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COMPARISON BETWEEN CALCULATED AND SITE MEASURED GRAVEL BED LOAD TRANSPORT RATE IN ZYGAKTIS RIVER, GREECE

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ABSTRACT

The present study examines the gravel bed load transport rate in Zygaktis River, Drama Prefecture, Northern Greece, and compares the field river bed load measurement values with those calculated by means of Meyer-Peter and Müller (1948) and Bakke et al. (1999) formulae, employing the B.A.G.S. (Bedload Assessment for Gravel-bed Streams) software generated by the U.S.F.S. (United States Forest Service). Stream discharges were measured by means of a Valeport current meter implementing the area-velocity method, and field-trapped gravel bed load was collected via a Helley-Smith sediment trap equipped with nylon-made mesh, whilst river channel slope was accomplished performing stadia work employing a Topcon spirit level and a nylon-made measuring tape for this task. River bed armoring surface gravel samples were collected implementing the Wolman pebble count method and river bed substrate samples were carefully collected paying attention to eliminate the possibility, the perennial character of the flow to wash out the fine particles from the samples, causing erroneous results.

Keywords: gravel bed load transport rate; Zygaktis River; Helley-Smith bed load trap; Wolman pebble count; Meyer-Peter and Muller formula; B.A.G.S. software.

1. Introduction

Bed load transport is a fundamental physical process in alluvial rivers, building and maintaining a channel geometry that reflects both the quantity and timing of water and the volume and caliber of sediment delivered from the watershed (Barry 2007). Bed-load transport is meant the movement of the solid material rolling or jumping along the bed of a river; transform of matter in suspension is not included (Meyer-Peter and Muller 1948). A great deal of scientists have been involved in developing formulae attempting to compute the bed load transport rate in gravel-bed rivers during the last decades. The relationship between the bed load transport rate and the flow characteristics has received a great deal of attention by researchers in sediment transport, and a bewildering number of empirical and semi-empirical equations have been proposed; Most of these bedload ransport relationships are based on the concept of incipient movement that is supposed to be governed by certain definable critical conditions (Paintal 1969). Estimates of bed load transport are used in the analysis of a wide range of practical and theoretical problems in hydrology, including the specification of environmental maintenance flows; computation of sediment loads; development of numerical models of channel evolution; and assessment of the effects of watershed disturbance and river management. Ideally, transport estimates should be based on field measurements of bed load taken over a range of flows. However, the effort involved in taking such measurements and the uncertainty associated with the data are often quite large, and thus it sometimes becomes necessary to compute bed load transport rates on the basis of an empirical relation (Mueller and Pitlick 2005). Estimates of sediment ransport rates in gravel-bed rivers are typically developed from formulae or from a sampling campaign. The former are notoriously inaccurate; the latter require a large effort and may still not achieve acceptable accuracy. A wide range of geomorphological problems, particular those at the watershed scale, could be addressed more accurately if reliable local estimates of transport rate could be incorporated routinely into such studies. This requires a method for estimating transport rate with acceptable accuracy and a minimum of effort (Wilcock 2001).

2. Field data for the Zygaktis river

2.1. Study site and reach

According to the Google Earth tool, the study reach was 58.31 m long, occupying a river longitudinal section segment located described by the coupled coordinates 41° 3'37.55"N - 24°15'54.41"E (elevation: 74 m) (upstream location), and 41° 3'35.74"B - 24°15'55.06"E (elevation: 73 m) (downstream location), respectively, hence the Google Earth tool yields a stream reach slope of 0.017150. However, a stream reach survey by means of nylon-made measuring tape, stadia rod and a Topcon spirit level proved a real stream reach length of 50 m and a corresponding slope (both of the stream bed as well as the stream free water surface, hence the total energy slope) of 0.0014085.

2.2. Volume changes and transport rates

Measurements of bed load transport were carried out at the same time as the discharge measurements. Table 1 presents the dates of the measurements, the stream discharge, the measured bed load transport rates and the calculated bed load transport rates employing the Meyer-Peter & Muller (1948) method and the Bakke et al. procedure (1999).

Table 1: Measured values of stream discharge, and measured and calculated values of bed load transport rates

Date	Stream discharge ($m^3 \cdot s^{-1}$)	Measured bed load transport rate ($kg \cdot m^{-1} \cdot s^{-1}$)	Calculated bed load transport rate Meyer-Peter & Muller (1948)] ($kg \cdot m^{-1} \cdot s^{-1}$)	Calculated bed load transport rate [Bakke et al. (1999)] ($kg \cdot m^{-1} \cdot s^{-1}$)
17/4/2014	1,658	0,00514	0,022796	0,022789
18/4/2014	1,679	0,00703	0,019567	0,046997
21/4/2014	1,723	0,00575	0,005364	0,020697
21/4/2014	1,773	0,00560	0,022623	0,038773
21/4/2014	1,734	0,00591	0,028012	0,028009

3. Bed load formulae used in calculations

3.1. Original Meyer-Peter and Muller formula (1948)

The Meyer-Peter and Muller (MPM) formula (Meyer-Peter and Muller 1948) has been often employed to compute rates of bed load transport (e.g., HEC 1991; Nicholas 2000) and was proved to function adequately well (Gomez and Church 1989). The equation has the form (Meyer-Peter and Muller 1948)

$$m_G=\frac{8}{g}\left(\frac{\rho_F}{\rho_F-\rho_W}\right)\sqrt{\frac{1}{\rho_W}}\left(\rho_W g I_r R_S-0.047\rho'\rho_W g d_m\right)^{3/2} \tag{1}$$

where m_G is the total specific bed load transport rate (dry mass per unit width and time).

3.2. The procedure of Bakke and others (1999)

The Bakke and others (1999) method is a calibrated procedure based on the Parker-Klingeman formula (Wilcock et al. 2009); Parker and Klingeman (1982) consider that individual particles in the pavement layer are sporadically plucked from the surface, creating pockets which become openings for exchange of the “hidden” finer material, and which they may fill when they capture larger particles once again; The “hiding factor” is described by the simple relationship

$$\frac{\tau^*_{ri}}{\tau^*_{r50}}\left(\frac{D_i}{D_{50}}\right)^{-exp} \tag{2}$$

where τ^*_{ri} is the reference Shields stress for particles of size class i ; D_i is the mean particle diameter size class i ; D_{50} is the median particle diameter for the bed material (either pavement or subpavement); τ^*_{r50} is the reference Shields stress associated with D_{50}; and exp is a Parker-Klingeman exponent (Bakke et al. 1999).

4. Results

4.1. Comparison between computed and measured discharge values

In order compare the calculated and measured on-site discharge values listed in Table 3, the following criteria were used: “root mean square error” (RMSE), relative error, Nash-Sutcliffe efficiency coefficient and correlation coefficient R.

$$\mathrm{RMSE}=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i-P_i)^2} \qquad (3)$$

The value of RMSE for the Meyer-Peter and Muller (1948) amounts to 0.0158 $\mathrm{kgm^{-1}s^{-1}}$.

The value of RMSE for the Bakke et al. (1999) amounts to 0.3176 $\mathrm{kgm^{-1}s^{-1}}$.

The relative error (%) is expressed as

$$\text{relative error}=\frac{O_i-P_i}{O_i}\times 100 \qquad (4)$$

The relative error for the Meyer-Peter and Muller (1948) varies between the values -2.39% and 0.07%.

The relative error for the Bakke et al. (1999) varies between the values -5.92% and -2.60%.

The efficiency E proposed by Nash and Sutcliffe (1970) is expressed by the following equation:

$$E=1-\frac{\sum_{i=1}^{n}(O_i-P_i)^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2} \qquad (5)$$

Efficiency for Meyer-Peter and Muller (1948) was found to be -633,42.

Efficiency for Bakke et al. (1999) was found to be -1891,61.

Table 2: Measured and calculated bed load transport rates

Date	Measured bed load transport rate ($\mathrm{kg{\bullet}m^{-1}{\bullet}s^{-1}}$)	Calculated bed load transport rate [Meyer-Peter & Muller (1948)] ($\mathrm{kg{\bullet}m^{-1}{\bullet}s^{-1}}$)	Ratio of measured to calculated discharge [Meyer-Peter & Muller (1948)]	Calculated bed load transport rate [Bakke et al. (1999)] ($\mathrm{kg{\bullet}m^{-1}{\bullet}s^{-1}}$)	Ratio of measured to calculated discharge [Bakke et al. (1999)]
17/4/2014	0,00514	0,022796	0,23	0,022789	0,23
18/4/2014	0,00703	0,019567	0,36	0,046997	0,15
21/4/2014	0,00575	0,005364	1,07	0,020697	0,28
21/4/2014	0,00560	0,022623	0,25	0,038773	0,14
21/4/2014	0,00591	0,028012	0,21	0,028009	0,21

5. Conclusions

It is concluded, for the Mayer-Peter and Muller (1948), that there is a very good approximation between the calculated and measured bed load discharge values and that the deviation for these values is not considerable except the first one; this deviation might be justified by either an occasional fault or an error occurred during the respective measurement. However, the degree of linear dependence between calculated and measured bed load discharge values, for the same method, is very low.

Respectively, it is concluded, for the procedure of Bakke et al. (1999), that there is a very good approximation between the calculated and measured bed load discharge values and that the deviation for these values is not considerable except the second and fourth ones; However the degree of linear dependence between calculated and measured bed load discharge values, for the same method, indicate a moderately strong to strong relationship between them.

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