International Journal of Hydrology Research
2019 Vol. 4, No. 1, pp. 1-12
ISSN: 2771-5590
DOI: 10.18488/journal.108.2019.41.1.12

ESTIMATION OF SUSPENDED SEDIMENT LOAD IN THE RESSOUL WATERSHED, ALGERIA

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Article History
Received: 2 January 2019
Revised: 6 February 2019
Accepted: 12 March 2019
Published: 8 April 2019

Keywords
Algeria
Watershed
Sediment rating curve
Prediction
Sediment yield.

ABSTRACT

Sediment load and its response to the variations of the hydrological elements are important to understand the phenomena of erosion. This study was fulfilled with the aim of developing a model to predict sediment load using sediment rating curve for the Ain Berda gauging station. The model was developed based on the available streamflow discharge and suspended sediment concentration data during sampled storm events over 39 year-period in the Ressoul watershed. Relationships between sediment concentration and water discharge were used according to single and rising-falling stage ratings to determine the best model for sediment load prediction. Additionally, a technique was devised to correct for log-transform bias on the sediment rating curves. The mean annual sediment yield during high and medium high flood events was 302 T km-2 yr-1. The high sediment loads in the study basin could be explained by the intensity of rain, the aggressiveness of the flows, the topography and the availability of sediments from hillslopes. The sediment load was dominated by winter and spring seasons accounting for 89% of the annual load. A high sediment supply in winter might confirm the intense geomorphic action caused by high intensity rainfall, low vegetation cover, and heavy machine activity in the agricultural fields. Following watershed management for local communities may bring multiple benefits. The adoption of suitable measures for soil conservation should reduce soil erosion and improve the livelihoods of the inhabitants. This study can serve as a reference for policymakers and planners.

Contribution/Originality: This study contributes on the existing literature on the estimation of suspended sediment yield using rating curve technique. The study outlines the analysis of some factors of erosion for estimating impacts of conservation methods on stream flow and sediment yield.

1. INTRODUCTION

Erosion is a critical process for land and watershed managers to understand, as sediment is the world's leading surface water pollutant. Excessive erosion results in significant soil losses, leading to declines in agricultural productivity [1]. The soils play a major role in the provision of services and goods provided by ecosystems to humans [2]. They support agricultural, forestry and pastoral production systems and contribute to climate regulation such as carbon sequestration. Also, soil erosion, which is a process of the surface soil alteration and relief modifications involving the detachment of soil particles, their transportation by the action of various agents and their deposition, occurred more frequently during phases of stronger human impact [2].

In Algeria, erosion is a major problem, its intensity varies from a zone to another zone. It is recognized by colonists and agronomists that soil erosion in this country is an environmental problem since the year 1930. More than 180 million tonnes of sediments are discharged into the sea each year reducing thereby the dams' lifetime [3]. The deposition level increased these years due to the fact of the highly-catchment basins erosion, especially at the East of the country where the erosion affects almost 40% of all lands. Excessive soil erosion in the mountainous Ressoul Highlands has brought about reduced soil fertility and caused transportation of considerable fine sediments outside the basin to downstream of Seybouse River. In fact, the Ressoul zone is identified by a Mediterranean climate with a seasonal contrast, where the soil erodibility can be affected by the dry and warm summer climate, and where the soil erosion can be affected by the concentration of precipitation events, particularly in the fall season [4].

Past studies of suspended sediment transport in northeastern Algeria have been carried out on determining some overall transport rate on an annual basis. The studies by Demmak [5] and Bourouba [6] have treated the phenomenon of erosion in a number of watersheds during the 7-year period 1972/73-1978/79. Their work was based on measured data of concentration and water discharge in order to evaluate sediment yields. The importance of the sediment discharge in Bouhamdane catchment has been underlined in a study of erosion by Heusch and Millies-Lacroix [7] and Sogreah-Sogetha [8] and they used empirical formulas to quantify the gross erosion in the basins of the Maghreb and the irrigated areas in Algeria.

More recent researches have been undertaken to predict sediment transport in some eastern watersheds. There has been a number of empirical, conceptual, and physical models to simulate watershed soil erosion. Selecting the right hydrological model for a specific watershed has always been a challenge, and field testing of watersheds and previous applicability of the model in hydrologically similar watersheds could help researchers to use the proper model for their purposes Ayele, et al. [9]; Begam and Barbhuiya [10]. Khanchoul, et al. [11]; Khanchoul, et al. [12] have predicted sediment yields in Mellah and Kebir watersheds through sections along the streams which provide reliable data in that of measurement sections, namely gauging stations. The suspended sediments in the Bouhamdane River have been measured and predicted by Louamri, et al. [13] using the relationship between suspended sediment concentrations and water discharges. He found that the sediment transport in this basin becomes significant during high water flows represented mainly by winter and spring seasons. The Bouhamdane watershed has also been studied by Bouguerra, et al. [14] who have used the soil loss equation (USLE) to assess water erosion at space scale and to determine the sensitive zones of soil erosion.

To predict reliable quantity and rate of sediment transport from the Ressoul land surface into the river, to identify erosion problem areas within a watershed and to propose management practices to reduce soil erosion, an empirical relationship model such as the rating curve technique could be utilized [15-17]. The two main contributions were as follows: (i) to reconstruct missing instantaneous suspended sediment concentration data according to storm events for the calculation of suspended sediment load in the Ressoul watershed, (ii) to analyze the annual and seasonal variability of the sediment load and to find out the reasons for the differences in suspended sediment loads between seasons by analyzing the relative effects of factors influencing sediment load such as lithology, topography, and land use. Through observations, attempts would be made to provide a preliminary basis for establishing soil erosion prevention and control measures tailored to the different land uses in this critical region.

A requirement for such statistical method was originally envisaged together with an intention to improve suspended sediment modeling. The selected method has tried to reconstruct missing suspended sediment concentrations from measured concentrations. This study has focused on the analysis of erosion factors to understand the variations in suspended sediment transport and its relation to rainfall and runoff.

Because of the means that requires to study bedloads, there was no work undertaken by the ANRH and therefore this type of load was not considered in this study. The collection of the hydro-climatic data and suspended sediment concentrations was possible with the collaboration of the different services of the National Agency of Hydraulic Resources (ANRH) of Constantine and Algiers.

2. STUDY AREA

The Ressoul catchment belongs to the great Seybouse basin (6475 km²). The former watershed, with an area of 107 km² at the gauging station of Ain Berda, has an elongated shape Figure 1. The name of Ressoul River is applied from the junction of Guis River with SW-NE direction and Bouala River with SE-NE direction. This basin shows a greatly dissected landscape dominated by a fairly high relief with 68% of the basin area exceeding 15% of slope Table 1. The steepness and the high drainage density (Dd > 3.30 km^{-1}) of the Guis subcatchment affect the soil stability and contribute to gullying and mass wasting (bank erosion, mudflows and landslides).

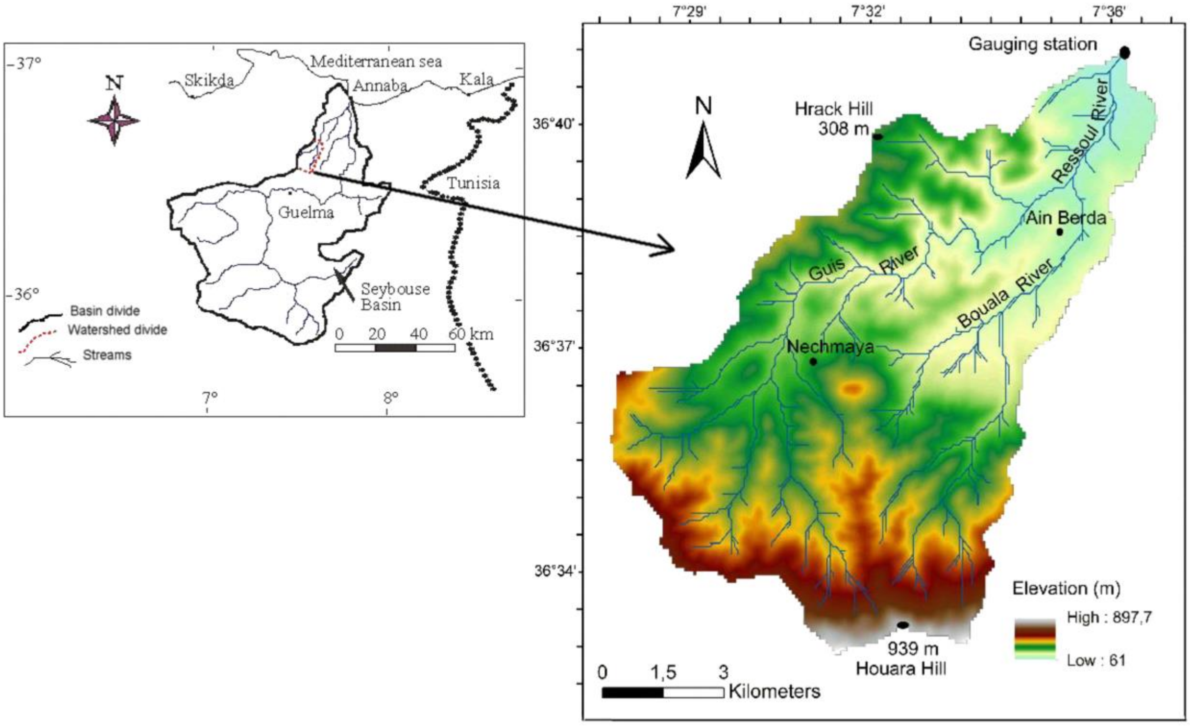

Figure-1. Location map of the Ressoul watershed.

Source: Khanchoul [18].

Table-1. Morphometric characteristics of the Ressoul watershed.

Watershed characteristics	Values
Basin area (km²)	107
Basin perimeter (km)	45
Hmax (m)	927
Hmin (m)	55
Hmean (m)	305
Basin shape	1.24
Drainage frequency (km^{-2})	6.58
Drainage density (km^{-1})	3.28
Average basin slope (%)	12.35
Time of concentration (hours)	5.50
Main stream length (km)	24

Source: Khanchoul [18].

The Ressoul watershed is essentially composed of upper Cretaceous marly limestone that forms 24% of the basin area Figure 2. The extended marly limestone outcrops, in association with other physical constraints such as steepness of hillslopes (exceeding 15%), poor vegetal cover (sparse forest and degraded bushes) and torrential rainfall conditions, have given a very dense network pattern and scoured surfaces of their clayey silty-gravelly soils. The extreme southern part that shows a range of higher hills (Houara Hill) and around Nechmaya village (median part) are represented by the Oligocene sandstone. The elongated ridges and fairly low hills which represent the rest of the lithologic formations: clayey shaly sandstone and clayey calcareous sandstone show a less important channeling. They are more protected by a densely and efficient plant cover (cork-oak forest and bushes). The recent alluvium and alluvial terraces, composed of loam, sand and gravel, are well developed along Bouala River and are less conserved along Guis stream where bank erosion is highly active.

The study watershed belongs to a subhumid climate of the Mediterranean type with a slightly fresh winter and a hot summer. Based on recorded daily rainfall of the 39-year period in the study basins (1975/1976 to 2013/2014), the Ressoul watershed is characterized by irregular annual precipitations with a mean annual rainfall of 675 mm and a mean annual temperature of 17°C. The temperatures vary between 11°C in January and 28 °C in August. The thunderstorms (daily rainfall more than 30mm per day) recorded at the Ain Berda rainfall station are most frequent from November to April and are present 3 days/year as a 39-year average.

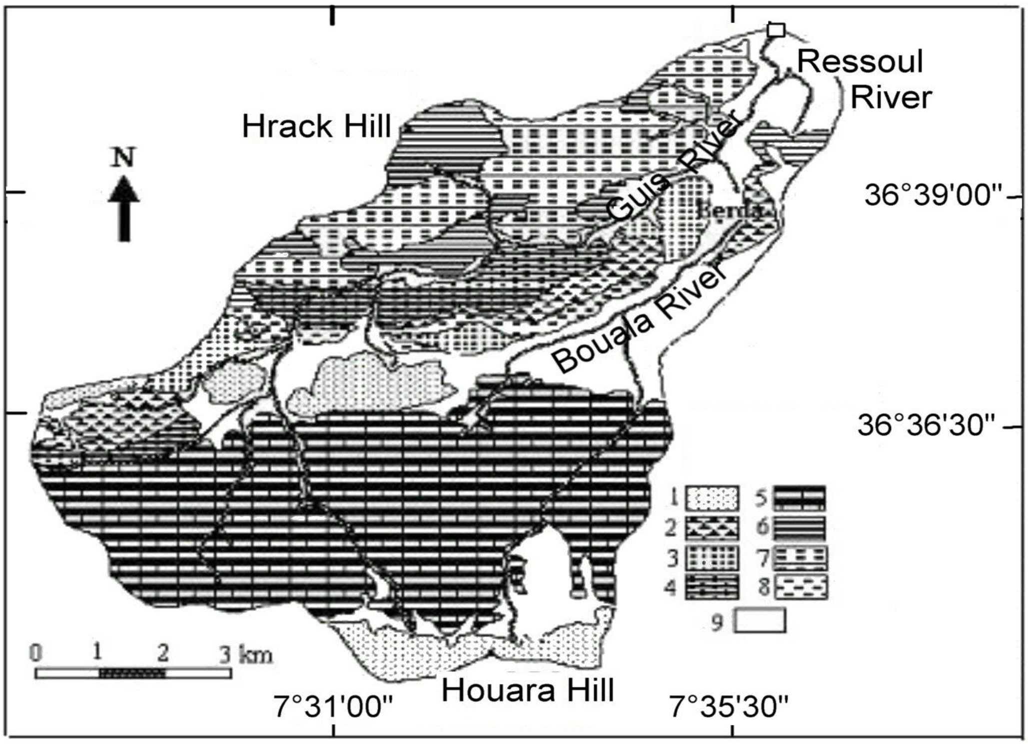

Figure-2. Lithologic map of the Ressoul watershed. 1: sandstone (Oligocene), 2: microbreccia (upper Cretaceous), 3: conglomerate (Mio-Pliocene), 4: micaceous sandstone (Oligocene), 5: marly limestone (upper Cretaceous), 6: clayey calcareous sandstone (lower Cretaceous), 7: clayey shaly sandstone (upper Cretaceous), 8: marl (Lutetian), 9: Quaternary formations.
Source: Khanchoul [18].

3. MATERIAL AND METHODS

3.1. Suspended Sediment Sampling and Analysis

Surveys of suspended sediment concentration and water discharge were carried out in the gauging station of Ressoul River. The water samples, which were taken in various conditions of stream flows, were filtered from one liter bottles using a filter of Laurent type (Ø = 32 cm). The filter and the mud contained in the bottle were weighed after drying during 30 minutes to eliminate the organic matter at a temperature of 110 °c.

The instantaneous values of concentration of storm events were sampled in variable time intervals between 1975/1976 and 2013/2014. The samples were often more numerous in periods of flood peaks with short time intervals (from half an hour to two hours).

3.2. Sediment Rating Curve Development

For storm events with few or no water samples, sediment concentrations were calculated with sediment rating curve at different water discharge time intervals. The sediment rating curves describe relationships between concentration and water discharge. Although the engineers would rather prefer to use the data obtained from measurements of transport rate wherever possible. It takes much time and is expensive method. Moreover, in many gauging stations there are generally water discharge measurements but not sediment load measurements, even in flood times.

As could be judged from Figure 3, there was no single relationship between the two variables because of the differences in the level of concentration for different highwater events and of different hysteresis relationship for each event [19-22]. For this reason, it was essential to introduce a method that could permit to construct valid sediment rating curves.

Regression models based on logged mean concentration for individual discharge classes have been applied to develop sediment rating curves. Thus, the chosen method applied in this paper has been developed by Jansson [23]. Rating relationships have been constructed by using linear least squares regression of the logarithmic transformed data. This straight line trend is commonly associated with a considerable degree of scatter related to the seasonal, hysteretic and exhaution effects and evidencing the complex controls of suspended sediment generation and delivery [24]. An attempt has been made to reduce this scatter by subdividing the rating relationship according to rising and falling stage conditions.

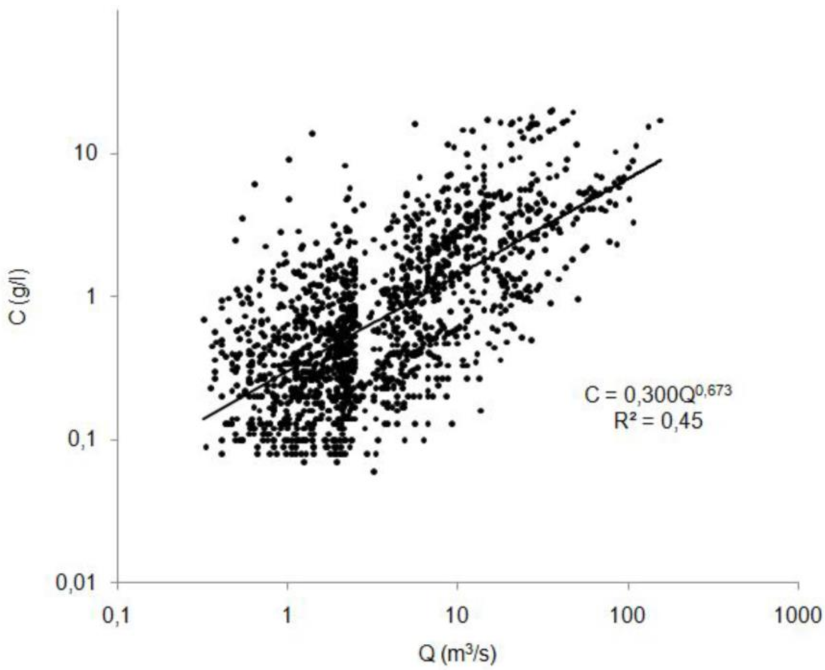

Figure-3. Sediment rating curve developed on water discharges and sediment concentrations.

The data set used to develop the sediment rating curves of Ressoul River consisted of 1670 measurements of instantaneous suspended sediment concentration and water discharge respectively. The procedure started by sorting the data that included measured values, and by regrouping them into distinct classes of water discharge. The definition of the width of each class interval depended on the data base in question. For the low discharge values the class interval could be narrow. This class interval would become progressively wider as the data base would become small at high water discharges. The mean sediment concentration of the measurements in every class was computed and entered in a plot to determine the change in direction of the sediment rating curve and to check the goodness of fit of the developed regression Figure 4. In considering the major factors governing temporal variations in suspended sediment concentrations, most workers have emphasized the dominant role of water discharge. High suspended sediment concentrations were in most cases associated with periods of high discharge, but closer inspection of this example could indicate that suspended sediment concentration was not a simple function of water discharge and that other factors, such as nature of the soil, land use and topography of the area where the rain might occur, could exhibit marked fluctuations in the supply of material to the rivers.

Based on changed direction of the means, the data base of the study watershed was divided into groups of data with one to three different regression lines with discharge threholds for each basin to establish the sediment rating curve Figure 4. As log-transformation was used to develop the regression equations, the re-transformed equations were corrected for bias Table 2. Miller [25] proposed a correction factor (CF) of a regression of natural logarithms. This factor was defined by the following formula Equation 1:

$$CF = \exp(0.5\sigma^2), \; \sigma^2 = 1/(N-1)^* \sum_{i=1}^{n} (\ln C_i - \ln C'_i)^2 \qquad (1)$$

σ^2 was the variance, C_i was the measured concentration taken from the long-term data records and C'_i was the estimated concentration computed from sediment rating curve. The corrected Equation 2 became as:

$$C = CF * aQ^b \qquad (2)$$

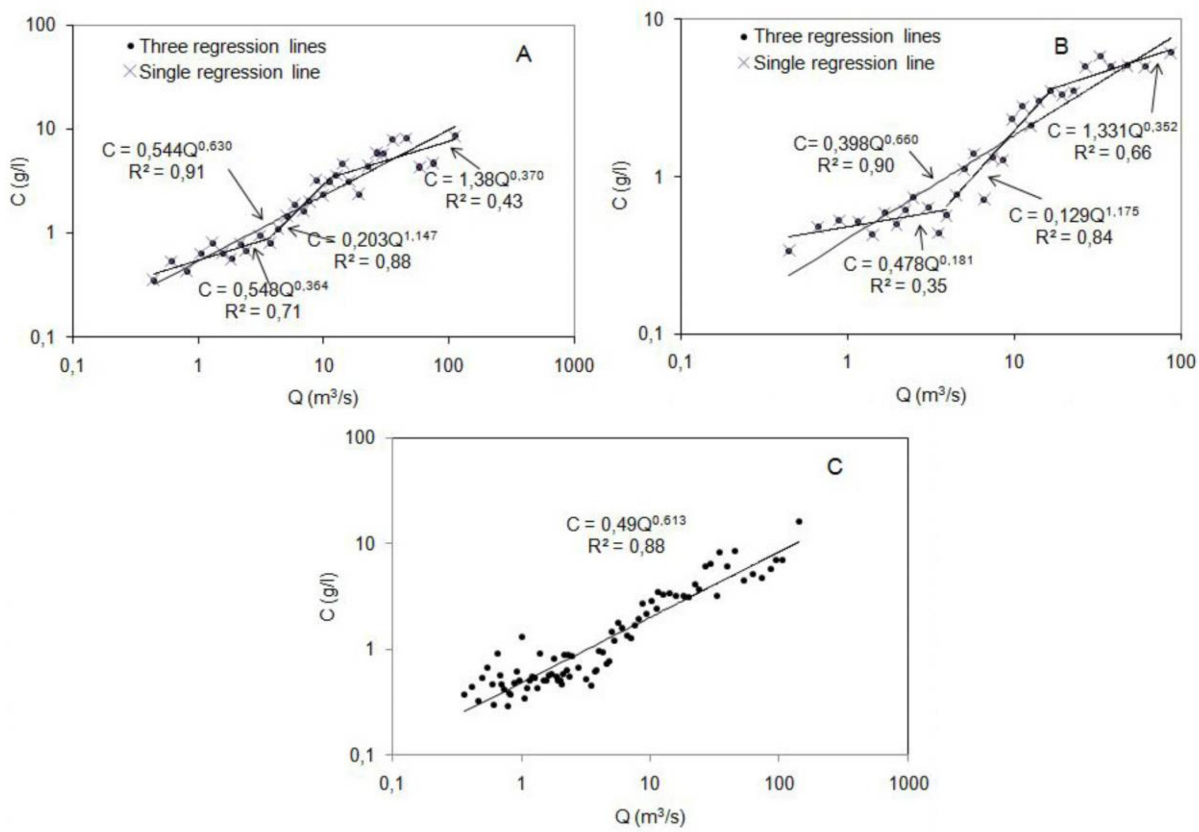

Figure-4. Sediment rating curves developed on mean concentration of water discharge classes according to rising stage (A), falling stage (B) and all data (C).

The various rating relationships were applied to the hourly flow data and the resulting estimates of annual sediment load were compared with the loads calculated from the measured suspended sediment transport. In case of sediment load underestimation, errors of estimation could be calculated in this analysis using a percentage of the value calculated from the continuous concentration data [26] as follows Equation 3:

$$\text{Error (\%)} = [(\text{rating curve estimate} \,/\, \text{continuous record load}) - 1] \times 100 \qquad (3)$$

where rating curve estimate was referring to the computed values using sediment rating curve equation and the continuous record load was the observed load calculated from the long-term data records.

4. RESULTS AND DISCUSSION

Two rating curve estimates were listed corresponding to the use of a single rating for all flow data and three ratings defined according to stage tendency Figure 4 and Table 2.

Table-2. Corrected equations of loads calculated from measured concentrations and from sediment rating curves.

Regression stages	a	b	R^2	CF
All data	0.490	0.613	0.88	1.0649
Rising stage:				
Single regression line	0.548	0.630	0.91	**
Three regression lines	0.548	0.364	0.71	1.0115
	0.203	1.147	0.88	**
	1.380	0.370	0.43	1.0428
Falling stage				
Single regression line	0.398	0.660	0.90	**
Three regression lines	0.478	0.181	0.35	1.0139
	0.129	1.175	0.84	1.0287
	1.331	0.352	0.66	**

**: number of water discharge classes insufficient to establish a bias correction or no need for bias correction because of a high coefficient of correlation.

The errors listed in Table 3 have demonstrated that the annual sediment loads calculated by using a single rating curve might involve a low overestimation (E = +0.14) and the application of separate rating equations for rising and falling stages has also resulted in a significant improvement in the estimate, but with slightly higher overestimation (E = +0.48). Nevertheless, the use of the discharge class method to develop sediment rating curves has provided good results as the sum of sediment discharges with measured concentration values were close to the sum of those calculated with concentrations predicted with sediment rating curve technique.

Table-3. Comparison of rating curve estimates of annual sediment load with loads calculated from measured concentration record.

Sediment load estimate	Sum of sediment load (x10^3 tonnes)	Error (%)
Measured concentration record	333.62	
All data:		
Before correction	319.82	-4.14
After correction	334.08	+0.14
Rising/falling stage	336.43	+0.48

In the following discussion, attempts have been made to explain the variation in sediment loads by looking at sediment loads on an annual and a seasonal scale.

4.1. Annual Variation

Using suspended sediment concentration measurements, the mean annual sediment yield during high, medium high and low flood events of the 39 years of the study period has shown a great variability from year to another in the Ressoul watershed and it is highly related to surface runoff Figure 5. The five years 1983/84, 1984/85, 2002/03, 2004/05 and 2011/12 with the highest annual loads have given 44.39% of the total sediment load of the 39-year period Figure 5.

Suspended sediment concentrations at the study basin are consistently higher and the highest values did not correspond to high sediment loads except for the two years 1983/84 and 1984/85. The sediment concentration distribution has shown a high variability of its values, ranging from 0.15 to 10.04, with a coefficient of variation equal to 0.82. The watershed mean annual rainfall and runoff values related to the storm events were equal to 367 mm and 61 mm. The basin has produced 1.26x10^6 tonnes of suspended sediment load, corresponding to a mean annual sediment yield of 302 T km^{-2} yr^{-1}. The tendency of sediment loads and runoffs has shown a significant relationship between the two variables from 2000/2001 to 2013/2014, which meant an increase in runoff was accompanied by an increase in sediment load; meanwhile, this relationship became insignificant from 1975/1976 to 1999/2000 Figure 5.

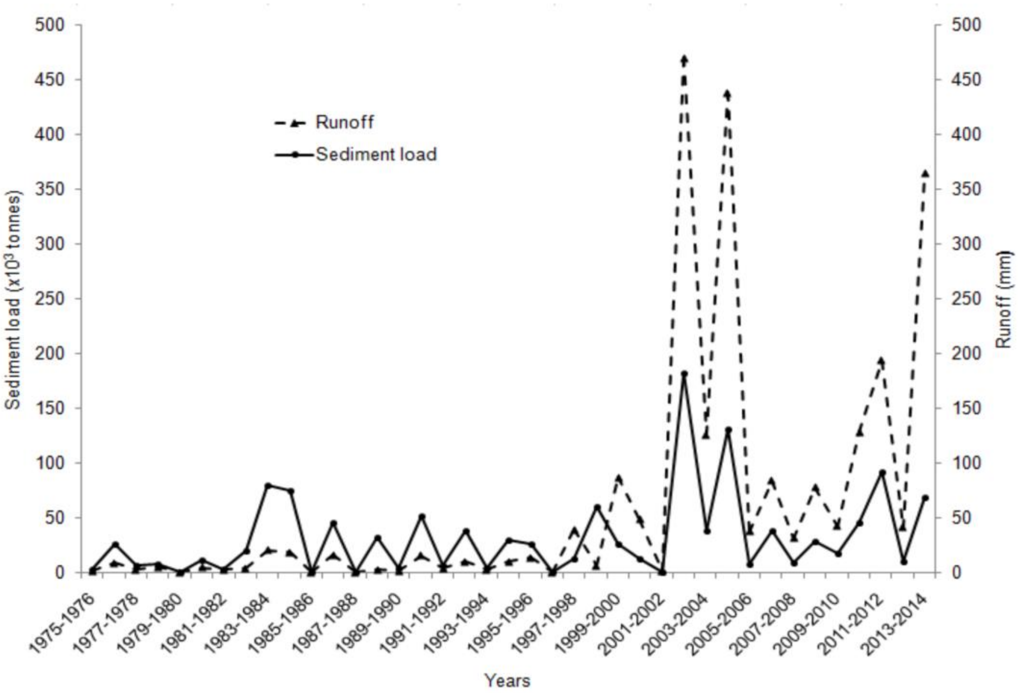

Figure-5. Annual values of runoff and sediment load recorded during storm events in the Ressoul watershed.

The sediment loads of the studied storm events have given an indication of the importance of the channel erosion on the marly limestone and clayey formations. The high values of stream frequency and drainage density were an example of that gullying Table 1. The zones relatively permeable are distinguished by a sandstone lithology and alluvial accumulations in the Bouala valley. The areas having more extended piedmonts surfaces consisted of very low permeable quaternary deposits have increased mass wasting and bank collapse, providing more suspended sediment concentrations during high and medium high rainfall periods.

4.2. Seasonal Variation

The monthly sediment load values of flood events during the 39-year period were higher in the winter (764.20x10^3 tonnes) and spring (359.46x10^3 tonnes) seasons. Indeed, the sum of the monthly sediment loads of winter season has represented 60.65% of the annual sediment load, whereas the spring season has produced only 29% Figure 6a. The autumn season is less characterized by high rainfall and runoff. This situation has provided less intense storm events and then lower suspended sediment concentrations.

Regarding the suspended sediment concentrations, the mean monthly values were also high during the winter and spring seasons with values of 0.52 g/l and 0.31 g/l respectively. It seems that the effect of the first rainstorms in autumn and first months of winter coupled with sparsely forested areas and bare agricultural lands on fairly steep hillslopes have been the dominant source of sediment supply to the streams. Figure 6b has shown that the suspended sediment concentration has risen to a maximum (in December) before runoff and rainfall (maximum values in January); this should explain the sediment supply that was ready to be transported during the summer and autumn seasons where the land was not covered with sufficient vegetation cover. Thus, the process of rainsplash has caused the washing of fine sediments from surfaces by sheetwash.

In addition, the winter months December to February were essentially characterized by rains of polar and cold air masses. These rains have produced more surface runoff than those of the autumn. A fundamental contrast in sediment generation processes were done in the study basin by an increase of available sediment supply in the headwater gullies and the lower reaches of Guis River that were less diluted by the volumes of baseflow during this season.

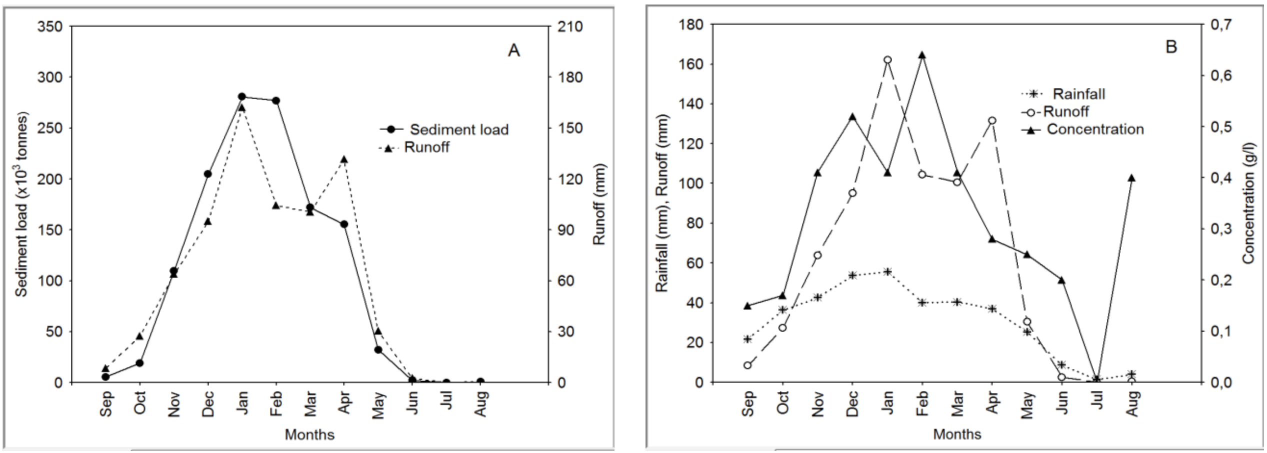

Figure-6. Monthly variations of sediment load, runoff and sediment concentration during storm events in the Ressoul watershed.

The spring season has given less sediment load and the reasons of this decrease was mainly due to the existence of a seasonal plant cover capable to reduce the mobility of sediment materials from hillslopes and to a reduction of flood events and runoff generated by high intensity rains that might lead to excessive surface erosion and rapid mass wasting.

As shown in Figure 6a, Ressoul watershed has shown a high surface runoff, especially in April, but a low sediment load and sediment concentration; and that in spite of high runoff coefficient (runoff and rainfall equal to 131.50 mm and 36.90 mm). This is should be probably to a certain water infiltration that happened from March to May at high vegetation cover. Also, the high runoff coefficient observed in April might be caused by higher groundwater flow or interflow at the end of the wet season.

4.3. Preventing and Managing Erosion

The information from the farmers regarding the history of the Ressoul basin has indicated that the natural forest of the area has depleted greatly as a result of the considerable increase of human population. The demographic growth has induced a stronger pressure on the land, leading to forest clearing for agriculture purpose. Moreover, the deforestation caused by wildfires has resulted in the extension of degraded woodlands, developed on clayey and marly formations on more or less steep slopes (eg. subwatershed of Guis). This situation has led to an increase of soil degradation and the sedimentation in streams. Bank-cutting on this subwatershed was described as an active source, with damage to streamside property and generation of landslides along the Guis River and its gully tributaries. Some landslides containing boulders are observed in the clayey piedmont areas on slopes exceeding 12% at a toe slope of Houara Hill. The highly fractured marly limestone surfaces were strongly dissected into the marl outcrops as gullying process. Soils developed on these lithologic formations were highly washed away into channel flow.

Identifying the controls on soil erosion, sediment delivery and sediment yield is an issue of concern to policy makers engaged in the management which requires strategies to circumvent negative impact from high sediment fluxes of rivers. In the Ressoul basin, and especially in the Guis subcatchment, the best solution to reduce soil erosion is reforestation of the sparse shrub-grasslands and burned forests in the southeastern and northwestern parts of the study basin. Further evidence could illustrate that changes in area-specific sediment loads could be attributed to low intensity land management practices. Therefore, it is important for those areas to require the most careful management to ensure soil stability. Thus, stream bank and gully erosion should be targeted by managing streams as revegetating bare banks, or installing gabions.

Concerning the restoration of landslide scars, which are numerous in the study area, tree planting was recommended for stabilizing slopes prone to mass movement. Deep rooted species such as eucalyptus, olive trees (Olea europaea) are suitable in this type of climate. In the areas of sparse grasslands and cultures, developed mainly on marly limestone and clayey hillslopes, the introduction of grass rotation is commonly practiced on grazing land, moving the stock from one pasture to another, to give more time for the grass to recover.

A risk of erosion might exist on cultivated lands that are on steep slopes. Multiple cropping, food-producing cultures on uplands, contouring to reduce soil loss from sloping land, and terracing (bench terraces on steep slopes, up to 45%) could be efficient to reduce soil erosion, especially on marly limestone and clayey calcareous-shaly sandstone surfaces.

5. CONCLUSION

The sediment transport was calculated for the Ressoul watershed. For storms with no or few water samples, a sediment rating curve was used. The sediment rating curves were developed with the discharge class method. The measured concentrations of all sampled storms were grouped into water discharge intervals and sediment rating curves were developed by using the mean concentrations and the mean discharges of the discharge classes.

The mean annual sediment loads during high, medium high and low flood events of the 39 years have provided information of the phenomena of erosion where it seems from the calculations that the Ressoul basin was undergoing a high land degradation. This watershed was affected by high relief energy and a more extended culture practices developed on sloping surfaces of clay-rich soils. These factors have accentuated the erosion dynamics that made this basin highly supplied in sediments during the winter and spring seasons. The Ressoul waterhsed was also distinguished by climatic and hydrologic conditions that provided more or less considerable sediment fluxes.

As understood from this study, the Ressoul River, given the sediment load responded more to runoff at flood events. Also, the modelling conducted with the regression model allowed to predict suspended sediment load and to determine its evolution with some hydroclimatic parameters for soil conservation planning in the future and flood disaster risk management.

A further implication of this study is that soil conservation efforts should be followed by farmers, whose activities might cause their lands to play important roles in the upland erosion system as runoff and sediment evacuation. An integrated watershed management approach needs to be adopted and the soil and water conservation technologies and approaches need to be applied in field situations, by the close collaboration with people and different agencies and not in isolation. Also, the conservation structures require regular maintenance of the used strategies of conservation practices for future development pathways for each of the land use types.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Contributors/Acknowledgement: Both authors contributed equally to the conception and design of the study.

REFERENCES

[1] D. J. Holz, K. W. Williard, P. J. Edwards, and J. E. Schoonover, "Soil erosion in humid regions: A review," *Journal of Contemporary Water Research & Education*, vol. 154, pp. 48-59, 2015. Available at: https://doi.org/10.1111/j.1936-704x.2015.03187.x.

[2] H. Briak, R. Moussadek, K. Aboumaria, and R. Mrabet, "Assessing sediment yield in Kalaya gauged watershed (Northern Morocco) using GIS and SWAT model," *International Soil and Water Conservation Research*, vol. 4, pp. 177-185, 2016. Available at: https://doi.org/10.1016/j.iswcr.2016.08.002.

[3] B. Remini, D. Bensafia, and T. Nasroun, "Impact of sediment transport of the Chellif River on silting of the Boughezoul reservoir (Algeria)," *Journal of Water and Land Development*, vol. 24, pp. 35-40, 2015. Available at: https://doi.org/10.1515/jwld-2015-0005.

[4] M. C. Ramos and J. A. Martínez-Casasnovas, "Impacts of annual precipitation extremes on soil and nutrient losses in vineyards of NE Spain," *Hydrological Processes: An International Journal*, vol. 23, pp. 224-235, 2009. Available at: https://doi.org/10.1002/hyp.7130.

[5] A. Demmak, "Contribution to the study of erosion and solid transport in Northern Algeria," Unpublished PhD Thesis, Paris, 1982.

[6] M. Bourouba, "Comparative study of the suspended sediment content of two intramontane Mediterranean wadis of Eastern Tell (Algeria)," *Annals of Geomorphology*, vol. 47, pp. 51-81, 2003.

[7] B. Heusch and A. Millies-Lacroix, "A method for estimating runoff and erosion in a basin," *Application in the Maghreb. Mines and Geology*, vol. 33, pp. 21-39, 1971.

[8] Sogreah-Sogetha, "General studies of irrigation and agricultural sanitation areas in Algeria. File O. Ministry of Agriculture and Agrarian Reform, Algiers," p. 164, 1969.

[9] G. Ayele, E. Teshale, B. Yu, I. Rutherfurd, and J. Jeong, "Streamflow and sediment yield prediction for watershed prioritization in the Upper Blue Nile River Basin, Ethiopia," *Water*, vol. 9, p. 782, 2017. Available at: https://doi.org/10.3390/w9100782.

[10] S. Begam and A. K. Barbhuiya, "Estimation of sediment yield of Sonai River using sediment rating curve and geographic information system," *International Journal of Advanced Research*, vol. 5, pp. 994-1000, 2017. Available at: https://doi.org/10.21474/ijar01/5415.

[11] K. Khanchoul, R. Altschul, and F. Assassi, "Estimating suspended sediment yield, sedimentation controls and impacts in the Mellah Catchment of Northern Algeria," *Arabian Journal of Geosciences*, vol. 2, pp. 257-271, 2009. Available at: https://doi.org/10.1007/s12517-009-0040-6.

[12] K. Khanchoul, Z. E. A. Boukhrissa, A. Acidi, and R. Altschul, "Estimation of suspended sediment transport in the Kebir drainage basin, Algeria," *Quaternary International*, vol. 262, pp. 25-31, 2012. Available at: https://doi.org/10.1016/j.quaint.2010.08.016.

[13] A. Louamri, A. Mebarki, and B. Laignel, "Interannual and intra-annual variability of the solid transports of Oued Bouhamdane, upstream of the Hammam Debagh dam (Eastern Algeria)," *Hydrological Sciences Journal*, vol. 58, pp. 1559-1572, 2013. Available at: https://doi.org/10.1080/02626667.2013.824089.

[14] H. Bouguerra, A. Bouanani, K. Khanchoul, O. Derdous, and S. E. Tachi, "Mapping erosion prone areas in the Bouhamdane watershed (Algeria) using the revised universal soil loss equation through GIS," *Journal of Water and Land Development*, vol. 32, pp. 13-23, 2017. Available at: https://doi.org/10.1515/jwld-2017-0002.

[15] M. Buyukyildiz and S. Y. Kumcu, "An estimation of the suspended sediment load using adaptive network based fuzzy inference system, support vector machine and artificial neural network models," *Water Resources Management*, vol. 31, pp. 1343-1359, 2017. Available at: https://doi.org/10.1007/s11269-017-1581-1.

[16] J. I. Slaets, H. P. Piepho, P. Schmitter, T. Hilger, and G. Cadisch, "Quantifying uncertainty on sediment loads using bootstrap confidence intervals," *Hydrology and Earth System Sciences*, vol. 21, pp. 571-588, 2017. Available at: https://doi.org/10.5194/hess-21-571-2017.

[17] Y. He, Z. Gui, C. Su, X. Chen, D. Chen, K. Lin, and X. Bai, "Response of sediment load to hydrological change in the upstream part of the lancang-mekong river over the past 50 years," *Water*, vol. 10, p. 888, 2018. Available at: https://doi.org/10.3390/w10070888.

[18] K. Khanchoul, *Water erosion and solid transport - case of watersheds in Northeastern Algeria.* France: Academic Editor, Collection OMN. PRES, 2015.

[19] M. B. Jansson, "Estimating a sediment rating Curve of the reventazon river at Palomo using logged mean loads within discharge classes," *Journal of Hydrology*, vol. 183, pp. 227-241, 1996. Available at: https://doi.org/10.1016/0022-1694(95)02988-5.

[20] K. Khanchoul and M. B. Jansson, "Sediment rating curves developed on stage and seasonal means in discharge classes for the Mellah wadi, Algeria," *Geografiska Annaler: Series A, Physical Geography*, vol. 90, pp. 227-236, 2008. Available at: https://doi.org/10.1111/j.1468-0459.2008.341.x.

[21] C. D. Guzman, S. A. Tilahun, A. D. Zegeye, and T. S. Steenhuis, "Suspended sediment concentration–discharge relationships in the (sub-) Humid Ethiopian Highlands," *Hydrology and Earth System Sciences*, vol. 17, pp. 1067-1077, 2013. Available at: https://doi.org/10.5194/hess-17-1067-2013.

[22] A. Costa, D. Anghileri, and P. Molnar, "Hydroclimatic control on suspended sediment dynamics of a regulated Alpine catchment: A conceptual approach," *Hydrology and Earth System Sciences*, vol. 22, pp. 3421-3434, 2018. Available at: https://doi.org/10.5194/hess-22-3421-2018

[23] M. B. Jansson, "Comparison of sediment rating curves developed on load and on concentration," *Hydrology Research*, vol. 28, pp. 189-200, 1997. Available at: https://doi.org/10.2166/nh.1997.0011.

[24] D. E. Walling and B. M. Webb, "The reliability of suspended sediment load data," *IAHS-AISH Publications*, vol. 133, pp. 177–194, 1981.

[25] D. M. Miller, "Reducing transformation bias in curve fitting," *The American Statistician*, vol. 38, pp. 124-126, 1984. Available at: https://doi.org/10.1080/00031305.1984.10483180.

[26] D. E. Walling, "Assessing the accuracy of suspended sediment rating curves for a small basin," *Water Resources Research*, vol. 13, pp. 531-538, 1977. Available at: https://doi.org/10.1029/wr013i003p00531.