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Bedform effect on the bed-load transport rate using a comparison between two bedform (flat and standing bedform)

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ABSTRACT

In this research, the impact of bedform on the bed - load transport rate was studied through experiments. The experiments were conducted on two cases, one when the bedform was flat, and the other when the bedform was standing wave.

The arrival time is the time of bed - load reaches a reference surface at the end of the flume. Noted that the arrival time of the bed - load to the end flume when the bedform as flat differs from the arrival time when the bedform as standing wave, It was found that the arrival time in the case of flat bedform is less comparing to the case when the bedform is standing wave.

Index form factor (*L*/L*) was proposed to distinguish between the flat bedform and the standing wave bedform, this factor was introduced in dimensional analysis with the other variables affecting the prediction of bed - load transport rate formula.

Linear regression was found to predict formula for index form factor *L*/L* and also prediction formula for computed the bed - load transport rate (q_s) with high R-square. The results from predicted formula were verified by comparing them with other researchers' formal's using statistical measures. At long last, it was found that the amount of the bed - load transport rate when the bedform was a flat is greater than the amount of the bed - load transport rate when the bedform was standing wave.

Since the value of the bed - load transport rate has to do with the decision to maintain the unlined channels and thus it affects the cost of maintenance of the unlined channels.

Keywords: Bed - load, Bedform, Transport rate, Flat bed, Standing wave

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1. Introduction

The study of bed - load transport is important as it affects hydraulic structures that are located on the unlined channels.As the bed - load accumulates upstream of the hydraulic structures, this requires maintenance of the channels in order to preserve the cross-section of channels and also maintain the efficiency of the hydraulic structures work.
So when the bed - load accumulates, a maintenance decision is made for the unlined channels and the time required for the bed - load to accumulate depends on the value of the bed - load transport rate.
In other words, when the bed - load transport rate is high, the maintenance periods for the channels are close to each other, and thus the maintenance cost of these channels increases and when the bed - load transport rate is low, the maintenance periods for the channels are far between, and therefore the maintenance cost for these channels decreases.
The value of the bed - load transport rate depends on many factors and variables in this research we will study the effect of the bedform on the bed - load transport rate value, which has an impact on the period and cost of maintenance of the unlined channels.

Many researchers have studied the behavior of sediment transport and carried out experiments to obtain empirical or semi-empirical correlation to find the amount of bed -load transport rate.
Researchers in references [1],[6],and [7] predicting formulas for finding the bed - load transport were based on mean shear stress, shear velocity, and Shields parameter.
Reference [4] had entered a bedform factor in bed - load transport formula, the Bedform factor as defined is the ratio of overall Chezy-coefficient to the Chezy-coefficient related to surface roughness, references[8] and[9]had entered a bedform factor in bed - load transport formula, bedform factor defined as the ratio of effective grain-shear stress to the bed shear stress, While reference [3] had to enter a bedform coefficient in equation bed - load transport assuming if dunes to be triangle cross-section.The bedforms when low flow velocities could be classified as ripples, dunes, flat, standing waves, and antidunes [2].
This paper will focus on studying the effect of the bedform on the bed-load transport rate, suggested we have two forms for the bed the first when the bedform is a flat bed and the second is standing wave bedform.
Experiments were performed when the bedform was a flat bed and measurement the bed-load transport rate, also the experiments were repeated when the bedform was a standing wave and measurement the bed-load transport rate, In order to study the effect of two bedforms on the bed-load transport rate.

1.1. Flume experimental and materials

It was used flume made locally for experimentation with Dimensions 3m length, 0.20 m width, and 0.30 m height. A valve and gate were used to control the flow of water are shown in Fig. 1, regarding the material of the bed was used sand with grain size equal or less than 3mm diameter.

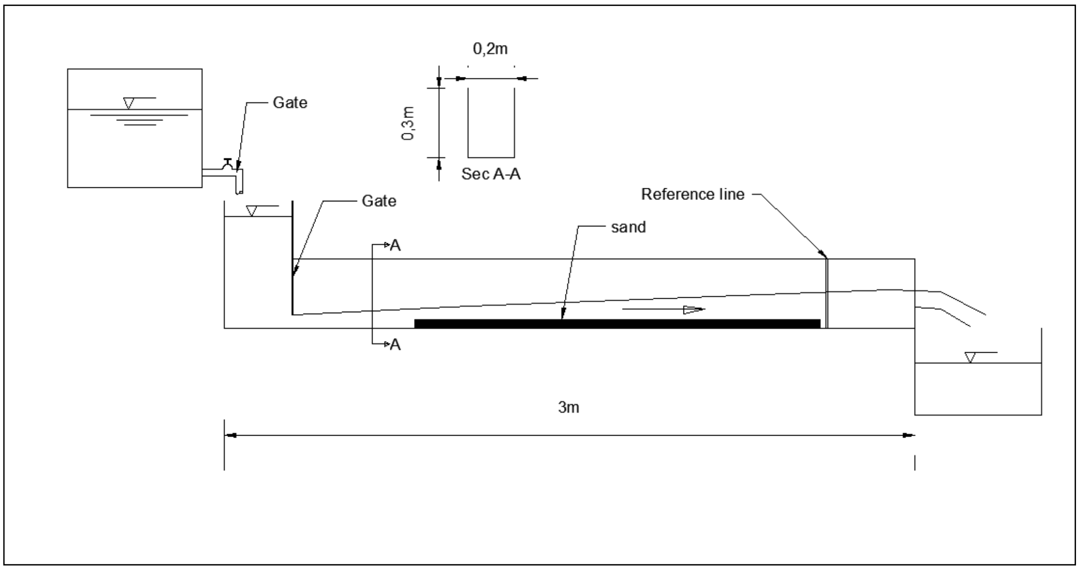

Figure1. Plan of the flume

1.2. Index form factor

A ratio between the surface area per unit width of the bedform (L*) and the projection of the surface area per unit width of the bedform (L) as shown in Fig. 2, this ratio regards as a factor used to distinguish between flat bedform and standing wave bedform.
comparing the surface area per unit width of the bedform (L*) and the projection of the surface area per unit width of the bedform (L) by finding the ratio between them, the ratio is equal to 1 when the surface area per unit width of the bedform (L*) is equal to the projection of the surface area per unit width of the bedform (L), meaning that the bedform is flat, and if the ratio greater than 1 when the surface area per unit width of the bedform (L*) is greater than the projection of the surface area per unit width of the bedform (L) that meaning the bedform is standing wave.
This ratio can be called the index form factor, which will be entered as a variable to prediction the bed-load transport rate formula in this paper
L*/L=1 …..Flat bedform; L*/L>1 ……Standing wave bedform.

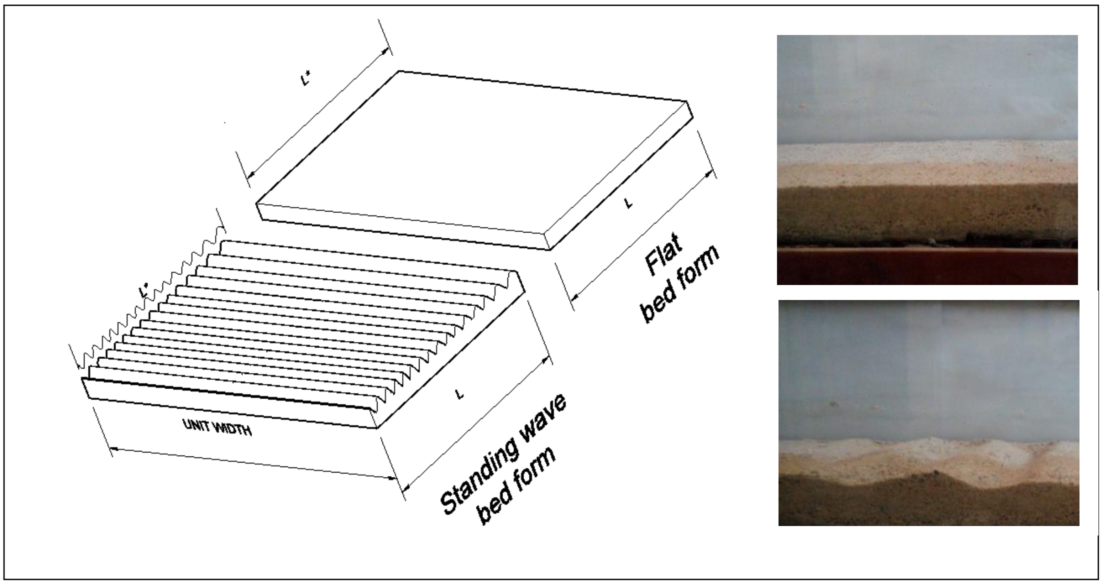

Figure 2. Shows the meaning of *L* and *L**

2. Experimental procedure

A flat bedform was created with a thickness of 4 cm and a bed length of 1.7 m using sand whose diameter is equal or less than 3 mm. A reference surface marked at the end of the flume about 20 cm as shown in Fig. 3
Four experiments were conducted when the bed was a flat bedform with four different flow velocities: 0.075, 0.080, 0.122 and 0.208 m/sec.
Each of these four experiments was recorded with a digital camera and each recorded film was cut into images every 5 seconds.
Before starting the experiments, it was measured the projection of the surface area per unit width (L) of the bedform, and the surface area per unit width (L*) of the bedform.
When the beginning of each experiment, the following measurements have recorded the velocity of flow (v), the volume of bed-load that accumulated after the reference surface, and the total time of the accumulated bed-load volume after the reference surface.
By using raster design AutoCAD the time of bed-load arrival after reference surface was measured also, in Fig. 3 are showing the reference surface and arrival time for the experimental no.1 when the bedform is a flat see the table 1.

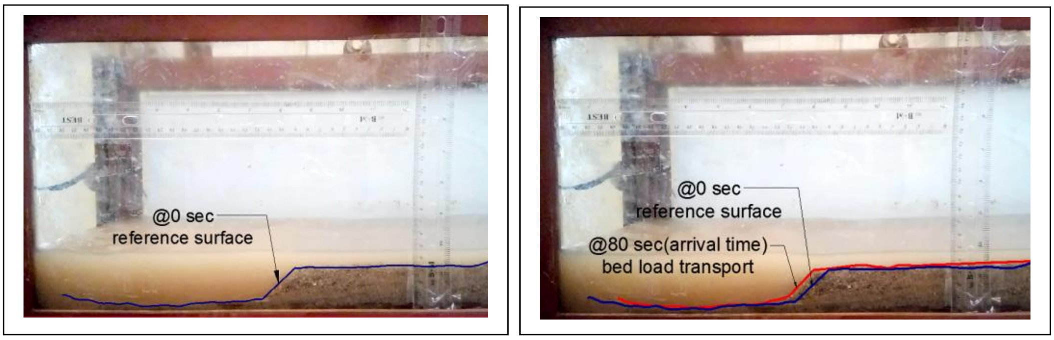

Figure 3. Shows two raster showing how to measure arrival time by raster design AutoCAD

From the volume of bed-load transport and total time could be calculated the bed-load transport rate (q_s), the data measured for four experiments when the bedform as a flat are listed in Table 1.

Table 1. Data measurements for experiments when the bedform as a flat bedform

Bedform	Experimental no.	Flow velocity V (m/sec)	Bed - load transport rate measurement qs(m2/sec)	Arrival time at reference line(sec)	L	L*
Flat bedform	1	0.0750	8.50E-06	80	1.7	1.7
	2	0.0802	8.62E-06	75	1.7	1.7
	3	0.1229	1.15E-05	70	1.7	1.7
	4	0.2082	1.34E-05	60	1.7	1.7

Four other experiments were conducted but this time the bed was created as a standing wave, With using the same quantity of sand that used in previous experiments when the bedform as flat and with 1.7m bed length as the projection of the surface area per unit width.
Experiments were done the same procedure previously with measured the surface area per unit width (L*)of standing wave bedform by Using raster design AutoCAD just to check the (L*) the data measured for four experiments when the bedform as a standing wave are listed in Table 2.

Table 2. data measurements for experiments when the bedform as a standing wave bedform

Bedform	Experimental no.	Flow velocity V (m/sec)	Bed - load transport rate measurement qs(m2/sec)	Arrival time at reference line(sec)	L	L*
Standing wave	1	0.0750	2.30E-06	140	1.7	2.66
	2	0.0802	2.39E-06	125	1.7	2.66
	3	0.1229	5.33E-06	105	1.7	2.66
	4	0.2082	7.60E-06	75	1.7	2.66

3. Data analysis

From table 1 the experiment (1) we find that the arrival time is 80 seconds when the bedform is a flat while from the table 2 the experiment (1) in the case of bedform is a standing wave, the arrival time is 140 seconds.
So through the values of arrival time are shown in Table 1&2 that the bed - load reaches beyond the reference surface in the case of the flat bedform earlier when the bedform was a standing wave bedform, The reason is that when the bedform is standing wave bedform, the surface of standing wave bedform begins to convert from the standing wave bedform to the flat bedform this takes more time when comparing it with the bedform is flat originally, so after converting the bedform standing wave to flat bedform the bed - load begins to reach to the reference surface.
From Table 1&2 found that the quantity of bed - load transport rate in the case of the flat bedform is greater than the quantity of bed - load transport rate in the case of the standing wave form. From the above, it is evident that the bedform has an effect on the value of the bed - load transport rate.
Also from the table 1&2, it was seen the bed - load transport rate increase with increasing the flow velocity as for the case of the flat bedform and standing wave bedform.
And when comparing the bed - load transport rate for the case of the flat bedform is greater than when the bedform is standing wave for the same velocity are shown in Fig 4&5.

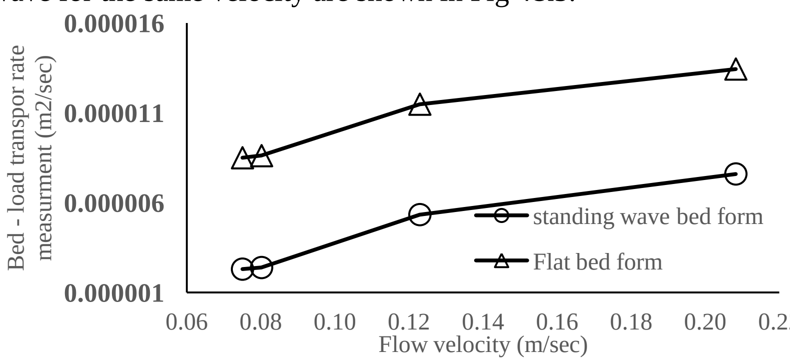

Figure 4. Relationship between the flow velocity and the bed - load transport rate

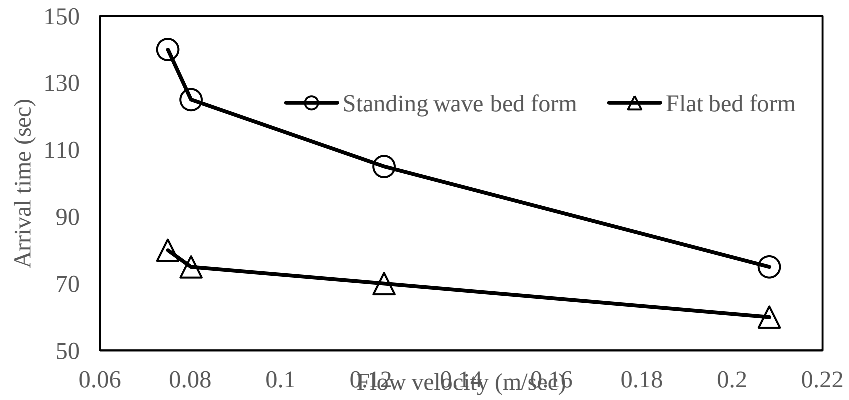

Figure 5. Relationship between the flow velocity and the arrival time

4. Reliability of measured bed-load transport rate

Graphically when comparing bed - load transport rate values measured by experiments with bed - load transport values calculated by the equations of researchers such as “Einstein, H.A”. [1], “Meyer-Peter, E.” [5], and “Nielsen, P.” [7], it was Found the measured values are closer to the values that calculated by “Meyer-Peter” formulas when the bedform is flat and are closer to the values that calculated by “Einstein “ formula when the form is a standing wave, are shown in Fig.6&7.

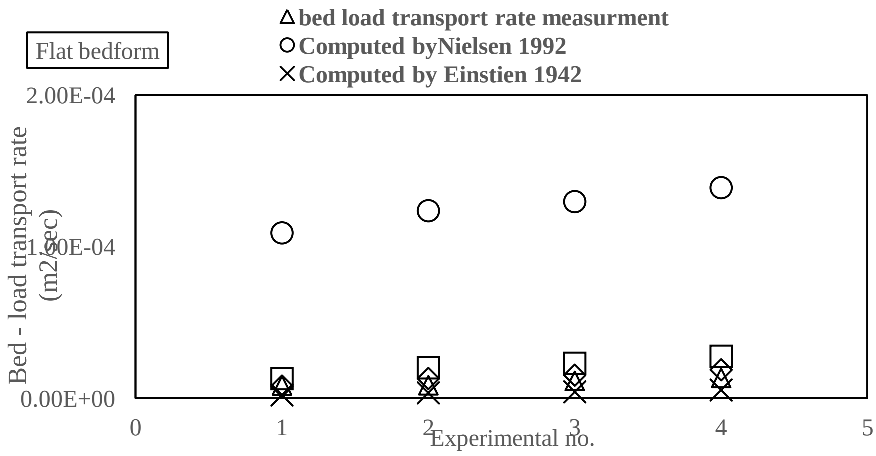

Figure 6. Comparison between measured bed - load transport rates with that calculated by the equations of researchers, when bed as flat bedform

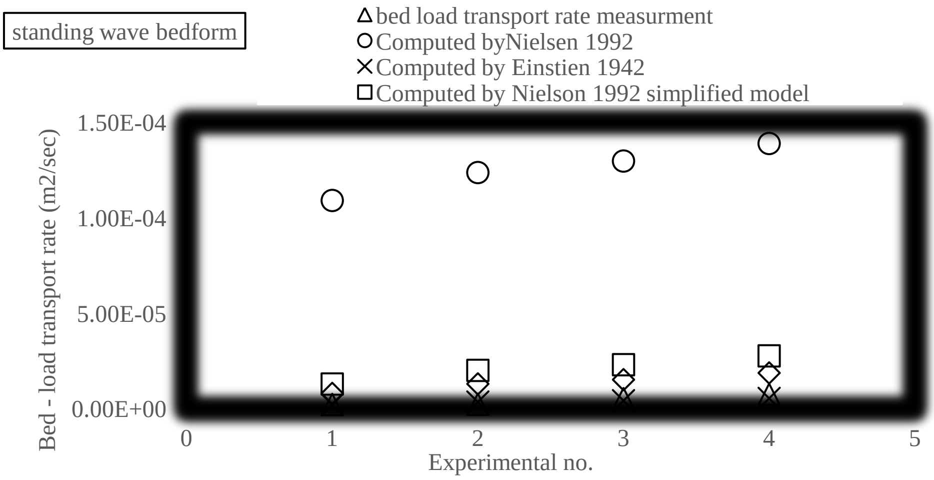

Figure 7. Comparison between measured bed - load transport rates with that calculated by the equations of researchers, when bed as standing wave bedform

Standard error (SE), root mean square error (RMSE), and standard bias (BIAS) can be used for the comparison between measured bed-load transport rate and that computed by" Einstein, H.A."[1], "Meyer-Peter, E."[5] , and "Nielsen, P. "[7], these measures were computed as :

$$SE= [\Sigma (q_m-q_c)^2 /N]^{0.5} \quad (1)$$
$$RMSE=\Sigma [(q_m-q_c) / q_m]^2 \quad (2)$$
$$BIAS = \Sigma| (q_m-q_c) / q_m | \quad (3)$$

Where q_m is the measured bed - load transport rate, q_c is the calculated bed - load transport rate, and N is a data number. The Statistical measures for bed–load transport rate when the bedform as a flat in the table 3, are showing that the measured bed–load transport rate is closer to the predicted values when using" Meyer-Peter " formula.

Table 3. Using statistical measures to a comparison between measured bed - load transport rates with that calculated by the equations of researchers, when bed as flat bedform.

Measures	Meyer-Peter formula [6]	Nielsen formula [7]	Einstein formula [1]	Nielson) simplified model [7]
SE	0.0000039771	0.00012	0.00001	0.00001
RMSE	0.538645361	512.70677	1.64909	4.22432
BIAS	1.297339575	44.87129	2.55564	3.94194

Also Statistical measures for bed –load transport rate when the bedform as a standing wave in the table 4, are showing that the measured bed –load transport rate is also closer to the predicted values when using "Einstein " formula.

Table 4. Using statistical measures to a comparison between measured bed - load transport rates with that calculated by the equations of researchers, when bed as standing wave bedform.

Measures	Meyer-Peter formula [6]	Nielsen formula [7]	Einstein formula [1]	Nielson simplified model [7]
SE	0.0000096	0.00012	0.0000013	0.00002
RMSE	31.91107842	5584.31759	0.36298	94.78361
BIAS	10.31723403	137.91155	1.03316	18.05119

5. Predicting the bed-load transport rate formula

Experiments results (**q_s , V,ρ,ρ_S,μ,g, d_s , L*, L**) where q_s is the Bed - load transport rate per unit width is the velocity of flow, ρ is the fluid density,ρ_s is the sediment density,μ is the Kinematic viscosity coefficient g is the acceleration of gravity, and d_s is the particle diameter, were used to predict expression for index form factor (L*/L). Buckingham's π-theorem used to analyze, the dependent variable π_1 is a function of others πs are independent variables its expressed as π_1=f (π_2, π_3, π_4, π_5, π_6) also can be written as f(π_1 π_2, π_3, π_4, π_5, π_6)=0
Each π-term was written as

$$\pi_1=L^*/L \quad (4)$$
$$\pi_2=q_s/LV \quad (5)$$
$$\pi_3= \rho_{S/}\ \rho \quad (6)$$
$$\pi_4=\mu/VL\rho \quad (7)$$
$$\pi_5=Lg/V^2 \quad (8)$$
$$\pi_6=d_s/L \quad (9)$$

Substituting the values π_1, π_2 , π_3 , π_4 , π_5 , and π_6 in f(π_1 π_2, π_3, π_4, π_5, π_6)=0 is get

$$f\,[\,L^*/L,\ q_s/LV,\ \rho_{S/}\rho,\ \mu/VL\rho,\ Lg/V^2,\ d_s/L] = 0 \tag{10}$$
Or
$$L^*/L = \Phi\,[q_s/LV,\ \rho_{S/}\rho,\ \mu/VL\rho,\ Lg/V^2,\ d_s/L] \tag{11}$$
Or
$$L^*/L = \Phi\,[q_s/LV,\ \rho_{S/}\rho,\ 1/Re,\ 1/Fr^2,\ d_s/L] \tag{12}$$

Where Re is the Reynolds number of flow, and Fr is the Froude number of flow.
Experimental data resulting after dimensional analysis are shown in the table 5 .linear regression by using SPSS can be prediction formula that explain the relationship between index form factor (L^*/L) and other dimensionless groups[q_s/LV, $\rho_{S/}\rho$, $1/Re$, $1/Fr^2$, d_s/L] the result of linear regression with (R^2 =0.994) is shown in Eq. (13)

$$L^*/L = -14125.172\ q_s/LV + 164.859\ \mu/VL\rho - 0.00026\ Lg/V^2 + 758.62\ d_s/L \tag{13}$$

Also by the same way can predict the formula for the calculated (q_s) with (R^2 =0.976)

$$q_s = LV\,[-.0000062\ L^*/L + 0.012\ \mu/VL\rho - 0.0000000184\ Lg/V^2 + 0.047\ d_s/L] \tag{14}$$

Through the formula (14) we see that the “index form factor” entered into the calculation of the bed - load transport rate as a variable.

Table 5. Experimental data resulting after dimensional analysis.

L^*/L	q_S/LV	ρ_s/ρ	$\mu/VL\rho$	Lg/V^2	d_s/L
1.565	1.80392E-05	2.65	0.00785	2961.78	0.001764706
1.565	1.75417E-05	2.65	0.00735	2592.97	0.001764706
1.565	2.55332E-05	2.65	0.00479	1102.90	0.001764706
1.565	2.14638E-05	2.65	0.00283	384.22	0.001764706
1.000	6.66667E-05	2.65	0.00785	2961.78	0.001764706
1.000	6.32345E-05	2.65	0.00735	2592.97	0.001764706
1.000	5.49541E-05	2.65	0.00479	1102.90	0.001764706
1.000	3.79601E-05	2.65	0.00283	384.22	0.001764706

When comparing the experimental measurement bed - load transport rate with Eq. (14) and with other researcher’s formula’s by using statistical measures.
Regarding eq(14) have smallest statistical measures (SE, RMSE, and BIAS) values when compared with other researchers formulas in case the bedform is flat bedform, the results are shown in table 6.

Table 6. Comparing the calculated bed - load transport rate by Eq, (14) with other researchers formulas in case the bedform is flat bedform

	Comparing the experimental measurement bed - load transport rate with that calculated by Eq. (14)	Comparing the experimental measurement bed-load transport rate with bed - load transport rate that computing by other researchers			
Measures	Eq. (14)	Meyer-Peter formula [6]	Nielsen formula [7]	Einstein formula [1]	Nielson) simplified model [7]
SE	0.0000018	0.0000039	0.00011	0.0000067	0.000011
RMSE	0.079	0.53	512.70	1.64	4.22
BIAS	0.436	1.29	44.87	2.55	3.94

In the case of standing wave bedform, we notice that the lowest statistical measures (SE, RMSE, and BIAS) values are for the "Einstein " equation, but equation (14) can be considered as having also the smallest statistical measures, the results are shown in table 7.

Table 7 . Comparing the calculated bed - load transport rate by Eq. (14) with other researcher's formulas in case the bedform is standing wave bedform

	Comparing the experimental measurement bed - load transport rate with that calculated by Eq. (14)	Comparing the experimental measurement bed-load transport rate with bed - load transport rate that computing by other researchers			
Measures	Eq. (14)	Meyer-Peter formula [6]	Nielsen formula [7]	Einstein formula [1]	Nielson) simplified model [7]
SE	0.0000017	0.0000096	0.00012	0.0000013	0.000016
RMSE	0.60	31.91	5584.31	0.36	94.78
BIAS	1.42	10.31	137.91	1.03	18.05

8 Conclusion and recommendation

The bedforms (flat and standing wave bedform) has an effect on the amount of bed - load transport rate, where the bedform is flat, the amount of bed - load transport rate is greater if the bedform is standing wave.
Thus, when the bedform is standing wave, the period of bed - load accumulation is long at upstream of the hydraulic structures, which leads to reduced maintenance times for the channels, and vice versa when the bedform is flat.
Since the formation of the bed depends on the Froude number, which is a function of flow velocity, then to reduce maintenance times and thus reduce the cost of the unlined channels, it is necessary to control the flow velocity of these channels to ensure that the bedform is standing wave.

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