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Monitoring and modeling of sediment transport in the watershed of Oued El Ardjem, Algeria

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ABSTRACT

Conservation and management problems of water resources have become increasingly influencing. The growing need for these resources increases the risk of degradation. Millions of tons of soil depart each year into the sea via rivers and a significant amount gets deposited at the bottom of our dams. Our job is to investigate a monographic approach to both analytic and synthetic flow methods, the hydrological regime, and sediment transport in suspension phase to determine the water surface and their spatio-temporal variability. Our study consists of two main parts: first, the diagnostic physical geographical catchment area which will show the main factors involved in the natural water flow, and thus determining basin characteristics. And second, the study of Ouled Ben Abdelkader gauging station for quantification of suspended sediment based on the regression method using different regression models for water and sediment discharge at different scales. The analysis was based on the regression method to find the best relationship for solid flow–liquid flow which leads to accepting of the power regressive model and its use in the quantification of sediment transport. The calculated intake is 18,087.66 tons/year at average where specific erosion is about 0.15 tons/km^2/year. An analysis of Sidi Yacoub dam reservoir siltation by bathymetric surveys method showed a retaining has a loss of 11% of its original capacity for 18 years of operation with 1.79% annual capacity loss.

Keywords: Modeling; Regressive model; Sediment discharge; Water discharge; Sediment suspension

1. Introduction

Water resources in Algeria are one of the main interests for the prosperity and development. Unfortunately, these resources are threatened by reduction in dam storage capacity due to siltation problems [1,2]. Siltation or sedimentation is a natural phenomenon of watershed degradation [3,4]. It is currently a concern for the huge population in the area to conserve water in the existing reserves [5–8]. This study aims to analyze the state of siltation in the Sidi Yacoub dam with a capacity of 268 Mm^3.

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The difficulties of siltation control and the state of siltation make it mandatory to use bathymetric data for this analysis; and these approaches aim to provide quantification in order to activate water regulation in our dams, affecting sediment yield factors and their deposition. Statistical analysis is one of the effective methods to achieve satisfactory results [9–11]. This study leads to the projection of preventive measures for dam siltation.

2. Materials and methods

2.1. Situation of Oued lardjem watershed

The Oued El Ardjem watershed is located in the Ouarsenis Mountains belonging to the Atlas Tell, and is an important joining between the mountains of northen Chelif plain, south of Tiaret [5]. The outlet of Oued El Ardjem is located in Sidi-Yacoub south of Chleff, oriented north-south west. The limits of the watershed extend from west to east between latitude 1˚15´ north and south with elevations axes between 35˚58´ and 35˚36´ [5].

2.2. Characteristics of the study area

The Oued El Ardjem study area occupies an area of 918 km^2 and a perimeter of 156 km, with a medium average slope of 21.62 m/km over a length of 62.72 km [5]. The maximum, minimum, and medium altitude is 1,270 m, 190 m, and 682.307 m, respectively, with a vertical drop of 323.648 m. The specific compactness index, $k_c = 1.44$, shows that the basin is elongated. The main valley drains toward a set of heterogeneous regions; the Ouarsenis Mountains regions are more degraded and difficult to restore, and their destruction is profound with a range of highly rugged topography [5]. Thirty-five percent of the basin area is between 800 and 1,200 m; Oued El Ardjem and its torrential tributaries are upstream with the high proportion of winter precipitation received by the mountain range, out of the latter; the river enters the Cheliff plain losing its torrential. The basin is characterized by low rainfall (average 359 mm) and a complex geological structure in the southwestern part of the basin, high rainfall (average 605 mm) and a simple geological structure in the central basin, and finally a small amount of rainfall and a simple geological structure in the northeast area [5]. The Sidi Yacoub dam is subject to silting, which lowers its initial capacity. The reason for the rapid siltation of the dam is that the watershed is formed of soft rock with scarce vegetation covering, which is degraded by humans [12–14]. Table 1 summarizes the characteristics of the basin.

2.3. Climate and hydrology

The Mediterranean climate, with its long dry summer and warm, and rainy and cold winter, is responsible for the great variation in the precipitation from one year to another in terms of amount and distribution. While the thermal regions are relatively homogeneous, the average temperature is around 18.2˚C. Evapotranspiration is about 1,500 mm, with a maximum of 237 mm in July and a minimum of 37 mm in December [5,14]. The watershed has an average annual rainfall of 324 mm evaluated by Thiessen method from the observations of rainfall stations over a period of 18 years. The watershed is controlled by a single gauging station. The characteristics of the annual runoff from this station are shown in Table 2.

2.4. Presentation of the data bank

All the research done on the sediment transport show the difficulty of measuring thrust although it constitutes a considerable share of total transport. So, it is the measure of transport in suspension. The data needed for this study are:

- The instantaneous discharge rates obtained from the calibration scales established by the ANRH Algiers.
- Daily instant concentrations obtained from records of water analysis.
- A file treated as a directory of average daily flow.
- The high water instant seized by ANRH Oran.

Table 1
Hydro-morphometric characteristics of the watershed

Characteristics	Unit	Symbol	Value
Area	km^2	A	918
Maximum altitude	m	Max.	1,270
Medium altitude	m	H_{moy}	682.31
Minimum altitude	m	H_{min}	190
Perimeter	km	P	156
Compactness index	–	K_c	1.44
Overall slope index	%	I_g	0.01
Index of rock slope	%	I_p	0.48
Drainage density	km/km^2	D_d	4.38
Equivalent width of the rectangle	km	L	14.64
Equivalent length of the rectangle	km	l	62.72
Class relief	–	–	R_6
Medium slope	m/km	I_m	21.62

Table 2
The annual runoff (period 85/86-2002/2003)

Years	Q_0 (m3)	M_0	A_0	h_0
1985–1986	2.00	2.17	63.06	68.69
1986–1987	1.07	1.16	33.84	36.86
1987–1988	1.23	1.33	38.73	42.19
1988–1989	1.45	1.58	45.83	49.92
1989–1990	1.26	1.36	39.6	43.13
1990–1991	0.94	1.02	29.63	32.27
1991–1992	1.19	1.29	37.5	40.84
1992–1993	1.15	1.25	36.21	39.44
1993–1994	0.91	0.98	28.63	31.18
1994–1995	3.30	3.59	104.11	113.41
1995–1996	1.76	1.92	55.62	60.58
1996–1997	1.15	1.24	36.13	39.35
1997–1998	1.37	1.49	43.15	47.00
1998–1999	1.38	1.49	43.39	47.26
1999–2000	1.16	1.26	36.68	39.95
2000–2001	1.48	1.61	46.74	50.91
2001–2002	1.13	1.23	35.73	38.92
2002–2003	0.72	0.77	22.56	24.57

Note: Q_0: medium flow; M_0: specific module; A_0: medium supply; h_0: water runoff.

Our concern is to see the behavior of daily medium flow from the period 1985/1986 to 2002/2003, indicating the dry years and wet years which may help in the search for models between the sediment water discharges and the watershed of Oued El Ardjem.

For this purpose, we calculated the runoff at the gauging station. There is a relationship between liquid flow and solid discharge. To calculate this, we proceed as follows: instantaneous liquid flow expressed in m^3/s is converted into instantaneous sediment discharge through the concentrations expressed in grams per liter. In general, this method aims at bringing the exact value and then adjusts an equation by the least squares method of two variables. Relationships between regressive parameters are determined and these relationships are used to compute and fill the data gaps. We applied the method of linear regression and the work is based on the least squares method.

The main regressive models are:

- The linear model $Y = a + b\,X$
- The parabolic model: $Y = a + b\,X + cx^2$
- The exponential model: $Y = b\,e^{ax}$
- The power model: $Y = b\,X^a$
- The logarithmic model: $Y = a + b \ln\,X$

The principle of least squares is to find the equation of adjustment that minimizes the spread or difference between the values observed in reality and theoretical given by the curve. To ensure the objective validity of the adjustment, we calculated the linear correlation coefficient which measures the intensity or degree of dependence between two variables (water discharge and sediment load). With a value of more than 0.7, the observation is good [9].

2.4.1. Derivation of the correlation

- *Interannual correlation derivation*: To combine all observations and research interrelationships, we use the regression models. Setting graph of all data flows of solid and liquid as shown in the figure shows dispersion in the form of a fan with the power model seeming to be best fit for the coefficient of determination, R^2.
- *Annual correlation derivation*: For this, we collected the annual observation for each year; we made the graph setting that allows the choice of the regression.

Given the value of R^2, it should be noted that both models fit the data, namely power and parabolic models with the exception of a few years. We report some figures that seem to be the most representative of the selected models (power and parabolic) for the representative station in the watershed.

- *Monthly correlation derivation*: In this step, the data pairs for each month are aggregated over the entire observation period (18 years).

Based on the R^2 values, we indicate that the power model provides the best correlation.

- *Seasonal correlation derivation*: It includes monthly observations (water discharge and sediment load) by dividing the normal hydrological year to four seasons, namely: Autumn: September, October, and November; Winter: December, January, and February; Spring: March, April, and May; Summer: June, July, and August.

The power model provides a good correlation for the season grouping data.

2.4.2. The instantaneous flow

Another method of homogenization data is to take the instant heights for which there has been no measurement of concentration and corresponding flow rates which are supplemented from calibration scales

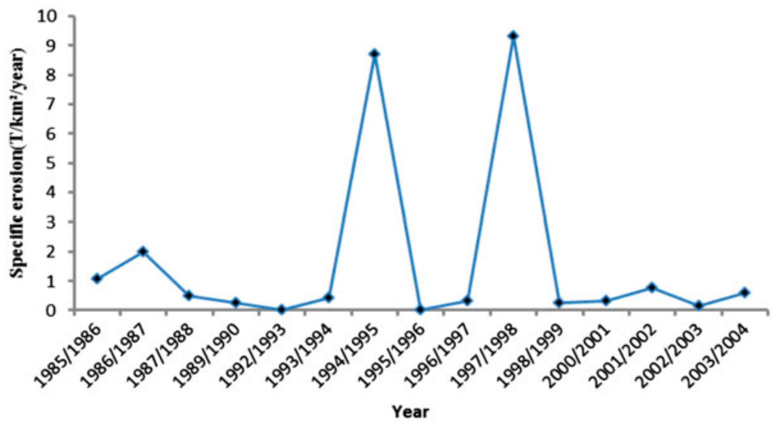

Fig. 1. Variation of the specific erosion at the annual scale.

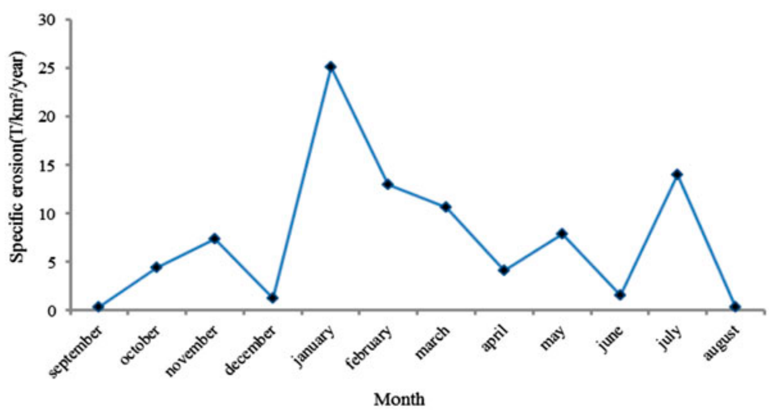

Fig. 2. Variation of the specific erosion at monthly scale.

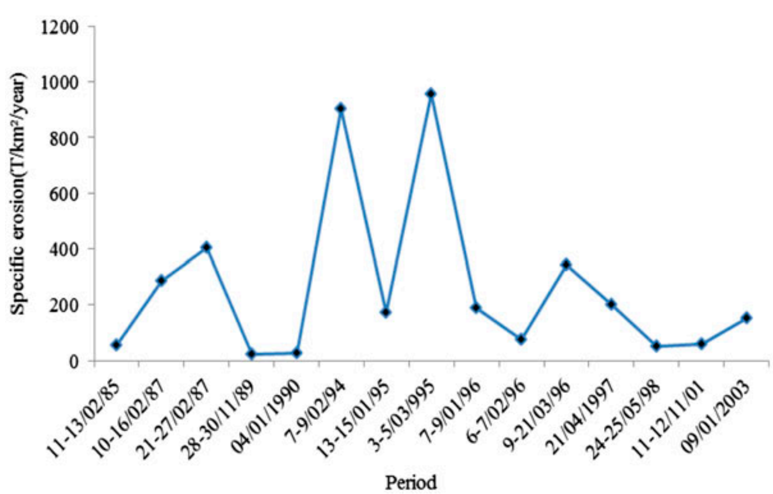

Fig. 3. Variation of the specific erosion of selected floods.

and calculate the instantaneous sediment for each height, then for each day of the year from the chosen model. The results found with the mean daily discharges from directories and those found from the instantaneous flow rates from measurements were compared. The aim is to show the relative error that may exist, using instant or average data.

3. Results and interpretations

The relationship between liquid flow–solid flow previously established on the basis of different regression models was used to correct and fill the missing data.

$$Qs = 3.25Ql^{1.45} \quad (1)$$

The erosion has been calculated specifically to the right of the station with the annual variation given in Fig. 1.

The application of the power model to the monthly scale allowed quantifying the contribution of sediment and even specific erosion as shown in Fig. 2.

Since most of the effects of sediment transport occur during floods, we selected a few exceptional floods to determine the relationship between liquid flow and solid discharge. In Fig. 3 seventeen floods were selected; the selection was based on the period or phases of the largest number of sample concentration and the highest number of floods occurrence.

4. Conclusion

Silting is a serious risk to water storage. The presentation of the study area has shown the erosion existence more or less remarkably. The medium slope, which is 21.62 m/km, has a direct influence on water velocity. The lithological characteristics of the watershed have marked the presence of marl in particular, and it should be noted that the marls are brittle rocks, a factor favorable for degradation [15]. The biogeographical characteristics show a lack of vegetation throughout the year and the surfaces are often subject to grazing. Regarding the weather, the region is located in a semi-arid region with an average rainfall of 324 mm. The analysis, based on the regression method for finding the best relationship for solid flow–liquid flow, leads to the accepting of the power regressive model and its use in the quantification of sediment transport. The average intake is calculated as 18,087.66 tons/year where specific erosion is 0.15 tons/km^2/year. An analysis of the siltation state of Sidi Yacoub dam reservoir by bathymetric surveys method showed a retaining loss of 11% of its original capacity for 18 years of operation with an annual capacity loss of 1.79%.

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