)	% (Percentage)
1	Larsen's Observational Methodology	145 667	71.4
2	Karim and Kennedy's Regression Method	727 644	356
3	Engelund and Hansen's Stream Power Technique	540 634	265
4	Akers and White Stream Power Technique	697 607	342
5	Yang Stream Power Technique with Dimensionless	204 130	100

There are many hydrologic, hydraulic, and physical factors that influence so as to regulate the transport of sediment challenge, and some of them have opposing consequences. Also, there aren't any reality sediment indicators to back up any one formula that can forecast the discharge of sediment in a way that is "exact." In actuality, it is inappropriate to discuss accuracy in this context. Regardless of the analytical component involved in determining a sediment transport formula, an empirical substantial element must always be completed in order to meet the local conditions both geographically and temporally. This is done by using measurable information to assess a relevant parameter in the model mathematically.

That is widely known for rivers in nature, especially the ones larger (such as in the case study). It is particularly accurate of very fine-bed streams. As a result, the predictions made by a sediment-transport formula are merely estimates. The degree to which the stated case's actual circumstances resemble the ideal conditions from which the formula was formed determines how accurate that estimation is. It is, therefore, widely acknowledged in practice that the calculated sediment load derived from various sediment transport formulas can yield remarkably diverse outcomes when compared to one another and from field measurements. Many researchers have assessed the precision of the majority of the existing transport of sediment models worldwide. An example of a study like this is the one conducted by Yang in 1996. The reliability of 13 procedures, including 8, Aker, and Yang, were examined in terms of six dimensionless variables: weighting of concentration by sediment (*C*), dimensionless shear velocity (U^*/ω), Froude number (*Fr*), dimensionless power stream unit ($U^* S/\omega$), the dimensionless diameter grain (*dg*) or mean diameter grain (*d*), and depth of relative (*D/d*).

[29] conducted a detailed analysis by using the difference ratios (*R*), which is defining such the rate of transport calculated divided by the observed transport rate. The acceptability range for comparison was set as [0.5 ≤ *R* < 2.0]. He utilized huge quantities of measurement information collected from flumes and rivers for

the analysis. He discovered the streaming capacity of dimensionless (10) achieved the highest level of among accuracy of 13 evaluated relationships.

Sensitivity parameters for the cover cases that adopted a range of values: *C* (ppm by weighting) = 10 – 100, *U* S/ ω* = 0.0005 – 0.1, *U*/ ω* = 2.5 – 15.0, *Fr* = 0.10 – 0.40, *D/d* = 1000 – 50000, and *dg* = 1.56 – 50.6 (or: d = 0.0625 – 2 mm). In contrast, the case study has specific values for these parameters: *C* by [29] = 57 ppm by weighting, *U*S/ω* = 0.0082, *U*/ ω* = 7.6, *Fr* = 0.12, *D/d* = 72510, and *d* = 0.11 mm (*dg* = 2.753). In regards to this research, the findings from the studies conducted in reference [23] can be succinctly summarized in Table (2). Therefore, the findings for [29] have been regarded in this research as a benchmark for comparing with other outcomes, shown in the percentage in Table (1).

Table 2: findings Summary that covers the case study to the cases of Yang [1996]

No.	Approach	Number of data	R	% (0.5 ≤ R ≤ 2.0)
1	Laursen-1958	2565	1.62	82
2	Engelund & Hansen-1972	2672	1.48	95
3	Ackers & White -1990	2565	1.42	92
4	Yang -1973	2672	1.39	93

The Nash-Sutcliffe model efficiency coefficient (NSE) is used to assess the projected accuracy of sediment transport models [15]. By definition, it is:

$$NSE = 1 - \frac{\sum_{t=1}^{T}\left(Q_0^t - Q_m^t\right)^2}{\sum_{t=1}^{T}\left(Q_0^t - \overline{Q_0}\right)^2} \qquad \dots (22)$$

Where $\overline{Q_0}$ is the mean of observed discharges, Q_m^t is the modeled discharge and Q_0^t is the observed discharge at time *t.* The resulting Nash-Sutcliffe Efficiency (NSE), assuming a perfect model with an estimated error variance of zero, is equal to (1). Conversely, a model yields a Nash-Sutcliffe Efficiency (NSE) score of (0.0) if it produces an estimated error variance equal to the variance of the observed time series. The observed mean is a more accurate predictor than the assessed model when the Normalized Standard Error (NSE), shown as NSE < 0, assumes a negative value. Figure (3) shows The goodness of Fit (NSE) diagram. There is a significant degree of agreement between the two sets of findings when the experimental and theoretical findings are compared.

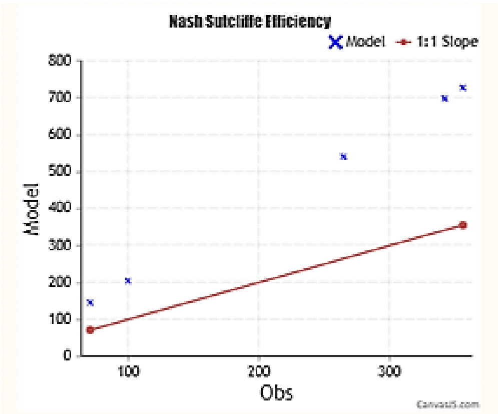

Figure 3: The goodness of Fit (NSE) diagram

Furthermore, as mentioned in [29], “it is exceedingly challenging, if not impossible, to suggest a single formula for engineers and scientists to utilize during fieldwork under all circumstances due to the significant uncertainties associated with calculating the discharge of sediment under various flow and sediment conditions, as well as different hydrologic, geologic, and climatic constraints”.

Based on the information provided above, the following can be inferred:

1. The discharge of the sediment of the Greater Zab River Basin (GZRB) is estimated to be around 205,000 m^3/Year, based on the projected flow rate of 330 m^3/sec.
2. It is not surprising that there are variations in the results of forecasting silt load in rivers when using different models.
3. It is crucial to measure the sediment load at significant places, particularly those that have an impact on the safety and well-being of a major city, as demonstrated in the case study.
4. It is recommended to take many values of the discharges in multi sections

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