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BEDLOAD ESTIMATION: CASE OF WADI EL-HAMMAM IN THE NORTH-WEST OF ALGERIA

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ABSTRACT

In Algeria, only the transport of suspended sediment is measured, the rate of bedload in the global transport of solids is estimated, approximately. Measures of bed load transport in the field are very costly, due to flow disturbances. As a result, evaluations of this type of sediment transport are difficult to carry out in the absence of databases. In this article, we tried to quantify this mode of transport at the wadi El-Hammam using the formula of Meyer-Peter and Müller. Formula that seems best adapted to the physical characteristics and flow conditions of the wadi studied. The results obtained show that the calculated bedload ratio is between 0.6 and 28% of the suspension. The quantities transported annually are very large and irregular as they vary from 2.3 to 32 Mg.km^{-2}.year^{-1}, characterising the Mediterranean mountains and semi-arid environments. A good correlation was found between the daily bedload flow and the liquid flow, the obtained model $Q_s = aQ^b$, can be easily used to estimate the bedload transport at the Hacine hydrometric station, located at the output and without data concerning this phenomenon.

Keywords: Bed load transport; Fergoug; Meyer–Peter and Müller formula; Suspension; Wadi El-Hammam.

1 INTRODUCTION

In Algeria, solid transport is evaluated at the hydrometric stations in the catchment areas for almost all flow episodes. Generally, we limit ourselves to the flow in suspension. The rate of bedload in the global solid transport is estimated in an approximate way. It is estimated between 15% and 25% of the suspension, according to several authors, reaching up to 30% of suspended solid transport [1]. It is evaluated at 32% of the total load for Haute Tafna in Algeria [2], and estimated at 15 to 25% according to LARFI [3]. The measurement of loading is indeed a problem the solution of which is not complete. River loading measurements are difficult or impossible in some cases [4], due to flow disturbances. As a result, assessments of this type of solid transport are difficult to conduct in the absence of databases. Faced with this difficulty, the engineer is often required to use the available empirical methods to estimate the quantities of sediment transported annually by rivers [5], without having any control devices for these results. In this context, we have tried to apply the formula of Meyer Peter and Müller [6] for the evaluation of bedload transport, the best known in river hydraulics to the river of wadi El-Hammam; this formula correlates the desired solid flow with the physical characteristics of the stream and the conditions of liquid flow. Several authors have tested this formula by applying it to natural streams, on the central third of the Rhone, for example, the formula was quite consistent with the facts [7]. In the southern coastal area of the Baltic, it was completely correlated with reality [8, 9]. In the case of the Niobrara River (Nebraska, USA), it led to solid flows up to 5 times too low [10]. It is therefore recommended to use this formula only for rather coarse aggregates with a diameter greater than 2mm, with uniform and non-uniform particle sizes and for a bottom slope range from 0.004 to 0.024 and for a shear force on the bottom (τ_0) ranging from 0.047 to 0.25 [11,12].

2 STUDY AREA

The Fergoug watershed makes part of the large Macta watershed (Fig.1). It is limited to the North by the Benichougrane Mountains, to the South by the Saida massifs, to the East by the Mina basin and to the West by the Mekkera basin. It is located between 0°30’ and 0°38’ East longitude and between 35°20’ and 35°50’ North latitude, covering an area of 851 km^2 corresponding to the confluence of the Fergoug and Tharzout wadis and the El-Hammam wadi, which constitutes the main wadi since it connects the two dams, Bouhanifia and Fergoug dam, over a distance of 56.2 km and a drop of 151 m, with an average slope of 0.27 % (Fig 2).

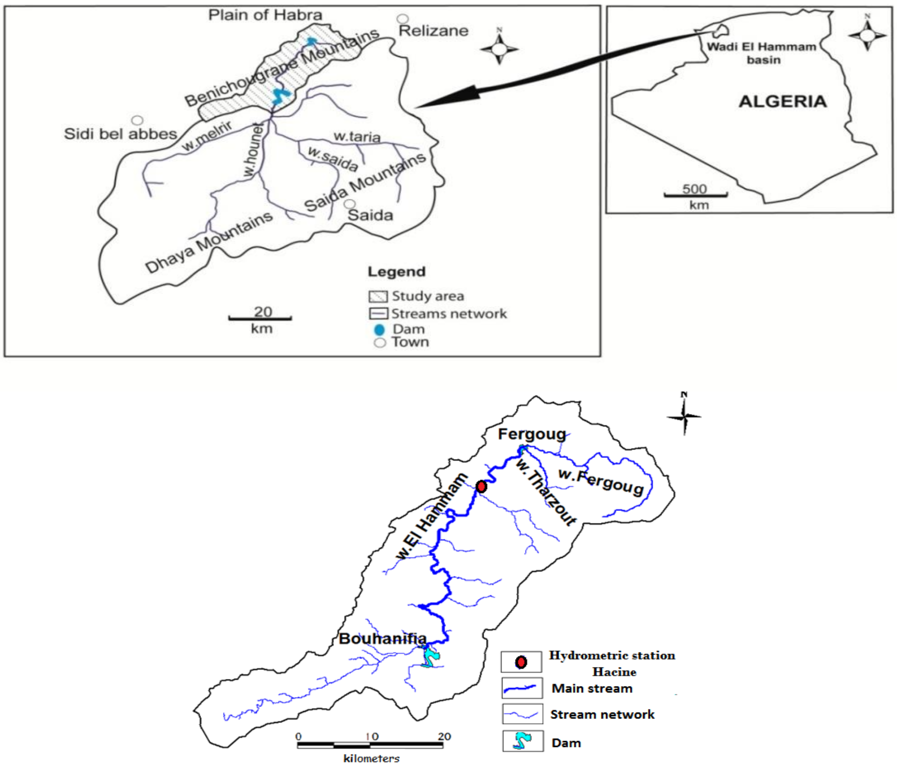

Figure 1. *Fergoug watershed*

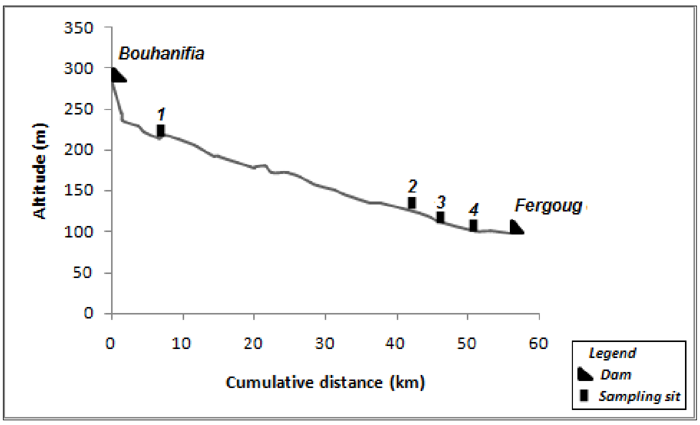

***Figure 2**. Longitudinal profile of the wadi El-Hammam and sampling site*

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The watershed of Fergoug presents a hydrographic unit of western Benichougrane. In this part, the Benichougrane massif is between two collapsed compartments: the plain of Habra and that of Ghriss which surround it to the north and to the south, it is presented here as a well individualized area of elevation with a mountainous aspect. The variation in altitude is very important, hence our catchment area is characterized by a majority of surfaces with steep slopes, greater than 21 % [13]. The climate in this region is semi-arid, the temperature average is 18 °C. The rainfall regime is very irregular and the basin receives annually between 196 and 375 mm with an average inter-annual of 274 mm at the Hacine station (1972–2010 period). The lithology of the watershed shows a great diversity of surface formations with a predominance of clay soils from marly formations, a degraded forest cover following human action and recent fires occupies the steep slopes of the wadi Fergoug watershed.

It should be noted that self-subsistence agriculture reigns there with overexploitation of the soil, permanent clearing and intensive overgrazing. Faced with this situation, water erosion has found its field of development due to the non-existence of protective vegetation, the low resistance of the land and its slopes [14].

2.1 Wadi El-Hammam characteristics

Wadi El-Hammam is located in the Northern slope of the high plains of Oran between 800 and 1200 m altitude. It rises 16 km south-west of Ras Elma, at an altitude of 1200 m in a South-East direction. An altitude variant from 284.5 m to 97.5 between the Fergoug dam and Bouhanifia. The specific power (for the flow at full edge) is 88.4 $W.m^2$. According to Brooke [15], it is a simplified meandering watercourse; it is a single-channel wadi where the meandering is relatively well developed within an alluvial plain of fluvial origin (index of sinuosity =1.57). The bed load is made up of sandy elements (Tab.1).

3 DATA AND METHODS

For each water level measurement recorded during the period (1993-2003) at the Hacine station, and by introducing the values of the median diameter of the bottom material and slope of the wadi calculated, in the Meyer-Peter and Muller, we calculate the daily load rate per unit of width of the wadi. For suspended solid transport, we have a series of measurements of water levels (H in cm), liquid flows (Q_l in $m^3.s^{-1}$) and suspended matter concentrations (C in $g.l^{-1}$) carried out by the services of the National Water Resources Agency (ANRH). The measures cover a period of 10 years (1993–2003).

3.1 Quantification of suspended sediments

The solid flow rates were obtained from the instantaneous values of the liquid flow rates, expressed in $m^3.s^{-1}$, and the concentration of suspended solids in $g.l^{-1}$. The latter is obtained according to the following protocol. At each water level reading, a sample of loaded water is taken from the bank on the surface of the wadi using a 50 cl bottle. The sediments are filtered and dried in an oven for 30 min at a temperature of 105 °C. Reduced to the unit of volume (1l), this load is attributed to the concentration in instantaneous suspension expressed as the watercourse in $g.l^{-1}$. The number of samples was adapted to the hydrological regime. These are carried out every day and intensified up to a quarter of an hour during flood periods [16]. The solid flow in suspension is therefore the product of the concentration evaluated in $g.l^{-1}$by the liquid flow measured in $m^3.s^{-1}$.

The annual flux of suspended solids exported by the wadi is calculated by the formula:

$$A_s = \sum_1^N (t_{j+1} - t_j) Q_j \, C_j \qquad (1)$$

where C_j, is the concentration measured at the instant tj corresponding to the liquid flow Q_j , N is the number of samples taken over the year in question, $t_{j+1} - t_j$ is the time step separating two consecutive samples.

Vol. 68 (2022), No. 2
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3.2 Quantification of bedload sediments

For the evaluation of solid flow by bedload, we used the formula of Meyer-Peter and Muller [6]:

$$\gamma.h.J(K/K_r)^{3/2} = 0.047(\gamma_s - \gamma)d + 0.25(\gamma/g)^{1/3} \,.q_s{}^{2/3} \tag{2}$$

from where:

$$q_s = 8(K/K_r)^{9/4}(g/\gamma)^{1/2}\left[\gamma.h.J - 0.047(\gamma_s - \gamma)d(K_r/K)^{3/2}\right] \tag{3}$$

$$q_s = 8(K/K_r)^{9/4}(g/\gamma)^{1/2}\ (\tau_0 - \tau_c) \tag{4}$$

$$q_s = 8(n_r/n)^{9/4}(g/\gamma)^{1/2}\ (\tau_0 - \tau_c) \tag{5}$$

where*:*

$$\tau_c = 0.047(\gamma_s - \gamma)d_{50} \quad ; \quad \tau_0 = \gamma.h.J \tag{6}$$

with:

q_s: computed bed load transport rate per unit width (kg.(s·m)$^{-1}$)
K_r: Manning-Strickler roughness coefficient of the bottom (m$^{1/3}$.s^{-1})
K: wall roughness coefficient (m$^{1/3}$.s^{-1})
n = 0.03 for walls made of fairly coherent materials.

For the calculation of K_r, we will use Strickler's formula:

$$K_r = 21/(d_{50})^{1/6} \text{ and } n_r = 1/K_r \tag{7}$$

d_{50}: mean diameter of bed load grains (m)
g: gravity acceleration (m.s^{-2})
γ_s: sediment density (kg.m$^{-3)}$
γ: water density (kg.m^{-3})
τ_0: actual shear stress (kg.m^{-2})
τ_c: critical shear stress (kg.m^{-2}), characterizing the incipient motion of bed grains
h: flow depth (m)
J: slope of energy line (%)

The basic limitations for the Meyer-Peter and Müller formula are the following:

- Slope of energy line (J) from 0.04 % to 2 %
- Sediment particle size (d_{50}) from 0.4 mm to 20 mm
- Flow depth (h) from 0.01 m to 1.20 m
- Sediment density (γ_s) from 0.25 to 3.2 (kg.m^{-3})

For the case of the wadi El Hammam studied, the calculated values of these parameters were done in four different and aleatory sites representing the samples, check these refined limits (Tab. 1 and Fig. 2). At the Hacine station, for each water level measurement recorded during the period (1993–2003) we calculate the daily bed load transport rate. By summation, we obtained the monthly total and therefore the annual total.

***Table 1.** Calculated and measured parameters for application of the Meyer-Peter formula*

Samples	d_{50} (m)	Wadi width (m)	K_r	n_r	J (%)
1	$0.83\cdot10^{-3}$	8.80	68.5	0.0146	0.435
2	$0.70\cdot10^{-3}$	8.90	70.47	0.0141	0.304
3	$0.55\cdot10^{-3}$	10	73.36	0.0136	0.298
4	$0.42\cdot10^{-3}$	7.50	76.73	0.0130	0291

Vol. 68 (2022), No. 2
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4 RESULTS AND DISCUSSION

Results obtained by applying the Meyer-Peter and Muller [6] formula show that the ratio (bed load transport/suspended transport) is variable from one year to another and oscillates between 0.6 and 28 %. the quantities loaded annually are very large and irregular since they vary from 2.3 to 32 Mg.km^{-2}.·year^{-1}. The quantity transported is almost twice the annual average value for 40 % of the years (Tab.2).

Table 2. *Annual values of bed load sediment load, suspended sediment load and specific degradation at wadi El Hammam (1993/1994–2003/2004)*

Years	Bedload sediment load 10^3 Mg	Suspended sediment load 10^3 Mg	Bedload /Suspension %	Specific degradation Mg·km^{-2}
1993/1994	23.859	2104.459	1.1	28.036
1994/1995	23.613	2440.305	1	27.747
1995/1996	26.772	414.026	6.4	31.460
1996/1997	4.833	23.142	21	5.679
1997/1998	15.885	497.644	3.2	18.666
1998/1999	5.033	17.988	28	5.914
1999/2000	1.955	312.913	0.6	2.297
2000/2001	13.429	193.041	7	15.780
2002/2003	10.228	345.492	3	12.019
2003/2004	27.285	234.157	11.7	32.062

This importance of sediments is explained in particular by the specific power at the high full edge of the wadi El-Hammam as well as by the high solid contribution in autumn. Note that October and September are the most productive months of sediments, producing respectively 73.5 %, 74.4 % and 82.4 % of the annual loading (Fig.3).

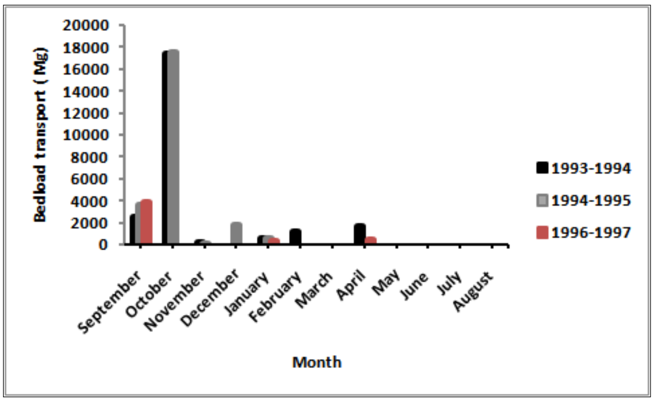

Figure 3. *Importance of bed load transport in autumn*

The importance of the bedload discharge is a characteristic of Mediterranean mountains and semi-arid environments [17], so our values are close to those highlighted in Wales and Scotland, where studies suggest values between 2.9 and 44 Mg.km^{-2}.·year^{-1} [18,19], very important values between 33.6 and 107.2 Mg.km^{-2}.·year^{-1} were also found in Diois (France) [20,21].

Vol. 68 (2022), No. 2
pp. 213–220, ISSN 1802-5420
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4.1 Relation between solid flow load and liquid flow

There is a close relationship between the solid flow determined from the Meyer-Peter and Muller [6] formula and the liquid flow characterizing wadi El-Hammam (Fig. 4), which is represented by a power law of the form $Q_s = aQ^b$. This result shows that there is a high correlation between these two quantities, representing the sedimentary dynamics of wadi El-Hammam. The potential model represents the overall trend of semi-arid Mediterranean watersheds [16, 22, 23, 24, 25]. The use of this type of model in the Hacine hydrometric station, located at the outlet and without bedload data is very important.

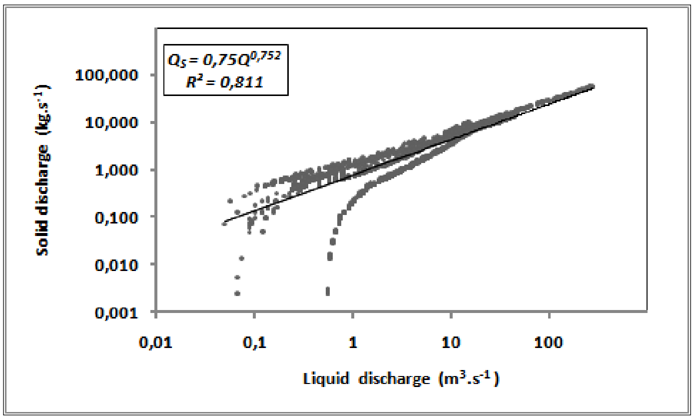

Figure 4. *Correlation between solid flow and liquid flow*

5 CONCLUSIONS

The bedload transport is never measured in Algeria; its rate in total solid transport is estimated, in an approximate way. It is for this reason that we tried to estimate it from formulas. There is a multitude of formulas, the choice of the Meyer-Peter and Muller formula is based on the fact that its limits of use correspond well to the physical characteristics of the El-Hammam wadi and the liquid flow conditions. The results of the calculations obtained for the observation period (1993–2003) show that the bed load transport is variable from one year to the next and represents between 0.6 and 28 % of the suspension. The quantities loaded annually are very large and irregular and vary from 2.3 to 32 $Mg.km^{-2}.year^{-1}$. For 40 % of observation period, the quantity transported is almost twice the annual average value. This importance is explained in particular by the specific power at the full high edge of the wadi El-Hammam as well as by the high solid contribution in autumn. The extent of bed load is typical of Mediterranean mountains and semi-arid environments [26]. Thus, our values are close to those highlighted in Wales and Scotland, from where studies put forward values including between 2.9 and 44 $Mg.km^{-2}.year^{-1}$ [27,28], very high values between 33.6 and 107.2 $Mg.km^{-2}.year^{-1}$ were also found in Diois (France) [29,30]. A better power-type correlation of the form $Q_s = aQ^b$, between instantaneous solid flow and liquid flow has been found; this model is very important if it is used at the Hacine hydrometric station located at the outlet and devoid of data concerning bedload. Finally, the formula of Meyer-Peter and Muller can be used for all our rivers in order to quantify the bedload instead of neglecting it, provided that these limits of use are respected.

Vol. 68 (2022), No. 2
pp. 213–220, ISSN 1802-5420
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Vol. 68 (2022), No. 2
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