Tikrit Journal of Engineering Sciences (2025); 32(2): 1985

DOI: http://doi.org/10.25130/tjes.32.2.12

IRAQI Academic Scientific Journals

ISSN: 1813-162X (Print); 2312-7589 (Online)

Tikrit Journal of Engineering Sciences

available online at: http://www.tj-es.com

TJES Tikrit Journal of Engineering Sciences

Estimation of Total Sediments Load for Makhoul Dam Reservoir

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Keywords:

Makhoul dam; Helley-Smith device; Bed load sediment; Suspended load sediment.

Highlights:

- *Using GIS programs to estimate the shape and size of the dam Reservoir before construction.*
- *Using field data and mathematical equations to estimate bed load sediments in rivers.*
- *Estimating the sediment load entering the dam reservoir before it is constructed to avoid future sediment problems.*

ARTICLE INFO

Article history:

Received	19 Jan.	2024
Received in revised form	25 Mar.	2024
Accepted	06 Apr.	2024
Final Proofreading	26 Apr.	2025
Available online	18 May	2025

Citation: Ghdhban II, Irzooki RH. **Estimation of Total Sediments Load for Makhoul Dam Reservoir**. *Tikrit Journal of Engineering Sciences* 2025; **32**(2): 1985.

http://doi.org/10.25130/tjes.32.2.12

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Abstract: The problem of sediment accumulation in dam reservoirs is considered one of the most important problems facing these large projects. The present study estimated the total amount of sediment from the Tigris and Lower Zab Rivers that will enter annually into the reservoir of the Makhoul Dam, which is currently under construction on the Tigris River in Iraq. Field and laboratory measurements were conducted to estimate the bed load of the two rivers using the Helley-Smith device, in addition to estimating this sedimentary load using five empirical equations. The filtration method was used to estimate the suspended load of the two rivers by taking samples and examining them weekly for one year. The results showed that the bed load of the two rivers using the Helley-Smith device was less than 1% of the suspended load. When calculating the bed load using the five applied equations, the results varied, as the Meyer-Peter, Schoklitsch, and Casey formula achieved unacceptable results, while the results of the Kalinske equation were good, as it estimated the bed load for the Tigris River to be 7.6% and for the Lower Zab River to be 10.9%. The results of the Einstein equation were also good, where the bottom load for the Tigris River was estimated to be 2.4% and the Lower Zab River 11.8%. The average of the results of the two equations was taken to represent the bed load and added to the suspended load. Also, the results showed that the highest value of the suspended load was during April for the Tigris and Lower Zab Rivers. The total sediment load of the Tigris River reached 2875461 tons annually, and the Lower Zab River reached 1503739 tons annually. In other words, the total sediment load of the two rivers entering the Makhoul Dam reservoir amounted to 4379200 tons annually, or the equivalent of 3368615 m^3 annually.

تخمين حمل الرسوبيات الكلية لخزان سد مكحول

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الخلاصة

تعتبر مشكلة تراكم الرسوبيات في خزانات السدود احدى اهم المشاكل التي تواجه هذه المشاريع الكبيرة، مشروع سد مكحول أحد السدود قيد الانشاء على نهر دجلة في العراق. أجريت هذه الدراسة لتخمين كمية الرواسب الكلية لنهري دجلة والزاب الاسفل التي ستصب سنويا في خزان سد مكحول. تم اجراء قياسات حقلية ومختبرية لتقدير حمل القاع للنهرين باستخدام جهاز هيلي سمث اضافة الى تخمين هذا الحمل الرسوبي باستخدام خمس معادلات وضعية. استخدمت طريقة الترشيح لتقدير الحمل المعلق للنهرين، بأخذ العينات وفحصها أسبوعيا لمدة عام واحد. بينت النتائج أن حمل القاع للنهرين باستخدام جهاز هيلي سمث كان بحدود ١٪ من الحمل المعلق. وعند حساب حمل القاع باستخدام المعادلات الخمس المطبقة، تباينت النتائج حيث لم تحقق معادلات Meyer-Peter, وSchoklitsch وCasey formula نتائج مقبولة بينما كانت نتائج معادلة Kalinske جيدة حيث خمنت حمل القاع لنهر دجلة ٧,٦ % ولنهر الزاب الاسفل ١٠,٩٪، كذلك كانت نتائج معادلة Einstein جيدة حيث خمنت حمل القاع لنهر دجلة ٢,٤ % ولنهر الزاب الاسفل ١١,٨ %. تم اخذ المعدل للمعادلتين ليمثل حمل القاع واضافته الى الحمل المعلق الذي بينت النتائج ان اعلى قيمة له كانت خلال شهر ابريل لنهري دجلة ونهر الزاب الأسفل. بلغ الحمل الرسوبي الكلي لنهر دجلة ولنهر الزاب الأسفل ٢٨٧٥٤٦١ و ١٥٠٣٧٣٩ طن سنويا، اي ان الرسوبيات الكلية للنهرين التي ستصب في بحيرة سد مكحول بلغت ٤٣٧٩٢٠٠ طن سنويا او ما يعادل ٣٣٦٨٦١٥ متر مكعب سنويا.

الكلمات الدالة: سد مخول، جهاز هيلي سميث، رواسب حمولة القاع، رواسب الحمولة المعلقة.

1.INTRODUCTION

Water resources are among the most important requirements for the continuation and perpetuation of human life, and life cannot continue without water. It is a resource that has a significant role in all aspects of life and is the main cause of development. Establishing hydraulic facilities, such as dams and reservoirs, for storing surplus water during the flood season is one of the most important practices for developing and managing water resources, flood prevention, and control [1]. Over 45000 large dams have been built worldwide for various purposes, such as power generation, flood control, and domestic or industrial water supply [2, 3]. The official statistics reported more than 98000 dams/reservoirs in China [4]. Many problems accompany dam construction, some of which reduce its value or may render it useless. The most serious problem facing the dam construction process is sediment accumulation. Sediment is a major problem in controlling and utilizing the earth's surface water [5]. Sedimentation in reservoirs worldwide has led to the loss of reservoir storage capacity, thereby reducing the useful life of dams. Therefore, it is necessary to assess reservoir sedimentation and plan for a specified full-service time of the reservoir [6]. Reservoir sedimentation is an ongoing critical concern worldwide, with a recorded global average of 33% of reservoir storage capacity already being lost therefrom, which is expected to exceed 50% by 2050 [7]. Sediments in channels and reservoirs are classified into two types according to how they move in the water: bed load and suspended load. The bed load moves near the bottom of the channel, while the suspended load moves randomly along the depth of the channel [8]. The suspended load is dominant in the amount of sediment in the river, where the researchers found that the percentage of the suspended load of the total sediment ranged from 85-99%, while the percentage of the bed load range was 1-15%. These percentages were exceeded by some studies, reaching 50% for each. Some researchers used the ratio between bed load and suspended load to determine the value of bed load in rivers due to the difficulty and complexity of doing so in practical ways. They used the Talghan and Jagrud rivers as cases [9-11]. They used the equations of Meyer-Peter-Muller, Casey, Schoklitch, and VanRijn to estimate the bed load and the equations of Einstein, Chang-Simons-Richardsin, Begnold, and Toffalati to calculate the suspended load. It was concluded that the Schoklitch equation provided the best estimate of the bed load for both rivers, while the Einstein and Begnold equation provided the best estimate of the suspended load for the two rivers. Talukdar et al. [12] conducted a study comparing the three methods for estimating bed load. They concluded that equations based on shear stress have worked better than other approaches (discharge, probabilistic, and regression). Imanshoar et al. [13] studied the density of sediment accumulated at the bottom of the reservoirs and its effect on the age of the reservoir. They suggested that the dead storage volume be 10% of the reservoir volume. Al-Ansari et al. [14] studied the bed load sediments of the Tigris River in Baghdad. The researchers found that 90.74% of the bottom materials are sand with an average grain diameter of 0.177 mm. Ouellet-Proulx et al. [15] conducted a study on the St. John River to estimate the amount of suspended sediment using a sediment classification curve and a model tree (M5′) with different predictors. The best results were obtained using M5′ with four predictors, returning an R2 of 0.72 on the calibration data and an R2 of 0.46 on the validation data. The researchers suggested the model tree approach for its relative ease of implementation and consistent performance. Gunawan et al. [16]

evaluated several equations to estimate the bed load, the suspended load, and the total load of the Cibuah River and Cikamiri River. They concluded that the formulas with the best performance were the Van Rijn method, the Yang method, the Bagnold method, the Engelund-Hansen method, the Karim-Kennedy method, and the Toffaletti method. Sulaiman et al. [17] studied the Euphrates River to determine the best equation for evaluating this river's total sediment. The researchers concluded that the Engelund-Hansen formula was the best formula for estimating the total sediments of the Euphrates River. Ghdhban and Irzooki [18] conducted a study to estimate the amount of sediment transported from the valleys to the Tigris and Zab rivers in the study area using the global equation for soil erosion. Liejy et al. [19] They used SPSS to derive hydraulic equations for their research on flow in channels and the correlation coefficient was good. Ghdhban and Irzooki [20] Conduct a practical study of evaporation in the current study area and deduce the annual evaporation rates therein. Due to the lack of previous studies that addressed the issue of sediments entering the Makhoul Dam reservoir, the present study estimates the annual sediments that enter the reservoir via the Tigris River and the Lower Zab River and that flow into the Makhoul Dam reservoir after its completion.

2.STUDY AREA OF MAKHOUL DAM

Makhoul Dam is one of the proposed dams on the Tigris River Basin in Iraq. This dam is in the northeastern part of Salah al-Din Governorate and the western part of Kirkuk Governorate, about 200 km north of the Samarra Barrage, after the confluence of the Tigris River with two important tributaries, the Upper Zab and the Lower Zab. Therefore, constructing the dam project will lead to controlling the flood waters of the river and its tributaries. It is one of the most important large hydraulic projects proposed by the international standards of the International Association of Large Dams [1]. Figure 1 represents the location of the Makhoul dam and reservoir on the map of Iraq. Table 1 shows the design specifications of the Makhoul Dam.

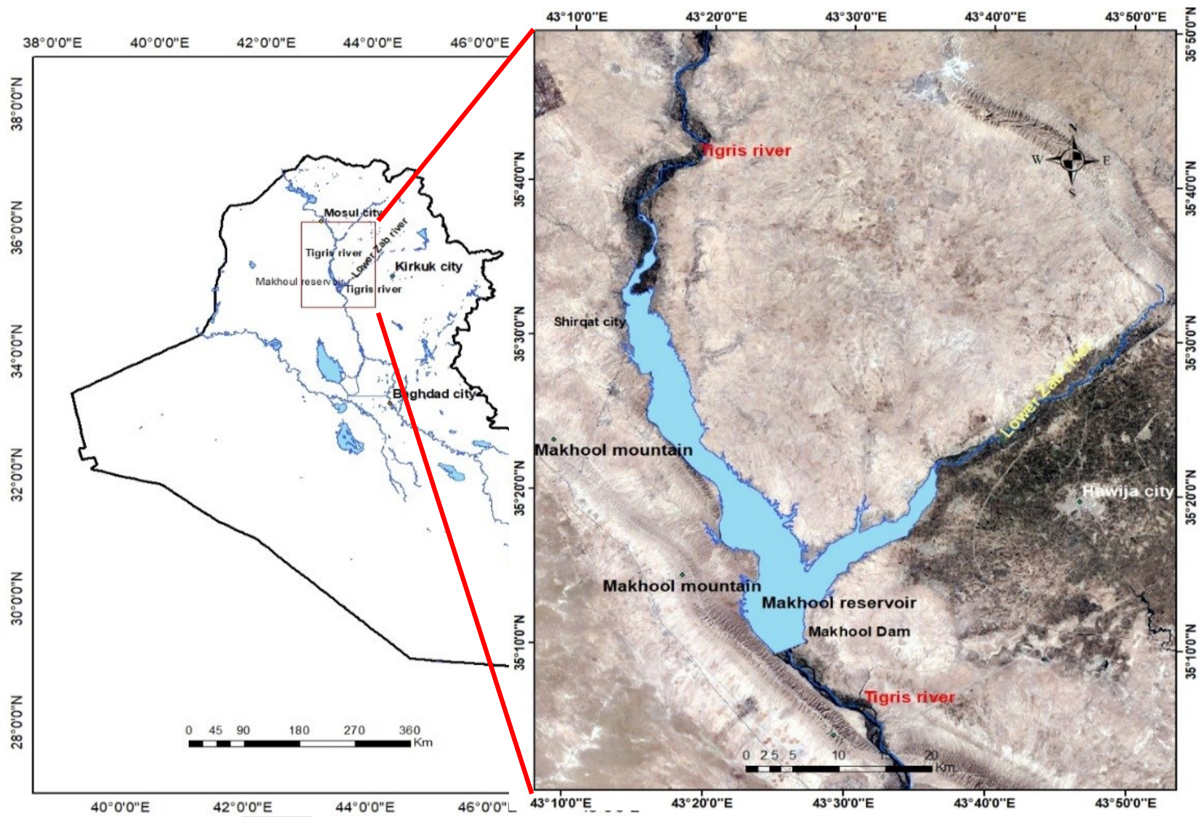

Fig. 1 The Location of the Makhoul Dam on the Map of Iraq.

Table 1 The Design Specifications of Makhoul Dam [1].

1	Dam top level	160 m above sea level
2	The highest height of the dam is at the lowest point at the bottom of the river	56 m
3	Width of the dam crest	12 m
4	The length of the dam at the top level	3670 m
5	The highest possible flood level	152.15 m above sea level
6	The highest annual operating level	150 m above sea level
7	The lowest annual operating level	140 m above sea level

3.GEOMETRY OF MAKHOUL DAM RESERVOIR

Arc GIS, Surfer, and Excel programs were used to analyze the reservoir geometric and calculate the dam reservoir's shape, size and area based on the given data of the dam's height. Digital Elevation Model (DEM) visualizations with a resolution of 30 meters were used to estimate the shape of the reservoir using Geographic Information System (GIS) programs (ArcGIS and Global Mapper programs). The Surfer program was used to calculate the size and shape of the reservoir at each level, which begins with the lowest operating level (140 meters above sea level) to the highest operating level (150 meters above sea level). The shape of the reservoir was drawn. Figure 2 represents the Makhoul Dam reservoir at maximum and minimum operating levels. The reservoir volume and area at each level were calculated using the Surfer program, as shown in Table 2. The area of the Makhoul Dam reservoir at the highest operating level (150 meters above sea level) is 229.85 square kilometers, and the total volume of the reservoir is 2.54 billion cubic meters. The reservoir extends in two branches, one of which extends into the Tigris River basin and extends for 50 km, and the second branch extends into the lower Zab River basin with a distance of about 25 km from the center of the dam.

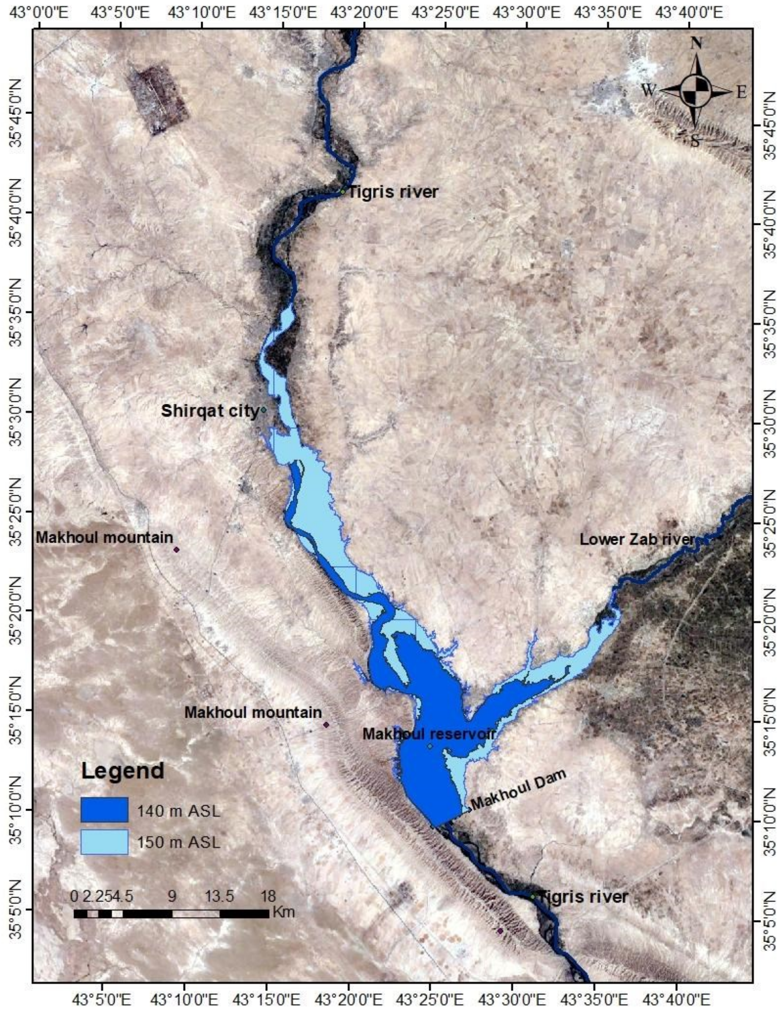

Fig. 2 Makhoul Reservoir at Maximum and Minimum Operating Level.

Table 2 Total Volume and Surface Area of Makhoul Reservoir.

Level (m) Above sea level	Surface area(km²)	Total storage volume (Mm³)
140	112.241166	850.95215
141	124.471576	980.335316
142	134.905632	1095.020056
143	143.687553	1235.729672
144	152.215458	1390.517535
145	162.157193	1553.056336
146	173.29138	1726.604755
147	187.387231	1908.388813
148	203.426975	2111.467842
149	215.350913	2325.477984
150	229.853036	2541.389189

4.THEORETICAL EQUATIONS FOR ESTIMATION SEDIMENTS

Several early studies examined sedimentation in canals and reservoirs. Many researchers have studied the movement of sediment grains, their movement, or their sedimentation in channels or reservoirs. The sediment load in the water has been divided into two types: the suspended load and the bed load. Equations have been developed by researchers to measure each type.

4.1.Bed Load Estimation

Many researchers have derived their equations to estimate the bed load, and they have been divided into three main groups:

1- DuBoys type equations: These equations are based on the shear stress relationship.
2- Schoklitsch-type equations based on the discharge relationship in the channels.
3- Einstein-type equations, which depend on the relationship of lifting forces.

Five equations, as shown in Table 3, that the researchers developed were used in this study to determine the bed load. They were selected because the variables in these equations can be computed while conducting fieldwork, inserting them into the equation, and getting the results [5, 8, 17].

4.2.Suspended Load Estimation

Table 4 shows the equations created by researchers to estimate the suspended load in rivers [5, 8, 17].

Table 3 Equations of Estimating Sediment Bed Loads.

Bed Load Equations	
Schoklitsch Equation	$g_b = 2500S^{1.5}(q - q_{cr})$ $Q_b = g_b W$
Kalinske Equation	$\frac{q_s}{u_* d_{50}} = fct_k[\frac{(\tau_o)_{cr}}{\tau_o}$
Einstein Equation	Φ=fct(Ψ) $\Psi = \frac{G_s - G_w}{G_w}\frac{d_{50}}{SR_h}$ $\Phi = \frac{g_b}{\gamma_s}\sqrt{\frac{G_w}{G_s - G_w}\frac{1}{g d_{50}^3}}$
Casey Formula (1935)	$g_b = 0.3675\rho_s S^{\frac{9}{8}}(q - q_c)$
Meyer-Peter Formula (1934)	$g_b^{\frac{2}{3}} = 250q^{\frac{2}{3}}S - 42.5d_{50}$

Table 4 Equations of Estimating Sediment Suspended loads.

Suspended Load Equations	
Forchheimer Equation (1930)	$q_s = k_F \frac{\gamma^2}{\gamma_s - \gamma}\frac{u^{-5}}{q}$
Rouse Equation (1937)	$g_s = \int_a^D C_u dy$
Einstein Equation (1950)	$g_s = \int_a^D C_a\left(\frac{D-y}{y}\frac{a}{D-a}\right)^z 5.75u_*' \log\log\left(\frac{30.2y}{\Delta}\right)dy$
Brooks (1963)	$g_s = C_{md}g\left[\left(1+\frac{u_*}{k\underline{u}}\right)\int_{AE}^1\left(\frac{1-y}{y}\right)^z dy + \frac{u_*}{k\underline{u}}\int_{AE}^1\left(\frac{1-y}{y}\right)^z \ln\ln y\, dy\right]$

5.FIELD AND LABORATORY WORK

Measuring sediments in natural rivers requires collecting field data and measuring them in the field and laboratory. This part will explain the methods and devices for field and laboratory measurement, as these measurements include:

1- Choosing two cross sections of the Tigris and Lower Zab rivers for taking weekly samples for each.
2- Make a cross-section of both rivers to measure discharge and velocity, and take bed load and suspended load samples.
3- Weekly bed load samples were taken using the Helley-Smith device and analyzed in the laboratory.
4- Weekly samples of the suspended pregnancy were taken using sample bottles and measured in the laboratory.
5- Analyze the samples taken and calculate their concentration per cubic meter.
6- Create a relationship linking the total sediment load with the discharge to find the annual sediment discharge transported by the Tigris and Lower Zab rivers.

7- Conducting the necessary field measurements by applying the empirical equations found by the researchers to compare them with the field measurements.

5.1.Sampling Sites

In this investigation, two presumptions were made before beginning field and laboratory measurements because the dam is currently under construction, and the reservoir does not exist. The first hypothesis is that the sediments presently transported by the Tigris and Lower Zab rivers in the two river sections selected for measurement are the sediments that will enter the reservoir following construction completion. This hypothesis relates to the current portion of the laboratory study. The second hypothesis is that the efficiency of the trap is 100%, which is the worst case. The two sampling sites were chosen for both rivers before the confluence of the two rivers, which was to be in a straight area of the river so that the results would not be affected by the curvature. A site was chosen on the Tigris River near the Zab district at coordinates (35° 15' 20" N, 43° 25' 50" E), and the second site was chosen on the Lower Zab River near the village of Tal Ali at coordinate (35° 22' 55" N, 43° 39' 00" E).

5.2.Hydraulic Measurements

Hydraulic measurements were performed to provide the information necessary to apply the equations for calculating the suspended load and bed load. These measurements are:

1- The cross-section of the river and calculating the area, wetted perimeter, and hydraulic radius at each discharge. The measurement was made for the Tigris River using the Acoustic Doppler Current Profiler ADCP due to the depth of the water and the large size of the river. As for the Lower Zab River, the cross-section was measured using surveying devices.

2- The rate of flow velocity using the float method for several points on the cross-section of the river while measuring the depths, then calculating the rate of velocity for the total flow.

3- Calculating the discharge rate using the average velocity and cross-sectional area, then comparing it with the discharge rate measured at the measuring stations, where the Tigris River discharge is compared with the measurement at the Shirqat station and the measurement of the Lower Zab River with the Dibs Dam measuring station.

5.3.Bed Load Measurement

Helley-Smith device was used to measure the bed load of the Tigris and Lower Zab rivers, and it is a widespread device due to its ease of use [21]. This device was manufactured locally, as it was not available in the laboratory, and according to the standard specifications, as shown in Figs. (3 and 4).

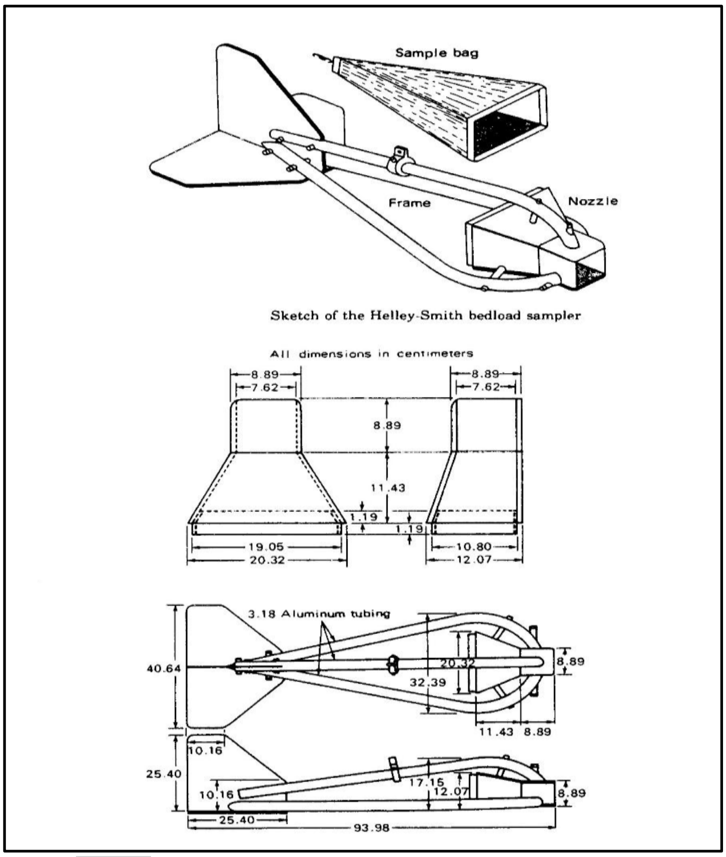

Fig. 3 Helley Smith Bed Load Sampler HSS [21].

Fig. 4 The Helley Smith Device Used in the Study.

One sample was taken every week for twelve months, from July 2022 to June 2023. Forty-eight weeks were spent collecting the samples. Three places were chosen for each sampling process: the first at a quarter from the left bank, the second at the center of the distance, and the third at a quarter of the distance from the right bank. The average of the three samples was taken. Extracting bed load samples is not easy; it takes a lot of effort to collect even a few samples. Temporal fluctuations in bed load transfer rates are very large and common even if flow conditions are constant. No strict procedures or accuracy standards were created to sample the bed load to ensure adequate results [22]. The dry weight and duration of the sample taken are the measurements made for every sample. Next, the bed load was calculated by applying the following equations, and a weekly measurement of bed load was conducted for the Tigris River and Lower Zab River.

$$Sb = \frac{\alpha m_s}{bT} \quad \text{(Kg/s.m)} \qquad (1)$$

for all river-width

$$Qb = Sb{*}W \ \text{(Kg/s)} \qquad (2)$$

where α: Calibration factor = 0.5 – 1.5, m_s: Dry mass of sample (Kg), b: Width of the device nozzle= 0.0762 m, T: Sampling period (s), and *W*: River width (m). To compare the findings with the results of the researcher's equations, only the logical results were satisfied. Tables (5 and 6) present the bed load and hydraulic measurement results for the Tigris and Zab rivers, respectively. As shown in Fig. 5 (a) sieve analysis of the bed load extracted from the Tigris River was conducted, and a relation was created to determine D50, D35, D90, and D10. Figure 5 shows that (D50=6 mm, D90=>14 mm, D10=0.6 mm, and D35=4 mm). Similarly, sieve analysis was conducted for the Lower Zab River, as shown in Fig. 6, where (D50=6 mm, D90=>14 mm, D10=0.9 mm, and D35=4 mm).

Table 5 Results of the Bed Load Sediment and Hydraulic Measurements of Tigris River Using the Helley-Smith Device.

Date	Discharge (m^3/s)	River width (m)	A (m^2)	R (m)	V (m/s)	S	Bed load (Kg/s)
08/07/2022	497	167	517	3.095	0.96	8.17* E-07	0
15/07/2022	523	167	533	3.191	1	8.51* E-07	0
22/07/2022	510	167	525	3.143	0.97	8.17* E-07	0
29/07/2022	569	167	561	3.359	1.01	8.11* E-07	0
06/08/2022	524	167	534	3.197	0.98	8.15* E-07	0
08/08/2022	515	167	528	3.161	0.976	8.21* E-07	0.000787
18/08/2022	525	167	534	3.197	0.983	8.2* E-07	0.001606
27/08/2022	530	167	537	3.215	0.986	8.19* E-07	0.000191
02/09/2022	527	167	535	3.203	0.984	8.20* E-07	0.00012
12/09/2022	506	167	522	3.125	0.969	8.21* E-07	0.000287
19/09/2022	527	167	535	3.203	0.984	8.20* E-07	0.000183
24/09/2022	522	167	532	3.185	0.98	8.19* E-07	0.000132
02/10/2022	531	167	538	3.221	0.988	8.20* E-07	2.82E-05
08/10/2022	527	167	535	3.20	0.984	8.20* E-07	0.000122
14/10/2022	528	167	535	3.20	0.985	8.21* E-07	1.22E-05
28/10/2022	548	167	548	3.281	0.999	8.18* E-07	6.84E-05
05/11/2022	595	167	577	3.455	1.03	8.12* E-07	0.0003
19/11/2022	598	167	578	3.461	1.034	8.16* E-07	4.46E-05

30/11/2022	536	167	541	3.239	0.991	8.19*E-07	0
02/12/2022	680	167	625	3.742	1.087	8.13*E-07	3.2E-05
09/12/2022	630	167	597	3.574	1.055	8.14* E-07	0.001099
17/12/2022	621	167	592	3.544	1.05	8.15* E-07	0.007043
29/12/2022	470	65	497	7.646	0.946	8.37* E-07	0
07/01/2023	332	160	392	2.45	0.85	8.75* E-07	0
04/02/2023	541	167	544	3.257	0.995	8.20* E-07	0
12/02/2023	551	167	550	3.293	1	8.16* E-07	0
18/02/2023	547	167	548	3.281	0.999	8.18* E-07	0
25/02/2023	547	167	548	3.281	0.999	8.18* E-07	0.000136
03/03/2023	580	167	567	3.39	1.02	8.15* E-07	8.32E-05
11/03/2023	555	167	553	3.311	1	8.10* E-07	0
17/03/2023	739	167	658	3.94	1.12	8.06* E-07	0.00440
25/03/2023	487	166	509	3.06	0.95	8.10* E-07	0
05/04/2023	442	163	476	2.92	0.92	8.11* E-07	0
13/04/2023	1296	167	929	5.56	1.395	7.89* E-07	0.001102
19/04/2023	932	167	758	4.53	1.22	7.92* E-07	0
25/04/2023	740	167	658	3.94	1.12	8.06* E-07	0
05/05/2023	538	167	542	3.24	0.992	8.19* E-07	0
13/05/2023	553	167	551	3.29	1	8.14* E-07	0
19/05/2023	512	167	526	3.149	0.97	8.15* E-07	0
30/05/2023	561	167	556	3.32	1	8.04* E-07	0
04/06/2023	474	166	500	3.01	0.95	8.29* E-07	0
09/06/2023	553	167	551	3.29	1	8.22* E-07	0
21/06/2023	472	166	498	3	0.94	8.22* E-07	0

Table 6 Results of the Bed Load Sediment and Hydraulic Measurements of Lower Zab River using the Helley-Smith Device.

Date	Discharge (m^3/s)	River width (m)	Area (m^2)	R(m)	V(m/s)	S	Bed load (Kg/s)
04/07/2022	9.4	61	41	0.672131	0.2295	4.33E-05	0
12/07/2022	9.4	61	41	0.672131	0.2295	4.33E-05	0
21/07/2022	10.56	67	46	0.686567	0.2295	4.21E-05	0
30/07/2022	13	68	46.5	0.683824	0.28305	6.44E-05	0
03/08/2022	9.4	61	52.27	0.856885	0.42075	0.000105	0
11/08/2022	79	80.75	76.77	0.950712	1.037	0.000557	0.00118
17/08/2022	61.14	79.5	69.17	0.870063	0.884	0.000455	0.000365
27/08/2022	46	78	65	0.833333	0.708305	0.00031	0.000425
02/09/2022	43.86	77	60	0.779221	0.731	0.000361	1.35E-05
11/09/2022	38.2	77.5	60.76	0.784	0.629	0.000265	1.53E-05
19/09/2022	54	78	63.46	0.81359	0.85	0.00046	4.15E-05
27/09/2022	26.4	76	56.5	0.743421	0.4675	0.000157	1.52E-05
01/10/2022	24.66	74.5	52.75	0.708054	0.4675	0.000168	6.8E-06
11/10/2022	5.3	61	39	0.639344	0.136	1.63E-05	0
15/10/2022	5.3	61	39	0.639344	0.136	1.63E-05	4.45E-06
28/10/2022	10.5	60	37	0.616667	0.28305	7.39E-05	0
05/11/2022	10.5	60	37	0.616667	0.28305	7.39E-05	0
19/11/2022	10.4	61	37	0.606557	0.28305	7.55E-05	0
26/11/2022	220	102	156	1.529412	1.411	0.000547	0
05/12/2022	80	80	80	1	1.003	0.000487	0
09/12/2022	17	62	60	0.967742	0.28305	4.05E-05	0
17/12/2022	22.3	73	69	0.945205	0.323	5.44E-05	0
06/01/2023	9.9	61	58	0.95082	0.17	1.5E-05	0
14/01/2023	9.9	62	58	0.935484	0.17	1.53E-05	0
21/01/2023	9.9	61	58	0.95082	0.17	1.5E-05	0
03/02/2023	150	90	118	1.311111	1.19	0.000478	0
18/02/2023	8	34	9.5	0.279412	0.85	0.001914	8E-05
26/02/2023	21.25	42	20	0.47619	1.0625	0.001469	0.000311
03/03/2023	35	50	33	0.66	1.0625	0.000951	0.000344
11/03/2023	57	80	54	0.675	1.0625	0.000923	0
17/03/2023	51.6	77	45	0.584416	1.1475	0.001304	0.001454
28/03/2023	55	79	51.5	0.651899	1.0625	0.000967	0.001868
05/04/2023	36	77	33.5	0.435065	1.0625	0.001657	0.002026
13/04/2023	37	25	20	0.8	1.275	0.001059	0.002776
20/04/2023	25	36	20	0.555556	1.275	0.001723	2.37E-06
25/04/2023	37	77	33.5	0.435065	1.0625	0.001657	0.001609
05/05/2023	1.7	16	2.3	0.14375	0.7225	0.003355	8.1E-07
13/05/2023	3	17.5	3.4	0.194286	1.0625	0.004856	2.92E-05
20/05/2023	10.26	38	14.5	0.381579	0.70805	0.000877	9.44E-06
29/05/2023	28	46	26.5	0.576087	1.0625	0.00114	0.016288
04/06/2023	9.35	35	11	0.314286	0.85	0.001637	0
12/06/2023	17.4	42	20.5	0.488095	0.85	0.00091	0
18/06/2023	61.6	81	58	0.716049	1.0625	0.000853	0
21/06/2023	68	84	64	0.761905	1.0625	0.000785	0

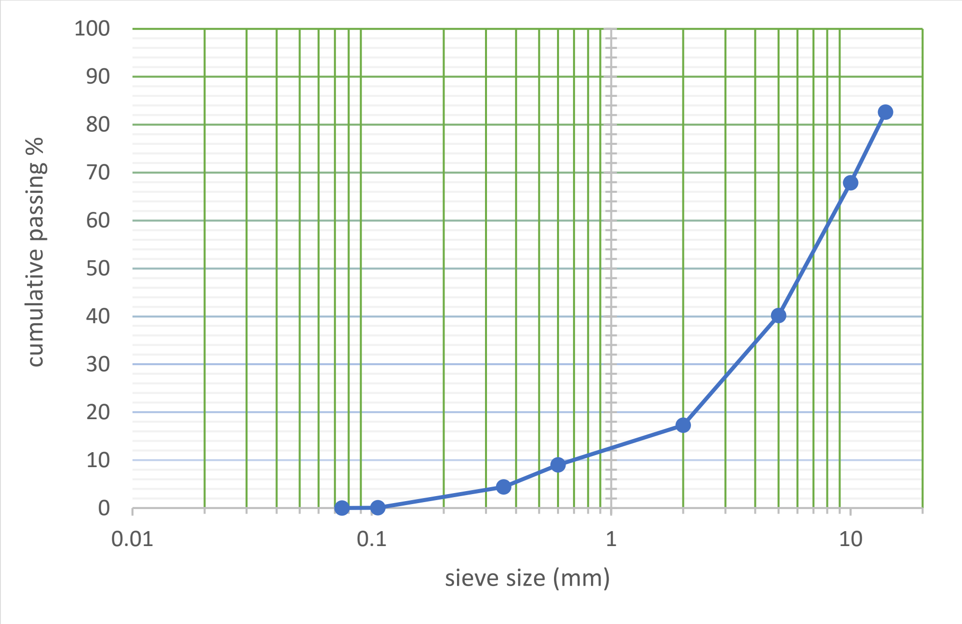

Fig. 5 Sieve Analysis of Bed Load Material for Tigris River.

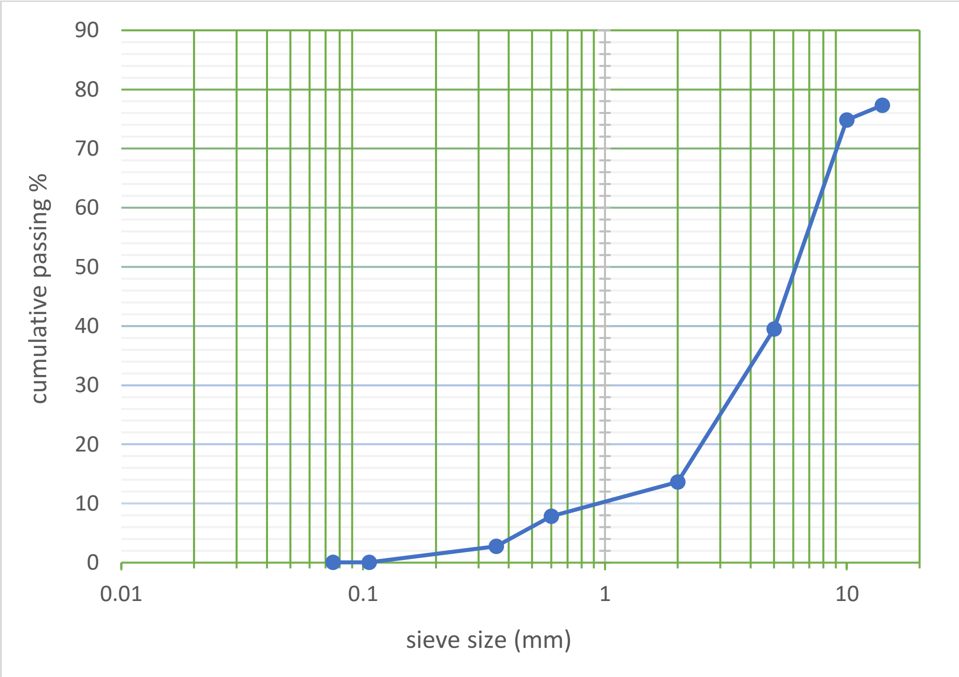

Fig. 6 Sieve Analysis of Bed Load Material for Lower Zab River.

5.4.Suspended Load Measurement

Prior research has demonstrated the significance of suspended loads, which comprise most sediment load and present the biggest problem in reservoir and dam construction projects. In light of this, scientists were keen to measure and ascertain the suspended load of rivers and to construct laboratory apparatus capable of collecting samples to ascertain the yearly loads transferred into dam reservoirs and, consequently, determining the age of the reservoir. The Bottle Sampler method was used in the present study to measure the suspended load of the Tigris and Lower Zab Rivers due to its availability, possibility of use, and acceptable accuracy, as the accuracy in this method reaches 90% [9]. This method is based on filling a bottle to determine the concentration of silt and/or sand at a specific point in the flow. Typically, the bottle is placed vertically and lowered to the sampling point, where the bottle is opened (mechanically or electrically). Following the researchers' prior procedure for filling the samples, weekly samples were gathered from the designated sections of the Tigris and Lower Zab Rivers at a rate of three to five points per cross-section. Furthermore, during every sampling procedure, the two rivers' flow velocity and discharge were measured. Each sample was filtered using sheets of material with a pore size of (2-3) microns after it was collected, and the next steps were completed once the sheets had been dried in a drying oven, Fig. 7. The following Calculations were performed for each sample, and then the average of the sample results was taken.

1- Measuring the weight of the empty filter paper (W1) using an electronic balance.
2- Perform the sample filtration process.
3- Dry the paper after the filtration process.
4- Measuring the weight of the filter paper and the sediment retains on it (W2).
5- Measure the volume of the water sample using a graduated cylinder (V).
6- Measure the weight of sediment retained by the filter paper and then calculate the sediment weight (W3):

$$\mathbf{W3 = W2\text{-}W1} \qquad (3)$$

7- Calculate the suspended sediment load (g_s) (kg/m3) from the following equation:

$$g_s = \frac{W_3}{V} \qquad (4)$$

8- Calculate the amount of suspended sediment passing during a unit of time from the equation:

$$Q_s\left(\frac{m^3}{s}\right) = g_s * Q \qquad (5)$$

where Q is the river discharge (m3/s).

Tables (7 and 8) tabulate the laboratory results for measuring the suspended load of the Tigris and Lower Zab Rivers, respectively.

Fig. 7 Devices Used to Measure Suspended Load.

Table 7 Results of the Suspended Load and Hydraulic Measurements of Tigris River.

Date	Discharge (m³/s)	g_s (kg/m³)	Qs (kg/s)
08/07/2023	497	0.037948718	18.86051
15/07/2022	523	0.033910891	17.7354
22/07/2022	510	0.019148936	9.765957
29/07/2022	569	0.032374101	18.42086
06/08/2022	524	0.02244898	11.76327
08/08/2022	515	0.035	18.025
18/08/2022	525	0.029258098	15.3605
27/08/2022	530	0.062585034	33.17007
02/09/2022	527	0.005729167	3.019271
12/09/2022	506	0.063333333	32.04667
19/09/2022	527	0.001271186	0.669915
24/09/2022	522	0.000434783	0.226957
02/10/2022	531	0.005555556	2.95
08/10/2022	527	0.022421525	11.81614
14/10/2022	528	0.000956938	0.505263
28/10/2022	548	0.024305556	13.31944
05/11/2022	595	0.035483871	21.1129
12/11/2022	594	0.0150237	8.924078
19/11/2022	598	0.001333333	0.797333
30/11/2022	536	0.005555556	2.977778
02/12/2022	680	0.048031496	32.66142
09/12/2022	630	0.003414634	2.15122
17/12/2022	621	0.031756757	19.72095
29/12/2022	470	0.000613497	0.288344
07/01/2023	332	0.012413793	4.121379
14/01/2023	327	0.0078684	2.572967
21/01/2023	270	0.034806	9.39762
04/02/2023	541	0.026595745	14.3883
12/02/2023	551	0.018248175	10.05474
18/02/2023	547	0.008666667	4.740667
25/02/2023	547	0.011068702	6.05458
03/03/2023	580	0.014084507	8.169014
11/03/2023	555	0.02601626	14.43902
17/03/2023	739	0.095652174	70.68696
25/03/2023	487	0.019047619	9.27619
05/04/2023	442	0.00325	1.4365
13/04/2023	1296	0.66438	861.0365
19/04/2023	932	0.07472	69.63904
25/04/2023	740	0.052	38.48
05/05/2023	538	0.0217	11.6746
13/05/2023	553	0.0137	7.5761
19/05/2023	512	0.00814	4.16768
30/05/2023	561	0.0579	32.4819
04/06/2023	474	0.033	15.642
09/06/2023	553	0.0206	11.3918
21/06/2023	472	0.0025	1.18

Table 8 Results of the Suspended Load and Hydraulic Measurements of Lower Zab River.

Date	Discharge (m³/s)	g_s (kg/m³)	Qs (kg/s)
04/07/2022	9.4	0.015065	0.14161
12/07/2022	9.4	0.020245	0.190307
21/07/2022	10.56	0.054067	0.570947
30/07/2022	13	0.065203	0.847635
03/08/2022	9.4	1.039634	9.772561
11/08/2022	79	0.177893	14.05351
17/08/2022	61.14	0.106415	6.506219
27/08/2022	46	0.108727	5.001455
02/09/2022	43.86	0.028571	1.253143
11/09/2022	38.2	0.033482	1.279018
19/09/2022	54	0.016957	0.915652
27/09/2022	26.4	0.01828	0.482581
01/10/2022	24.66	0.018182	0.448364
11/10/2022	5.3	0.047458	0.251525
15/10/2022	5.3	0.000784	0.004157
28/10/2022	10.5	0.012291	0.12905
05/11/2022	10.5	0.039216	0.411765
13/11/2022	10.5	0.063742	0.669291
19/11/2022	10.4	0.00339	0.035254
26/11/2022	220	16.61446	3655.181
05/12/2022	80	0.110625	8.85
09/12/2022	17	0.028467	0.483942
17/12/2022	22.3	0.049682	1.107898
30/12/2022	17	0.099652	1.694084
06/01/2023	9.9	0.008502	0.08417
14/01/2023	9.9	0.008502	0.08417

21/01/2023	9.9	0.008502	0.08417
03/02/2023	150	0.532544	79.88166
13/02/2023	7	0.187432	1.312024
18/02/2023	8	0.043646	0.349171
26/02/2023	21.25	0.013901	0.295404
03/03/2023	35	0.022912	0.801909
11/03/2023	57	1.25914	71.77097
17/03/2023	51.6	0.018966	0.978621
28/03/2023	55	0.098889	5.438889
05/04/2023	36	0.016571	0.596571
13/04/2023	37	1.730233	64.0186
20/04/2023	25	0.008763	0.219072
25/04/2023	37	0.007432	0.275
05/05/2023	1.7	0.021711	0.036908
13/05/2023	3	0.023792	0.071375
20/05/2023	10.26	0.011579	0.1188
29/05/2023	28	0.023699	0.663584
04/06/2023	9.35	0.0525	0.490875
12/06/2023	17.4	0.015152	0.263636
18/06/2023	61.6	0.132414	8.15669
21/06/2023	68	0.08837	6.00916

6.RESULTS AND DISCUSSION

6.1.Results of Bed Load Sediments

Figures 8 and 9 show the amounts of bed load sediments measured in the field using the Healy Smith device. In addition, this part of the sediment was calculated using several equations mentioned in Table 3. The Helley Smith field measuring device results showed that the ratio of bed load to the total sediment load was about 0.005% in the Tigris River and 0.089% in the Lower Zab River. This percentage is much lower than the normal rate of bed load rate, which ranges between (1-15)%. The results obtained from the equations showed significant variation. The Schoklitsch and Meyer-Peter equations yielded illogical results, as the bed load percentage calculated using these equations was less than zero. On the other hand, the Casey equation produced wildly inflated results, with the bed load percentage reaching 98%, making it incapable of estimating the load of the Tigris and Zab Rivers. The Kalinske and Einstein equations gave a logical estimate of the bed load for both rivers for most of the study period. According to the Kalinske equation, the Tigris River's bed load was 7.6%, while the Lower Zab River's bed load was 10.9%. Both rates are within the typical bed load range, as seen in Figs. 10 and 11. The results of Einstein's equation showed that the percent of bed load was 2.4% and 11.8% for the Tigris River and Lower Zab River, respectively, as shown in Figs. 12 and 13. These are also logical results that fell within the natural rates of the ratio of bed load to the total sediment load. It is evident from the above that the bed load can be estimated using either the Einstein equation, the Kalinske equation, or both.

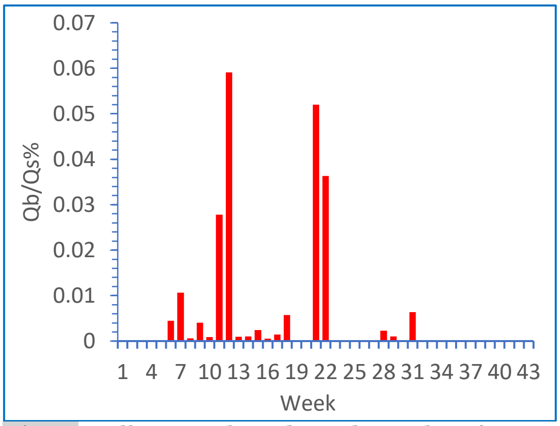

Fig. 8 Helley-Smith Bed Load Results of Tigris River.

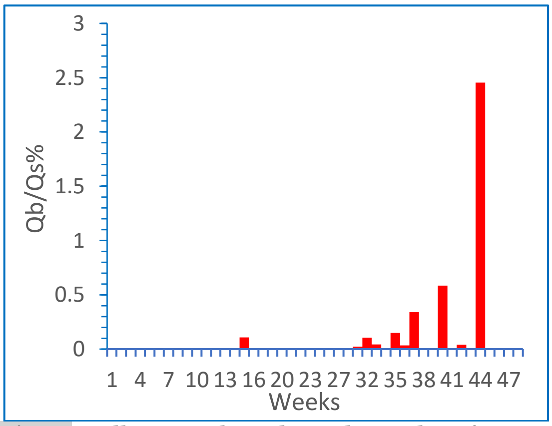

Fig. 9 Helley-Smith Bed Load Results of Lower Zab River.

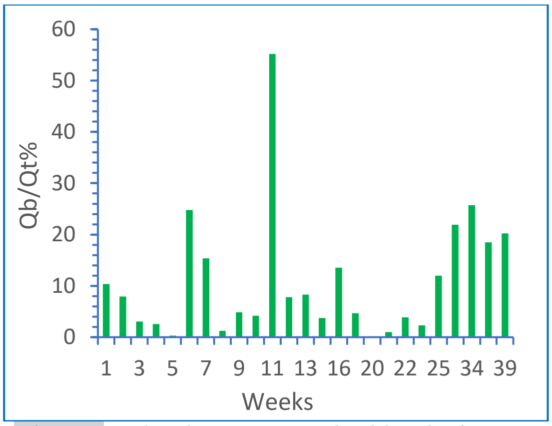

Fig. 10 Kalinske Equation bed load of Tigris River.

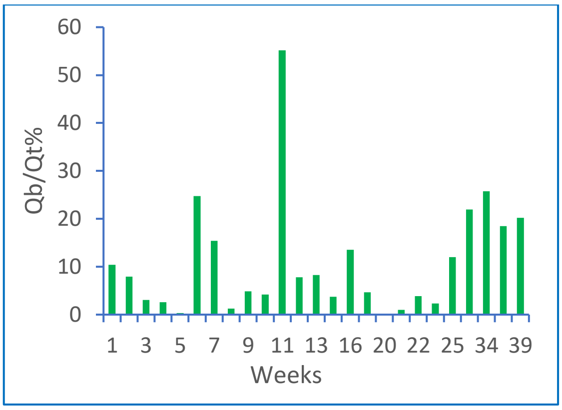

Fig. 11 Kalinske Equation bed load of Lower Zab River.

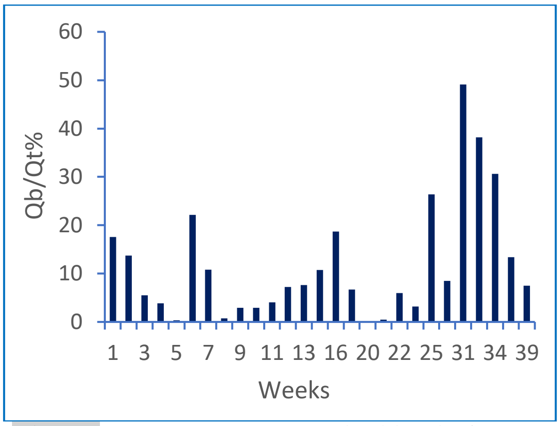

Fig. 12 Einstein's Equation bed load of Tigris River.

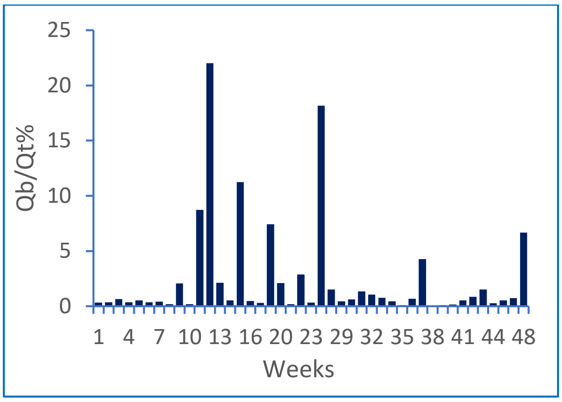

Fig. 13 Einstein's Equation bed load of Lower Zab River.

6.2.Suspended Load Sediments for Tigris River

The suspended load was related to the discharge using an exponential relationship to calculate the daily, monthly, and annual suspended load [23]. The following is inferred about the relationship between the Tigris River's flow discharge and suspended load for each of the four seasons, as depicted in Table 7.

For summer:

$$Q_s = 4 * 10^{-63} Q^{24.085} \quad (6)$$

(R^2=0.8469)

For autumn:

$$Q_s = 4 * 10^{-37} Q^{14.185} \quad (7)$$

(R^2=0.8936)

For winter:

$$Q_s = 2 * 10^{-6} Q^{3.1569} \quad (8)$$

(R2=0.8267)

For spring:

$$Q_s = 3 * 10^{-12} Q^{5.246} \quad (9)$$

(R^2=0.9882)

where:

Q_s: Suspended load sediment (ton/s), and

Q: daily discharge (m^3/s)

In the previous paragraph, the bed load was measured and estimated in several ways, and the best result obtained was the Kalinske equation of 7.6% and the Einstein equation of 2.4%. Therefore, the two results will be adopted together, and their average will be taken, which is 5%. Thus, this percentage was added to the suspended load to calculate the total sediment load. It is clear from the data above that the total amount of sediment load in the Tigris River throughout the study period fell between 4574 and 2548389 tons/month. As seen in Fig. 14, September had the lowest monthly value of sediments recorded, whereas April had the highest value because of the Tigris River floods. The entire annual load of sediments collected in the Tigris River during the research year was estimated to be around 2875461 tons.

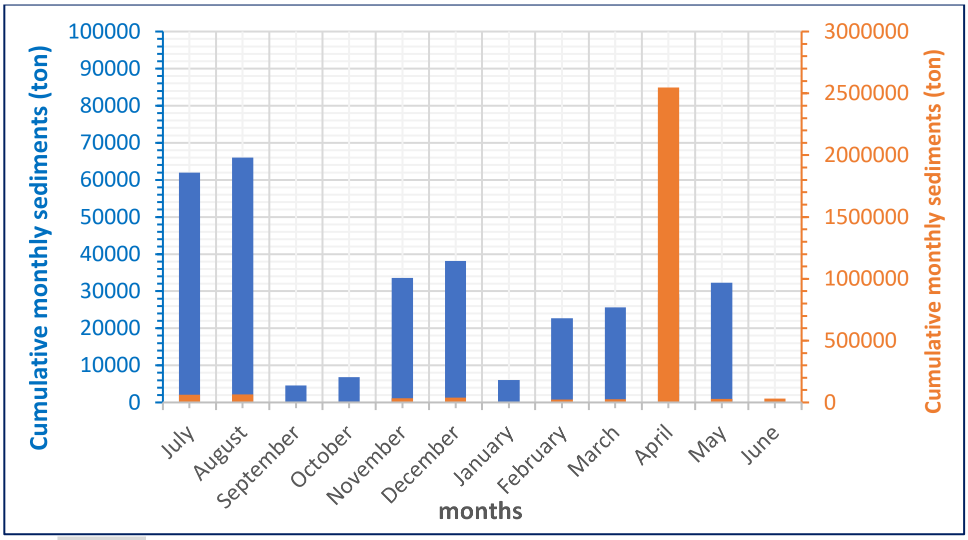

Fig. 14 Monthly Sediment Load of Tigris River During the Study Period.

6.3.Suspended Load Sediments for Lower Zab River

The relationship between the suspended load and the Lower Zab River discharge for four seasons was determined using the data collected, as indicated in Table 8.

For summer:

$$Q_s = 0.711Q^{1.617} \quad (R^2=0.9748) \tag{9}$$

For autumn:

$$Q_s = 0.0019Q^{3.0629} \quad (R^2=1) \tag{11}$$

For winter:

$$Q_s = 0.0318Q^{2.3992} \quad (R^2=0.9874) \tag{12}$$

For spring:

$$Q_s = 0.0002Q^{3.6471} \quad (R^2=0.9832) \tag{13}$$

The bed load was measured and estimated in several ways, and the best result obtained was the Kalinske equation, with a ratio of 10.9%, and the Einstein equation, with a ratio of 11.8%. Accordingly, the two results will be adopted together, and their average will be taken, which is 11.35%. Therefore, this percentage was added to the suspended load to calculate the total sediment load in the Lower Zab River. From the foregoing, it is evident that the Lower Zab River's total sediment load varied from 187 tons in September, the lowest monthly value recorded during the study period, to 1100876 tons in April, the month with the highest monthly value due to flooding. The total amount of sediment load that flowed through the Lower Zab River during the research year was calculated to be 1503739 tons, as illustrated in Fig. 15. The submerged density of the sediment varies depending on its type, the degree of its compression at the bottom, and other factors. The life of the dam depends on the annual decrease in the volume of the reservoir due to sediment entering it. The average density of submerged sediment was 1.3 tons/m^3 [23], so the annual volume of sediment entering the reservoir was 3,368,615 m^3/year.

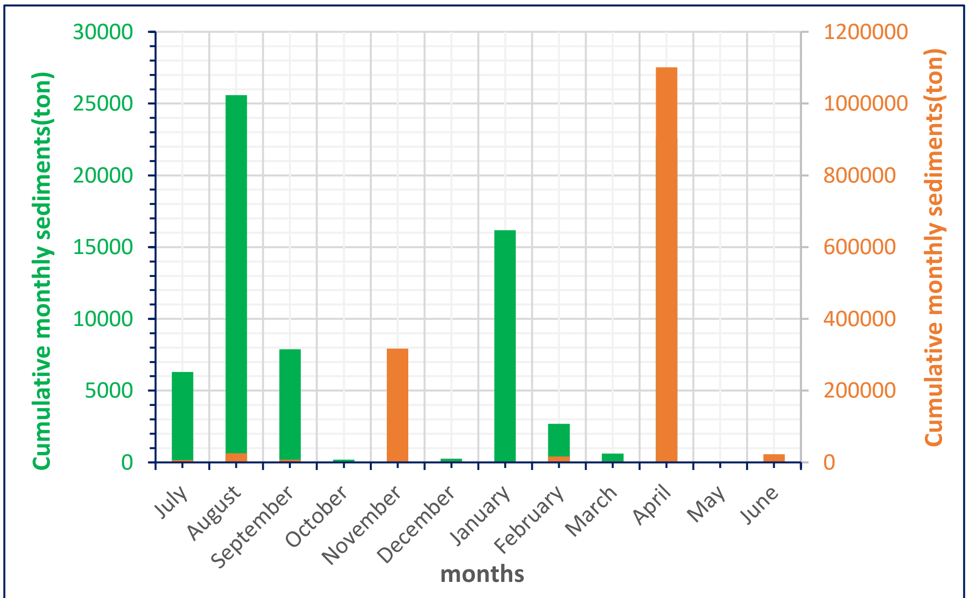

Fig. 15 Monthly Sediment Load of Lower Zab River during the Study Period.

6.CONCLUSIONS

1- This study calculated the total amount of sediment the Tigris and Lower Zab rivers would deposit annually into the Makhoul Dam reservoir. According to the findings, 4379200 tons of sediment are anticipated to reach the Makhoul Dam reservoir annually from these two rivers, with the Tigris River estimated to be around 2875461 tons, and Lower Zab River was calculated to be 1503739 tons.
2- The submerged density of the sediment varies depending on its type, the degree of its compression at the bottom, and other factors. The life of the dam depends on the annual decrease in the reservoir's volume due to sediment entering it. The average density of submerged sediment was 1.3 tons/m^3, so the annual volume of sediment entering the reservoir was 3,368,615 m^3/year.
3- It is recommended that the best engineering and economical methods be studied to get rid of the accumulated sediments in the dam reservoir by increasing the percentage of dead reservoirs or bypass tunnels, reducing the sediments entering the reservoir by using traps or secondary dams, reducing the efficiency of the trap, methods of removing Sediments of hydraulic and mechanical types, or finding new and innovative ways to remove or minimize sediments.
4- Study of a project concerned with addressing and reducing the problem of sedimentation by exploiting the vegetation cover of the area to reduce soil erosion and thus reduce sediment reaching the dam reservoir.

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