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Experimental Approach for Bed Load Transport of Non-Uniform Sediment of the Nile River, Egypt

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ملخص البحث:
يعتبر فهم حركة رسوبيات مواد القاع فى الانهار من الامور المهمة في علم الجيومورفولوجيا الهيدروليكية حيث أن الهدف الرئيسي من دراسة حركة إنتقال رسوبيات مواد القاع فى الانهار هو التنبؤ بالمعدل السنوى للرواسب فى الانهار لما له من أهميه قصوى في تصميم أعمال المنشأت المقامه على الانهار ، وتحسين الملاحة النهريه، وتقييم مخاطر الفيضانات ، وإستقرار ميول القنوات وأحواض الترسيب. الهدف الرئيسي من هذا البحث هو دراسة تأثير حركة رسوبيات مواد القاع ذات التدرج الحبيبى الغير المنتظم في نهر النيل فى مصر وذلك من خلال إستخدام معادلات رياضيه مبنيه على إختبارات معمليه للتنبوء بمعدل حركة رسوبيات مواد القاع مثل معادلة Myer Peter & Muller وذلك من خلال إدخال معامل تصحيح جديد λ للمعادله والذى يعتمد على دمج خصائص مواد القاع ذات التدرج الحبيبى الغير منتظم (d_{50}, d_{90}, d_{10}, σ_g) وذلك لتتناسب مع خصائص مواد القاع لنهر النيل فى مصر حيث أكد هذا البحث إمكانية تحسين معدل التنبؤ لمعادله MPM حتى يمكن تطبيقها على ظروف نهر النيل في مصر بدقة عالية.

ABSTRACT:

To improve the predictions of bed load transport rates using empirical formulas. Field measurements along the Nile River in Egypt were collected using Delft Nile Sampler (DNS) and employed to enhance the prediction of MPM formula. The formula was improved by introducing a correction factor λ based on characteristics of sediment mixture and shear stress parameter T. Field measurements were used to compare between different bed load transport formulas in terms of the accuracy and reliability, including van Rijn (1984a), and the modified van Rijn equation This research confirmed the possibility of improving the predictions of MPM formulas by incorporating the effect of a non-uniform sediment mixture and shear stress parameter T. The results of the modified MPM equation was verified using 13 experimental flume tests which was conducted at the hydraulics research institute (HRI), Delta Barrage, Egypt. The research confirmed that the modified MPM formula can be applied to the Nile River conditions in Egypt with good accuracy.

Keywords: Field measurements, bed load transport, Nile River, Myer Peter and Muller, sediment mixture, bed load transport formula

1. INTRODUCTION

Due to inaccuracies and uncertainties associated with bed load transport, field measurements are often collected to calibrate the formulae. Calibration of bed load formulae with field measurements is known to improve accuracy (Wilcock 2001)[1], but bed load sampling is both expensive and difficult, which leads some practitioners to simply apply bed load formulae without calibration (Doyle et al. 2007)[2].Various types of formulas are available to predict the bed load, suspended load and transport rates.

Each of them are based upon varying theoretical consideration, statistical interpretations of basic data. The majority of these relationships have been developed to sand bed channels. These formulas are often segregated into bed load, suspended load, and wash load. They may sometimes also be segregated into bed material load and wash load the comparison of bed load transport formulae is not a new idea. Numerous comparison studies of total sediment load (including suspended load and bed load) have been conducted over the past decades (e.g., Chien 1956 [3]; Yang and Molinas 1982[4]; Van Rijn 1984[5]).Although most of these studies favor sand bed channels, a few studies also include elements pertinent to coarse bed channels (e.g., Karamisheva et al[6]. 2006; Molinas and Wu 2001[7]; Pacheco- Ceballos 1989[8]; Wu et al. 2000[9]).Yang and Huang (2001)[10] used large flume data to test a series of formulae that included mostly total load equations with a few interspersed bed load transport equations. They also referenced an additional 12 total load comparison studies largely dealing with total load formulae and sand-bed channels. McLean (1980)[11] reported that very little effort had been made to test bed load predictive formulae on gravel bed streams until that time. McLean (1980) used field data from five rivers (Vedder River near Yarrow, Canada; Elbow River near Bragg Creek, Canada; North Saskatchewan River at Nordegg, Canada; Snake River near Anatone, Washington; and Clearwater River near Spalding, Florida) to compare the MPM formula to the Einstein (1950) and Ackers and White (1973) equations. Results showed, for example, that the MPM formula over-estimated bed load transport and produced significant erroneous zero-transport predictions. Gomez and Church (1989)[12] observed that there were more bed load equations than reliable datasets for comparison of coarse bed streams. They used 358 measurements, 90 of which came from flume experiments and the rest from field sampling, to test 12 predictive equations including the MPM formula on gravel bed streams. Most of the formulae over predicted bed load transport, and none of the formulae, including MPM, provided satisfactory results. Consequently, none of the formulae was recommended for use in predicting bed load transport. As part of their study, Gomez and Church (1989) indicated that bias between measured and calculated values could be minimized by shifting the formula as long as the trend of the formula matches the data, which is a form of calibration. Reid et al. (1996)[13] used data from Nahal Yatir, an ephemeral stream located within the Negev Desert, to perform a comparison study of six bed load equations. Their work was unique because the bed load was transport-limited, indicating the gravel- bed stream had no armor layer due to the high amount of available sediment. The tested equations included the MPM and Parker Surface based on the 1990 formula (Parker 1990). The results indicated that the MPM and Parker (1990) formulae provided satisfactory results. The MPM formula was the most accurate predictive formula, but it was sensitive to the selected representative diameter. The best results for the MPM were reported when using adiameter weighted by the decimal portion of the sample in each size fraction. Three bed load comparison studies were published in 2003. Almedeij and Diplas (2003)[14] used 174 measurements from three gravel-bed streams to test four equations, one of which was the MPM. None of the equations performed well and often over or under predicted the transport by one or two orders of magnitude. Bravo-Espinosa et al. (2003)[15] used 1,020 measurements from 22 gravel-bed streams to test seven equations, one of which was the MPM. Although it was not the best predictor, the MPM formula did relatively well at predicting sediment transport in transport- limited situations. Martin (2003)[16] used data from the Vedder River in Canada to test four formulae, including the MPM. She reported that all four formulae tended to under predict bed load transport and that the MPM often inaccurately predicted zero transport. Barry et al.

(2004)[17] used 2,104 measurements from 24 gravel bed rivers in Idaho to test eight different variations of four bed load transport equations including two versions of the MPM formula. In addition to the equations evaluated here, they propose a new empirical formula that can be calibrated using sub-basin characteristics. In their study, formulae with thresholds (such as the MPM) performed poorly and often erroneously predicted zero transport and site-specific hiding functions did not guarantee better results than off-the-shelf functions .

This research uses bed load measurements along the Nile River, Egypt to develop a new correction factor λ to MPM formula by incorporating the effect of a non-uniform sediment mixture and shear stress parameter T to be suitable to be applied on the Nile River, Egypt with good accuracy. The modified formula was verified using flume tests to extend the range of its application.

2. DATA COLLECTION

All field measurements used in this research were conducted by Hydraulics Research Institute (HRI) of the National Water Research Centre (NWRC), Egypt survey team and equipment using Delft Nile Sampler (DNS) (van Rijn, L. C., and Gaweesh, M. T. (1992))[18]. Main topographic and hydraulic characteristics of the collected data were described previously (Abdel-Fattah et al. 2004[19]; Amin 1999[20]). Measuring locations were chosen to cover the entire length of the Nile River starting from downstream (OAD) ending at upstream Delta Barrage. The first measuring location was divided into eight measuring sites at Bani Mazar city[20], the second measuring location was divided into six measuring sites at El–Korimat city[21], the third measuring location was divided into six measuring sites at Aswan city[22], the fourth measuring location was divided into six measuring sites at Quena city[23] and the fifth measuring location was divided into six measuring sites at Sohag city[24]. Those measuring sites locations were chosen to give an accurate representation of bed load discharge along the entire length of the Nile River. Measured data was analyzed and used to compare between measured and predicted bed load transport rate using different formulas.

3. ANALYSIS OF COLLECTED DATA

Collected data was analyzed and relation between parameters was estimated, the result of the analysis can be summarized as follows:

1. The values of the uniformity coefficient (Cc) and (Cu) for the collected sediment samples along the Nile river revealed that the bed materials of the Nile River are non-uniform, Where the uniformity coefficients ranges between 1.73 to 2.24 for Cu, Cc ranges between 0.89 to 1.17.

2. The transport of non-uniform bed materials in the Nile River is influenced by grain size characteristics and the flow conditions which can significantly change the shear stress acting on the transported bed load which studied in another research.
3. Shear stress parameter T increase when flow velocity is more than 0.4 m/s.
4. The bed load transport rate in the Nile River increase when shear stress parameter T value more than 3.
5. Overall Chezy Coefficient (C) increase when flow velocity increase.
6. The bed load transport rate increase when flow velocity increase more than 0.6 m/s.

4. COMPARISON BETWEEN MEASURED AND COMPUTED BED LOAD TRANSPORT RATE USING DIFFERENT FORMULAS

Measured bed load transport along the Nile River was compared with computed bed load transport using different prediction well known formulas as Mayer Peter and Muller (1948)[25], Van Rijn (1984) and modified Van Rijn (1998). Those formulas were chosen because they were developed under hydraulic and sediment conditions suitable for sand bed rivers and suitable to be applied on the Nile River condition. Figure (1) shows comparison between measured and computed bed load transport using the mentioned formulas. Table (1) shows the statistical characteristics of the errors for different equations using measured data of the Nile River, including the average, minimum, and maximum errors and variation coefficient of the errors.

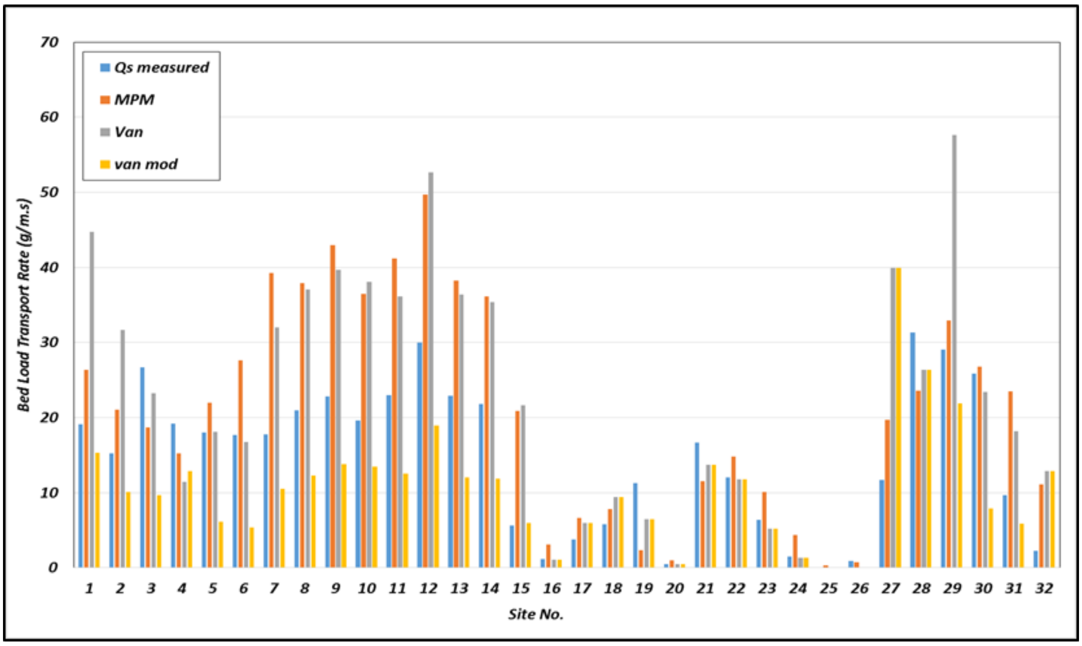

Fig. 1: Comparison between Measured and Computed Bed Load Transport using Different Formulas

Table (1): Error Statistics for Different Equations using Field Data (Abdelhaleem F.S 2019)[26]

Statistical characteristics	Average, (%)	Minimum, (%)	Maximum, (%)	Variance
MPM (1948)	73.35	-79.31	382.12	89.55
van Rijn (1984a)	54.15	-99.86	460.22	121.96
Modified van Rijn	-15.84	-99.86	460.22	88.00

<u>The previous results revealed that:</u>

- The average error of the mentioned formulas indicates that the MPM formula (1948) and van Rijn (1984a) did not under predict the measured values, although, the large variances suggest that maximum error may have influenced these results.
- The prediction of the MPM equation is close to the observed data, more than the other equations.
- The MPM formula generally over predicts the bed load transport rates by a factor varying from 0.21 to 4.82.
- The bed load transport rates are over predicted when the MPM formula is applied to sediment mixtures which was studied in this research.
- The MPM formula is equation considers the transport of graded and uniform bed materials to be the same (Hunziker and Jaggi 2002)[27] and not accurate in case of non-uniform sediment mixture.

Based on the previous results it was clear that the non-uniform formula of MPM is not accurate for the case of Nile River, Egypt and need to be enhanced.

5. ADAPTATION OF MEYER PETER & MULLER FORMULA

5.1 Comparison between Measured and Computed Bed Load Transport Rate using Myer Peter &Muller Formulas

Using the method of Qi et al. (2018)[28] a statistical analysis of the predictive errors of the original MPM equation was conducted. Figure (2) shows error distributions of the original MPM Formula for all collected bed load measurements. The relation between measured and calculated bed load transport rates with respect to shear stress parameter T. Figure (3) shows comparison between measured bed load transport rate and computed bed load transport rate by MPM formula with respect to bed shear stress (T).

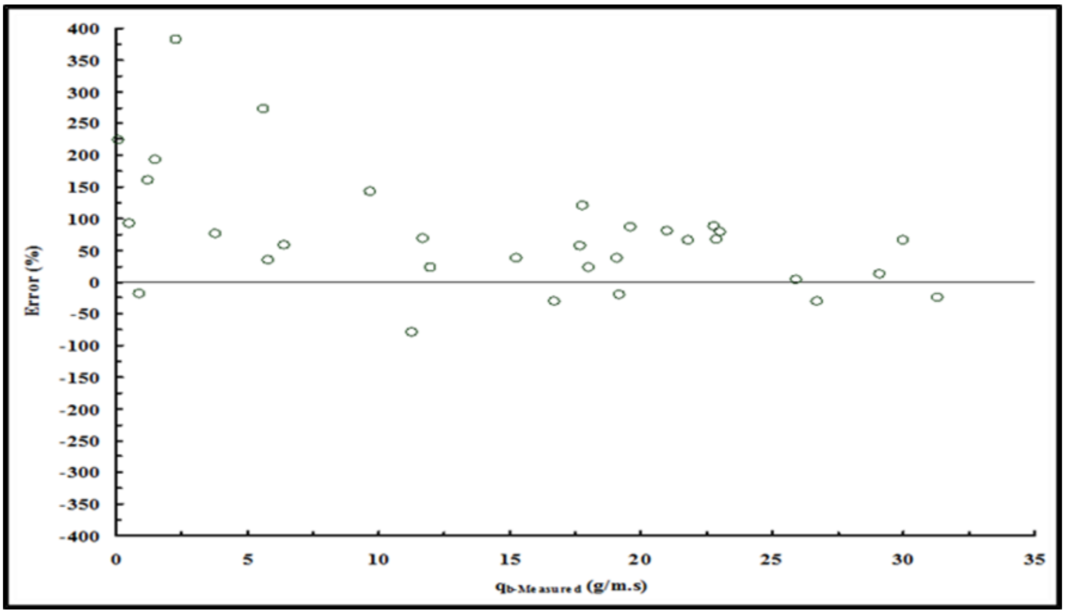

Fig. 2: Error Distributions of the Original MPM Formula for all Field Data

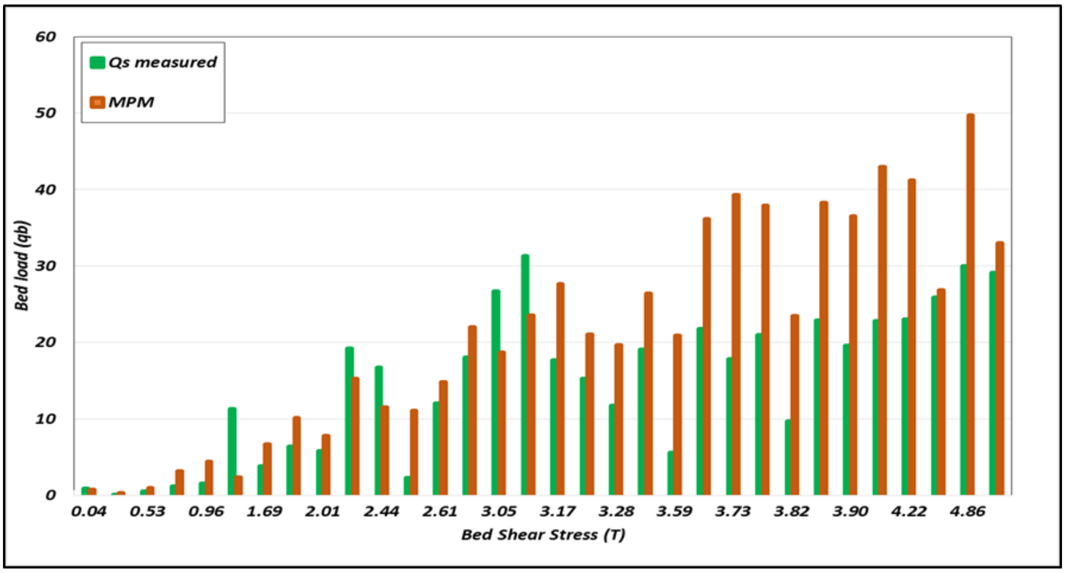

Fig.3: Comparison between Measured Bed load Transport rate and Computed Bed Load Transport rate by MPM formula with respect to bed shear stress (T**)**

From the previous results it was concluded that.

- A statistical analysis of the predictive errors of the MPM equation is located in the range between −50 and +100%. Where the positive values indicate over predict and the negative values indicates under predict.
- MPM formula predict the measured values until the value of shear stress parameter T less than 3 however the formula over predict the measured vales when T more than 3.

5.2 Modification of Myer Peter & Muller Formula

MPM presented an empirical formula for uniform sediment based on data from experiments in flumes. The advantage of this formula is that it can be used for graded sediments under uniform flow conditions simple formula was obtained, which is frequently used to predict the bed load transport rate as follows:

$$\phi = 8\ (\mu\Theta - 0.047)^{1.5} \qquad (1)$$

Adaptation of Myer Peter & Muller equation was performed by adding correction factor λ to the original formula. The correction factor λ is dependent on the characteristics of sediment mixtures (d_{50}, d_{90}, d_{10}, d_{35} and σ_g) with respect to the value of shear stress parameter T more than 3 3 which describe the effect of the sediment gradation. Regression and statistical analysis were done by means of regression technique called data fit version 6.x program by oakdale engineering which include multi-dimensional regression model capability. By applying the mentioned regression program for the measured bed load transport rates along the Nile River. The new form of MPM formula can be written as follows:

$$\phi = 8\ (\lambda\mu\Theta - 0.047)^{1.5} \qquad (2)$$

Where:

$$\lambda = \exp\{\ a\ (d_{35}/d_{50}) + b\ (d_{50}/d_{90}) + \sigma\ c + d\} \qquad (3)$$

a, b, c and d are the regression variable results and their values as follows:

a = -0.43

b = 0.15

c = -1.68

d = 2.84

5.3. Results of the Modified Formula

The results of the modified formula was compared with measured bed load, the original MPM, van Rijn (1984a) and modified van Rijn formula (Abdel-Fattah et al. 2004). Figure (4) shows comparison between measured bed load transport rate and estimated values by MPM modified formula and other tested equations. The results of the modified formula and the original MPM formula was compared with shear stress (T). Figure (5) shows comparison between measured bed load transport rate and computed bed load transport rate by original and modified MPM formula with respect to bed shear stress (T). Figure (6) comparison between measured and calculated bed load transport rate. Figure (7) comparison between measured and calculated bed load transport rate versus the Number of Measurements.

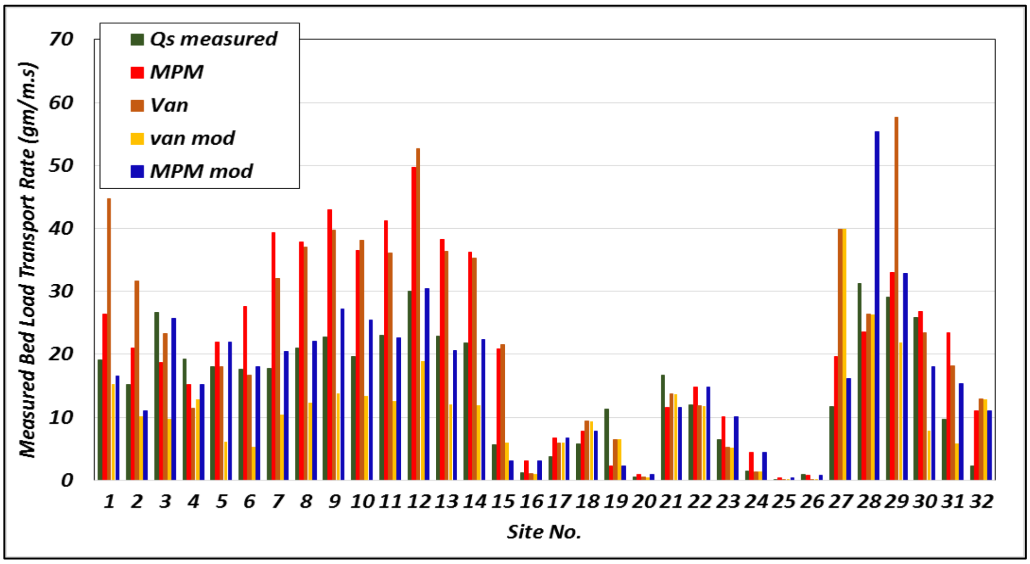

Fig.4: Comparison between Measured Bed load Transport Rate and Estimated Values by MPM Modified Formula and other Tested Equations

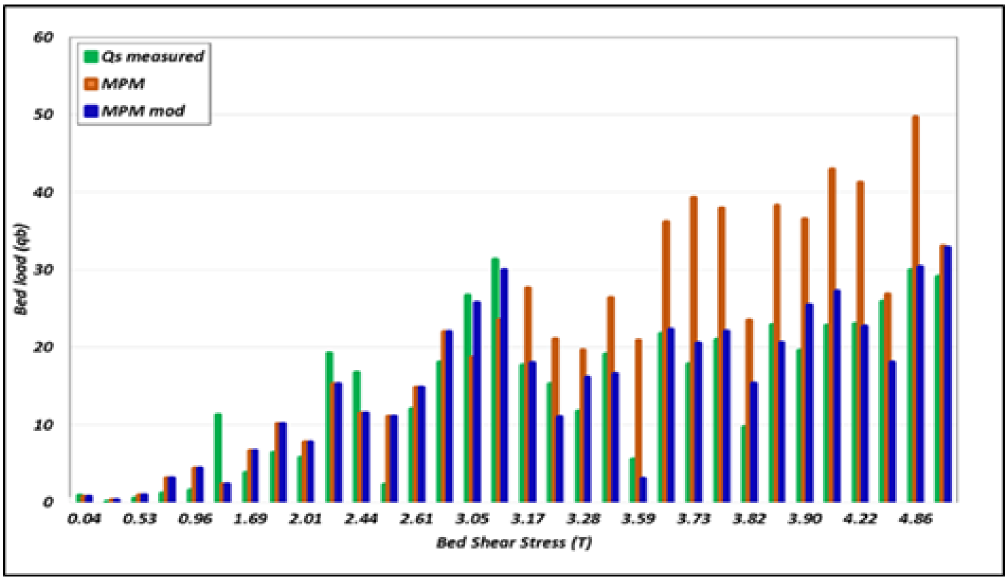

Fig.5: Comparison between Measured Bed load Transport rate and Computed Bed Load Transport rate by Original and Modified MPM formula with respect to Bed Shear Stress (T)

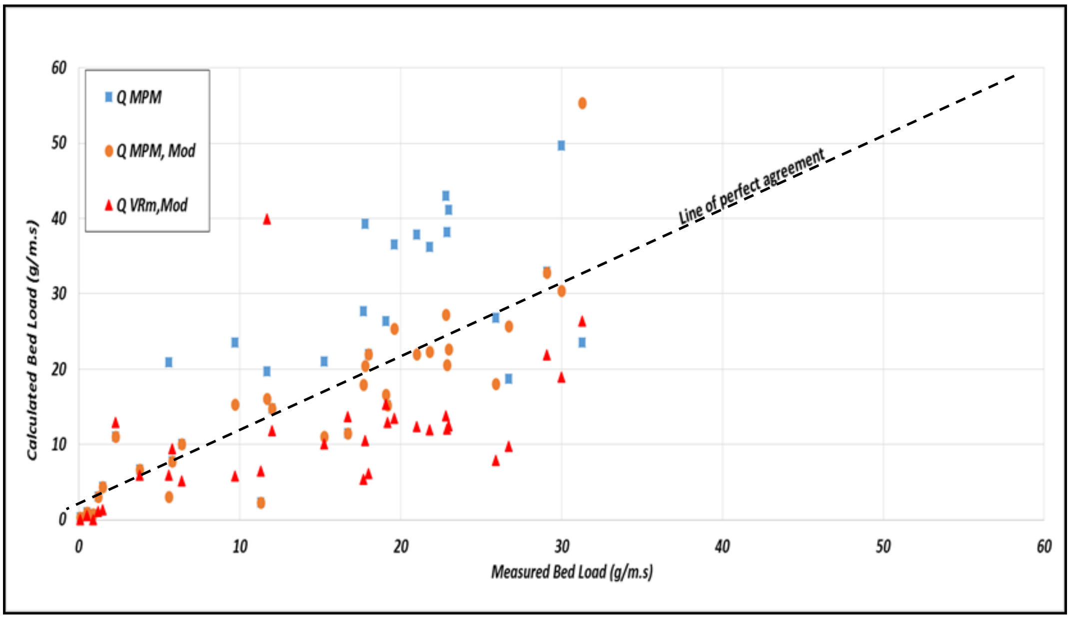

Fig. 6: Comparison between Measured and Calculated Bed Load Transport Rate

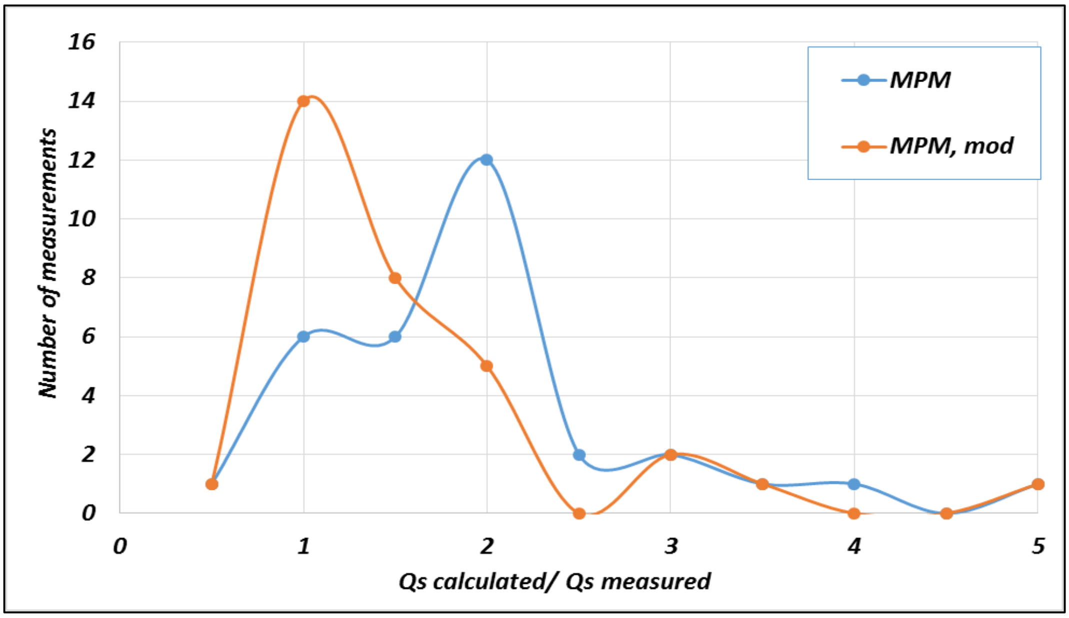

Fig.7: Comparison between Measured and Calculated Bed Load Transport Rate versus the Number of Measurements

<u>From the previous results it was concluded that:</u>

- The predicted bed load transport rate calculated by original MPM formula is quite satisfactory when T < 3.
- The prediction of MPM formula become less satisfactory when T > 3 which was studied in this research in order to improve the prediction of bed load transport rates.
- The modified MPM formula significantly improves the performance of the original MPM equation for the bed load transport rates in the Nile River it predicts the actual bed load transport rates by a factor ranging between 1.05 and 1.77.
- Referring to line of good agreement between measured bed load transport rate and calculated bed load transport rate using Van Rijn and MPM modified formulas in Figure (7), the modified formula improved the prediction of bed load transport rate.

- Comparing the calculated bed load transport rate divided by the measured ones versus the number of measurements indicates that the modified formula of Myer peter & Muller gives a better results than the original formula in the case of the Nile River, Egypt.

The previous results proved that the modified MPM equation is more suitable for the Nile River conditions than other equations. the new form of the MPM equation is highly recommended for practical use under Nile River conditions.

6. VERIFICATION OF THE MODIFIED FORM OF THE MPM EQUATION

Verification of modified MPM formula was performed using a set of 13 experimental flume tests. All tests of this research were conducted at the flume at the Hydraulics Research Institute (HRI), delta barrage, Egypt within the period of September 2017 to December 2018. The flume tests were conducted under different uniform flow conditions and the characteristics sediment mixtures used in the tests was chosen carefully to cover the mean grain size (d_{50}) of the Nile River, Egypt.

6.1 Description of the Flume

Before starting tests and in order to simulate the characteristics of the sediment mixture of the Nile River. Sand used flume tests was sieved using three large rectangular standard sieves dimension of 0.85 mm, 0.500 mm and 0.355 mm respectively. Each amount of sand retained on each sieve was separated individually then mixed with tested ratios to cover the characteristics of sediment mixture d_{50} in the Nile River which is the main objective of the research. The study tests were performed at a horizontal flume 23 m long, the channel has a rectangular section which is 0.73 m wide and 0.80 m high. For most of the experiments both flume wall sides were of concert except for 3.5 m long of flume is from transparent plastic (Plexiglas) to allow visual investigation of the bed profile and water surface profile. The bed of the flume is made of concrete and covered with sand mixture with 0.16 m thickness. Water enter the flume from underground tank total capacity of 80 m^3 by centrifugal pump with total discharge of 0.2 m^3/ s (200 l/s). The flume was operated as a closed circulating discharge system. The tail water depth was controlled at the downstream end of the flume using tail gate. Figure (8) shows experimental flume details. the flume was operated as manual sand feed system using sand feeding box dimension of (0.74 m* 0.30 m * 0.30 m) provided with four pipes at the bottom of the box with 1 inch diameter and 15 cm apart, this box was placed just upstream the flume to provide constant sand feeding rate with respect to test time. A Sediment trap dimension of (2 m * 0.74 m * 0.2 m) was constructed at the downstream end of the flume floor to collect sediment load transport during the different study tests. Water escaped through screens at the side wall of the sediment trap while all the sand settled to the bottom then collected, dried and weighted for each scenario to determine the transport rate with respect to test time.

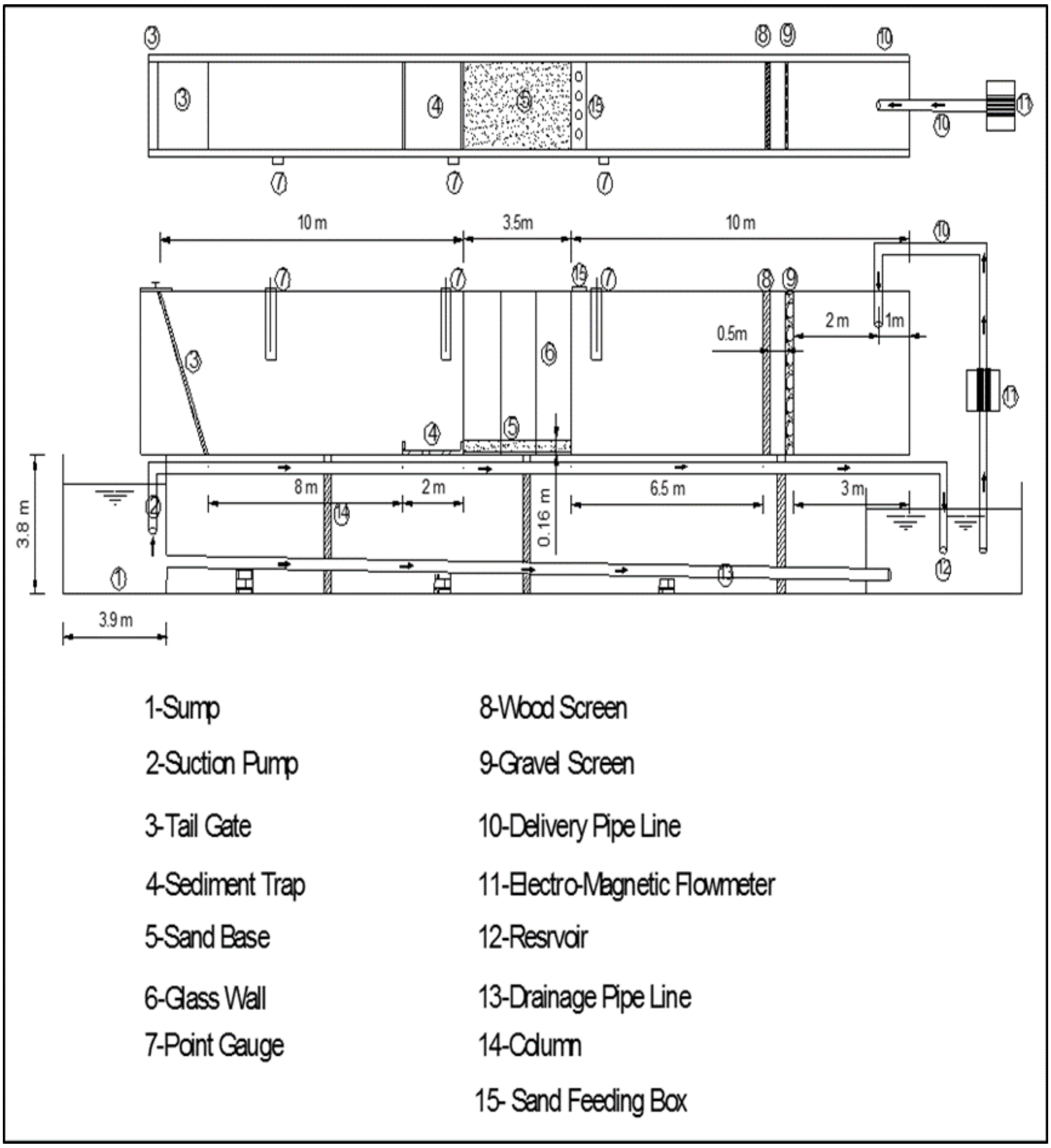

Fig. 8: Experimental Flume Details

6.2 Methodology of Flume Tests

Validation of the modified of Myer Peter & Muller formula was conducted using 13 flume tests. The velocity during tests ranges between 0.43 m/s to 0.80 m/s and the grain size diameter (d_{50}) for all tests ranges between 0.43 mm to 0.69 mm. All tests parameters were carefully chosen cover the range of velocities and characteristics of mean grain size of sediment in the Nile River based on the analysis of collected data. The study tests were classified into two groups this classification was done by means of constant mean particle diameter d_{50}. Group (A) study the influence of d_{50} ranges between 4.70 mm to 6.58 mm and average velocities ranges between 0.53 m/s to 0.67m/s. Group (B) study the influence of d_{50} ranges between 4.55 mm to 6.93 mm and average velocities ranges between 0.43 m/s to 0.80 m/s. Table (2) shows boundary conditions for test groups.

Table (2): Boundary Conditions of Test Groups

Group	Test No.	Flow condition			Sieve analysis of the bed material				
		U (m/s)	H (m)	I 10^{-4}	d_{10} (mm)	d_{35} (mm)	d_{50} (mm)	d_{90} (mm)	σ_g
Group A	1	0.53	0.35	2.00	2.42	3.65	4.87	8.39	1.48
	2	0.56	0.38	2.04	2.47	3.78	5.09	8.56	1.67
	3	0.58	0.36	4.67	3.41	5.00	6.58	9.48	1.52
	4	0.55	0.32	2.00	2.45	3.58	4.70	8.00	1.624
	5	0.62	0.32	3.24	3.16	4.71	6.25	9.38	1.54
	6	0.67	0.30	2.41	3.22	4.73	6.23	9.37	1.54
Group B	7	0.46	0.38	2.75	3.03	4.98	6.93	9.61	1.27
	8	0.72	0.25	3.66	4.50	5.70	6.89	9.37	1.48
	9	0.60	0.28	1.00	3.07	4.10	5.12	9.23	1.55
	10	0.43	0.25	3.35	3.81	4.47	5.12	9.51	1.46
	11	0.64	0.26	2.60	3.30	4.31	5.32	9.63	1.46
	12	0.80	0.30	2.55	2.45	3.50	4.55	7.96	1.64
	13	0.58	0.36	4.67	3.41	5.00	6.58	9.48	1.52

6.3 Experimental Conditions

Before starting the experimental work the following boundary conditions had to be taken in consideration.

- Flow regime.
- Limitation with respect to sediment mixture.
- Flow dimension and maximum water discharge.

6.3.1 Flow regime

In this research the flow is considered steady flow and the $f_r < 0.4$ ($f_r = u/(\sqrt{gh}) < 0.4$) for all the study cases with different sand mixtures.

6.3.2 Limitation with respect to sediment mixture

In order to carry out the study tests at different flow conditions the variation in bed material in grain size is not allowed to be too large because the coarse fraction could not reach the threshold of motion condition while the finer fraction will go in suspension. The non-uniformity for the sand mixture used in tests was achieve, where (cu < 4 or cc > 3 or cc < 1) for the sand mixture used in tests. Table (3) shows the values of uniformity coefficient for the sand mixture used in the study test.

Table (3): Values of Uniformity Coefficient (Cu, Cc) of Sand mixture Used in Tests

TEST NO.	d_{60}	d_{10}	d_{30}	Cu	Cc
1	0.744	0.341	0.514	2.18	1.04
2	0.705	0.316	0.487	2.23	1.06
3	0.703	0.322	0.484	2.18	1.03
4	0.579	0.247	0.379	2.34	1.00
5	0.772	0.388	0.55	1.99	1.01
6	0.76	0.381	0.54	1.99	1.01
7	0.455	0.203	0.287	2.24	0.89
8	0.519	0.245	0.35	2.12	0.96
9	0.534	0.245	0.369	2.18	1.04
10	0.522	0.242	0.425	2.16	1.43
11	0.549	0.307	0.445	1.79	1.17
12	0.571	0.33	0.462	1.73	1.13

6.4 Experimental procedures

Before starting tests some individual variables have to be set up for controlling sediment-transport rates those variables are water discharge, mean velocity, mean water depth and sediment characteristics (size distribution, shape, and density) and other variables, such as water temperature, which have influence under certain conditions.

- The flume bed was covered with the same sand mixture used in feeding during tests with thickness of 0.16 m. the variation of sand bed grain size was chosen to be not too large because the coarse fraction couldn't reach threshold motion and the fine fraction will go in suspension.
- Constant amount of sand per unit time was determined from the transport rate to be continuously flushed manually into the flume using the sand feeding box to distribute the sediment load regularly at the entrance of the flume. This amount of sand was changing after each time set with respect to the amount of collected sand in the sediment trap with respect to each test requirements.
- Designed flow discharge for the test requirements was adjusted using electromagnetic flow meter to enter the flume at constant rate during test duration. The test.
- Water depth was adjusted before starting each test using flip gate located at the downstream end of the flume.
- Flow velocity was measured before staring each test using electromagnet current meter at three locations distributed along the flume bed.

- Water temperature was measured before and after running each test using infrared thermometer with laser pointer.

6.5 Running the experiment

Running each test for set of working hours about 5 hours a day. After each set of working hours the amount of sand in escaped in the sediment trap was collected weighted then divided on the test duration to determine the transport rate then flushed again into the flume using the sand box during test the previous steps were repeated until equilibrium of the test was achieved when water surface profile and bed slop remain the same over time and the amount of sand in sediment trap equal the amount of sand flushed into the flume using sand feeding box during all test duration. The equilibrium was achieved for most tests after about time ranging between 80 to 160 hour from beginning test.

6.6 Measurements after Equilibrium

1. **Water Slop Measurements**

Water surface slope was measured after equilibrium of each test using three point gauges distributed long the flume and installed within stilling wells hinged at the walls of the flume with accuracy of ± 0.1 mm.

2. **Water Depth Measurement**

Elevations of the water depth after equilibrium was measured to the nearest 0.1 mm using 3 point-gages distributed along the flume. The elevation difference between the point gauges give the water depth.

3. **Velocity Measurements**

Three velocity measurements V_1, V_2, V_3 distributed along the flume were measured after the equilibrium using electromagnet current meter. The average mean velocity V_m was determine.

4. **Sediment-Transport Rate Measurements**

- The water-sediment mixture leaving the flume fell into a sediment trap. Water escaped through screens at the side wall of the sand trap while all the sand settled to the bottom.
- The amount of sand in the sediment trap was collected and weighted. The total bed load transport rate q_t was determined from the average mass of dry sand collected in the sand trap with respect to actual test time average.
- The difference between the actual bed load transport rate ($q_{t,avg}$) and time average suspended load transport rate (q_s) was used to as to estimate the bed load transport rate, equation (1) determine the actual bed load transport rate.

$$qs = \int_a^h [u * c * dz] \qquad (1)$$

Where

a = thickness of the bed load layer

h = water depth

u = flow velocity (m/s)

c = suspended load concentration (g /m^3)

It was observed that the suspended load was relatively small with compered with bed load of during all study tests so it can be neglected.

5. **Check on Sediment-Transport Rate**

In order to check on the sediment transport rate at the end of each test , sand box dimension of (0.20 m × 0.20 m × 0.10 m) and volume of the 0.004 m^3 was immerged in the flume sand floor to be filled with sediment load during test feeding time. The sand collected in box was weighted, dried and sived after each test. The total bed load transport rate q_t was determined from the average mass of dry sand collected in the box with respect to average box filling time. This step was used to gives an accurate estimation of the sediment transport rate during the study tests and to check on the sediment transport rate calculated from the collected sediment in sediment trap.

6. Collected Sediment from flume bed

The quartz sand used for the experiments was fairly non-uniform in size with a median sieve diameter ranging between 0.658 mm to 0.445 mm. Transported material trapped in the sediment trap had virtually the same size distribution as the material remaining on the flume bed. Three bed samples were taken at three different locations along the flume bed. A sieve analysis test was performed to each sample individually to determine the bed sample characteristics.

7. Results of Flume Tests

Results of each test was analyzed and relations between parameters were estimated to use the results in validating the modified Myer Peter & Muller formula. Table (4) shows parameters of flume tests results.

Table (4): parameters of Flume Tests Results

Test no.	y (m)	Sx10^{-3} (-)	u (m/s)	d_{10} (mm)	d_{35} (mm)	d_{50} (mm)	d_{90} (mm)	σ_g (-)	d_m (mm)	ν x 10^{-6} (m^2/s)	τ_{cr} (N/m^2)	q_b g/m.s
1	0.35	2.00	0.53	0.24	0.36	0.49	0.84	1.479	0.44	0.98	0.35	13.00
2	0.38	2.04	0.56	0.25	0.38	0.51	0.86	1.669	0.46	1.01	0.35	9.00
3	0.36	4.67	0.58	0.34	0.50	0.66	0.95	1.524	0.59	1.01	0.35	14.22
4	0.32	2.00	0.55	0.25	0.36	0.47	0.80	1.624	0.56	1.00	0.35	5.63
5	0.32	3.24	0.62	0.32	0.47	0.63	0.94	1.544	0.50	1.00	0.38	29.28
6	0.30	2.41	0.67	0.32	0.47	0.62	0.94	1.54	0.56	0.84	0.38	33.78
7	0.38	2.75	0.46	0.30	0.50	0.69	0.96	1.727	0.42	1.00	0.224	8.85
8	0.25	3.66	0.72	0.45	0.57	0.69	0.94	1.48	0.34	1.00	0.25	22.52
9	0.28	1.00	0.60	0.31	0.41	0.51	0.92	1.55	0.46	1.00	0.28	13.51
10	0.25	3.35	0.43	0.38	0.45	0.51	0.95	1.461	0.46	1.00	0.27	7.88
11	0.26	2.60	0.64	0.33	0.43	0.53	0.96	1.465	0.48	1.00	0.28	31.53
12	0.30	2.55	0.80	0.25	0.35	0.46	0.80	1.637	0.41	0.87	0.29	40.54
13	0.36	4.67	0.58	0.34	0.50	0.66	0.95	1.524	0.59	1.01	0.321	13

7.1 Analysis of Flume Tests

The measured bed load rate from all tests were compared with the estimated bed load rate from the original and modified Myer Peter & Muller formula. Figure (9) shows comparison between measured and computed bed load transport rate using original and modified MPM formula. The relation between the original and modified formula with respect to shear stress parameter T was estimated as shown in figure (10). Figure (11) shows comparison between measured and calculated bed load transport rate versus the number of measurements.

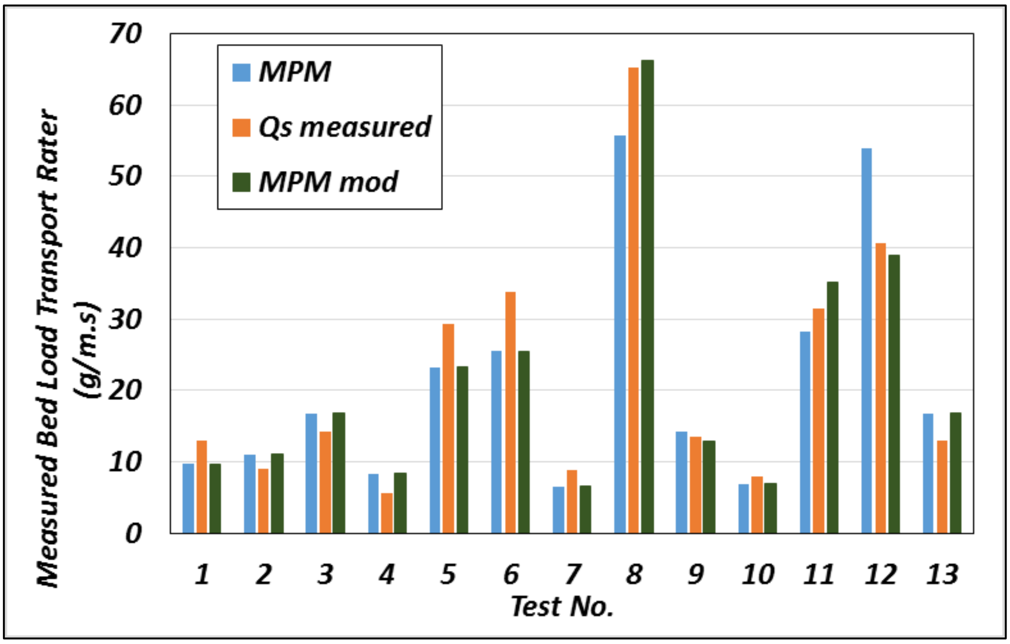

Fig. 9: Comparison between Measured and Computed Bed Load Transport Rate using Original and Modified MPM Formula

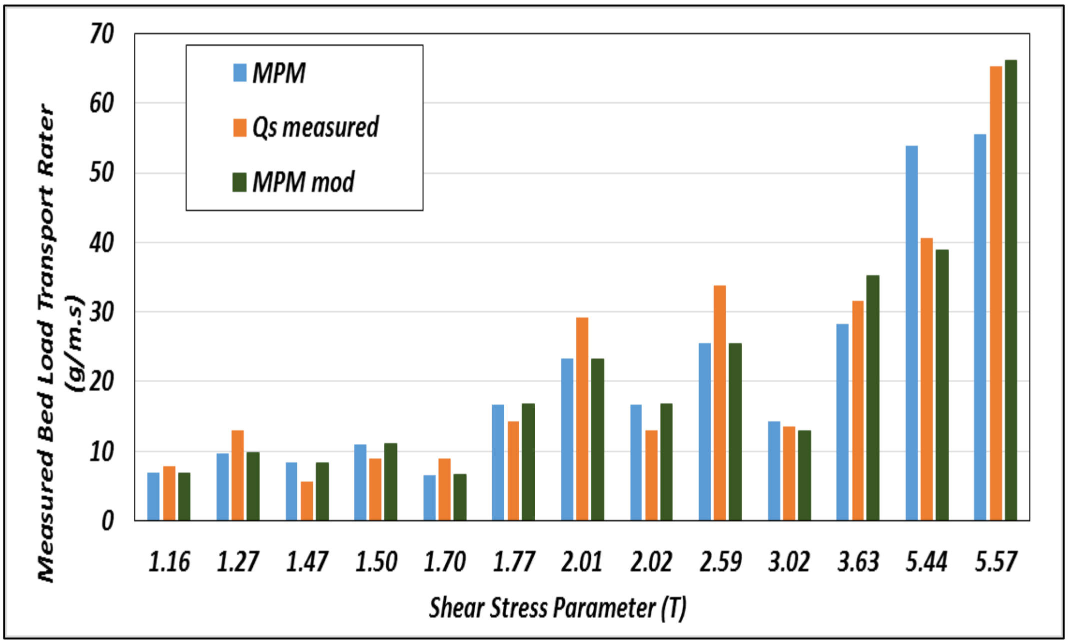

Fig.10: Comparison between Measured and Computed Bed Load Transport Rate using Original and Modified MPM formula versus Shear Stress Parameter (T)

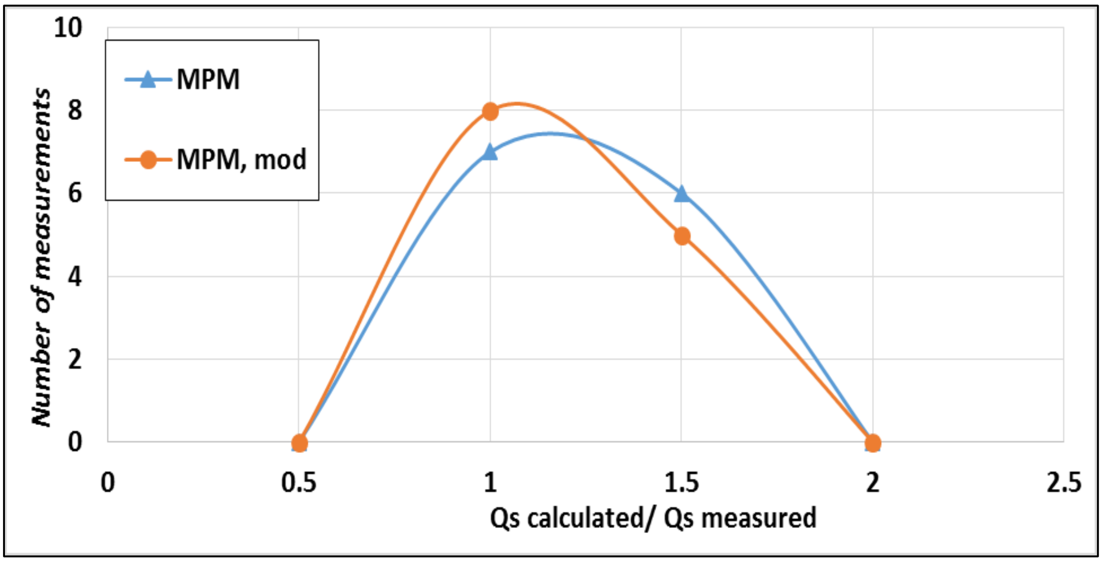

Fig. 11: Comparison between Measured and Calculated Bed Load Transport Rate versus the Number of Measurements

<u>The results of the flume tests revealed that:</u>

- The non-uniformity of sediment mixture also has an effect on the prediction bed load transport rates.
- The modified MPM equation shows good agreement with the results of all the tests which means that the new form of the MPM equation performed better under laboratory conditions compared with the original MPM formula than those obtained based on the field data.
- The predictions of the original MPM equation are satisfactory for low rates of bed load transport and small dimensionless bed shear parameters ($T \leq 1.8$).
- The modified MPM equation results is uniformly distributed around the value of (qb-estimated/qb-measured= 1).
- The modified MPM equation is suitable for laboratory and basic investigations and can be applied for Nile River, Egypt with good accuracy.

7. CONCLUSION

Based on the results, analysis and the estimated relations between parameters it was concluded that:

1. The values of the uniformity coefficient (Cc) and (Cu) for the collected sediment samples along the Nile river revealed that the bed materials of the Nile River are non-uniform.
2. The transport of non-uniform bed materials in the Nile River is influenced by grain size characteristics and the flow conditions which can significantly change the shear stress acting on the transported bed load.
3. The comparison of the measured bed load transport rate and estimated bed load transport rate using different tested equations revealed that the prediction of bed load transport rate using MPM equation is close to the measured data more than the other equations.
4. MPM formula predict the measured values until the value of shear stress parameter ($T \leq 1.8$), however the formula over predict the measured vales when (T) more than 3.

5. By introducing correction factor λ dependent on the sediment mixture characteristics to the original form of MPM formula the prediction of bed load transport rate was improved.
6. The modified form of MPM equation shows good agreement with the results of all the tests which means that this new form of the MPM equation performed better under laboratory conditions compared with the original MPM formula.
7. The modified MPM equation results is uniformly distributed around the value of ($q_{b\text{-estimated}}/q_{b\text{-measured}}$= 1), and the modified MPM equation produces better results than those obtained from the original MPM formula.
8. The modified form of MPM equation is suitable for laboratory and basic investigations.
9. The modified form of MPM can be applied for Nile River conditions in Egypt with good accuracy.
10. The new modified formula is highly recommended for practical use. However, care must be taken when applying Equation to address the transport of bed materials under other conditions because the procedure proposed in this study for developing the correction factor is based on a limited number of field measurements.

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NOTATION

The main variables used in this paper are listed as follows.

t	Temperature
h	Water depth
I	Energy gradient
U	Time average velocity
d_{35}	The size at which 35% by weight is finer
d_{50}	The size at which 50% by weight is finer
d_{90}	The size at which 90% by weight is finer
d_m	Average diameter of bed material
σg	Standard deviation of sediment mixture
Ѵ	kinematic viscosity coefficient
$\tau_{b,cr}$	Critical bed shear stress
u^*	Total bed shear velocity
D^*	Dimensionless particle diameter
C	Overall chezy coefficient
Ć	Grain related chezy coefficient
τo	Laursen bed shear stress
τb	Bed shear stress
τci	Critical shear stress from due to grain resistance
T	Dimensionless bed shear parameter
μ	Bed form factor or efficiency factor
ϴ	Mobility (shield) parameter
$ϴ_{cr}$	Critical shield parameter

Ks Effective bed roughness
g Gravity acceleration
Qs Measured bed load
Cu uniformity coefficients
Cc uniformity coefficients
q_b volumetric Bed load transport rate
ϕ dimensionless bed load transport rate(-)
λ_{mod} correction factor

ABBREVIATION

D.N.S :Delft Nile Sampler
HRI :Hydraulic Research Institute
MPM :Myer Peter & Muller
NWRC :National Water Research Center
O.A.D :Old Aswan Dam

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