Estimated Flows of Suspended Solids by the Statistical Analysis of Outfall Drainage Basin of Tafna (Algeria)

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Abstract

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The solids transport is a complex phenomenon; the intensity of these phenomena varies greatly with the general environment: geology, degree of rock alteration, hydrology, vegetation, climate, etc. The extent of the phenomenon is out of proportion in semi-arid areas or areas with temperate climates. So Algeria is one of the countries most affected by this phenomenon and its consequences. To enable a rapid response to demands from engineers for the quantification of bed load transport at the outlet of a catchment area, a simple tool easy to implement has been developed. The principle adopted is based on hydrometric data from gauging stations, and seasonal and annual analyses have defined an appropriate method for estimating the sediment yield. The study was conducted by analysis of average flows. The Pierre de Chat Station at the outlet of the Tafna watershed was used for application. The results obtained were quite satisfactory because the correlation coefficients of the model: $Q_S = f(Q)$ are between 87 and 96%. This method once refined can be generalized to all the watersheds of northern Algeria.

Keywords: catchment; erosion; sediment transport; statistics; suspension; Tafna

Algeria is a semi-arid and even arid country (200 to 400 mm of rain annually) and renewable water resources are low, irregular, and located in the coastal band. To this effect the National Agency of Dams (NAD) has until now realized about 60 large dams with a capacity of 6 billion m^3. But with a specific erosion rate between 2000 and 4000 t/km²/year (Demmak 1982), every year the Algerian hydraulic infrastructure is amputated a capacity of 45 million m^3 (Remini 2004; Remini *et al.* 2009) following the silting. Unfortunately, the problems of erosion and sediment transport can reach a magnitude likely to completely sterilize the water management efforts and rivers (Achite & Meddi 2004, 2005).

Given the importance of this problem, and to enable a rapid response to demands from engineers for the quantification of suspended sediment at the outflow of a catchment area, a simple tool easy to implement was developed. The principle adopted is based on hydrometric data from gauging stations, and seasonal and annual analyses have defined an appropriate method for estimating sediment yield. It is in this meaning that a part of this study is to evaluate the suspended sediment in the basin of Tafna.

MATERIAL AND METHODS

General approach. It appears as follows:

(a) Data collection contributing to the phenomenon (water discharge Q, solids concentrations).

(b) Statistical processing of data and computer.
(c) Determination of appropriate models $Q_S = f(Q)$ between liquid flow rates and solids discharge.
(d) Study of discharge rate regimes of rivers by frequency analysis (flow duration curves) using the file of mean daily liquid discharge as long as possible and without lacuna.
(e) Finally, an estimate of the mass of suspended sediment by the combination between the model $Q_S = f(Q)$ and the cumulative frequency curve of liquid discharge (UNESCO 1986).

Evaluation of suspended solids. The estimation of the mass of suspended sediments is done according to the following steps:
– Construction of the cumulative frequency curve of liquid discharge.
– Division of the cumulative frequency curve of liquid discharge into several frequency intervals ($f_{i,fi+1}$).
– Determination of liquid discharge that met or exceeded the median *QI* corresponding to each frequency interval.
– For each liquid flow rate *QI*, the flow is calculated using the solid Q_{Si} statistical model $Q_S = f(Q)$.
– Evaluation of interannual average sediment discharge by (Bouchelkia & Remini 2003; Bouchelkia 2009):

$$Q_{sm} = \sum_{i=1}^{n} Q_{si} \times (f_{i+1} - f_i) \qquad (1)$$

Presentation of the study area and used data. The catchment area of the Tafna is located in the extreme northwest of Algeria. The area of 6900 km^2 is crossed by one of the largest wadi in western countries: Tafna, which flows from west to east, from Morocco to the Mediterranean Sea (near Beni Saf), the length of the main riverbed is 759 km (Figure 1).

This region is dominated by the massive Jurassic mounts of Tlemcen, composed of very resistant dolomitic limestone. Culminating at 1843 m a.s.l. at Jebel Tenouchfi, the basin is bounded by the principal relief (Monts de Tlemcen) between the Mediterranean and the high plains of Oran and relayed to the west by the Middle Atlas of Morocco and to the east by the mountains of Daia (Saida). The basin consists principally in the south of a WSE-ENE oriented mountainous bar (800–1400 m), while the plains areas of Maghnia of Hannaya and of Sidi Abdelli are largely dominating in the north. This orographic structure, dominated in the north by the mounts of Traras (1081 m a.s.l.) of small width, results in an effective barrier for precipitation, which explains the aridity of the plain of Maghnia. In 75 km as the crow flies, we pass from semi-arid domain to humid Mediterranean domain, from a mountainous area to a relatively flat area (Belarbi 2010).

The hydrographic network of the Tafna River mainly consists of two arteries: Wadi Tafna in the west and Wadi Isser in the East, it takes its source in the mountains of Tlemcen.

The soils of the Tafna basin consist of four major groups:
– The alluvial soil covering the low terraces and floodplains of the wadis;
– The stony land in the foothills of the mounts of Tlemcen and of Traras;
– The red soils crust, localized in the plains of Maghnia and Ouled Riah;
– Marly lands, covering much of the region of Tlemcen (Bouanani 2005).

The vegetation is a key factor in rapid surface runoff, evaporation rate and the retention basin. So the presence of vegetation will act as a regulator in the flow regime.

The collection of data consists in a systematic analysis of parameters: depth of water and concentration of solid particles collected at the Pierre de Chat Station situated on the Tafna River at the outlet of the basin, these data are from the National Agency of Hydraulic Resources (ANRH). Data

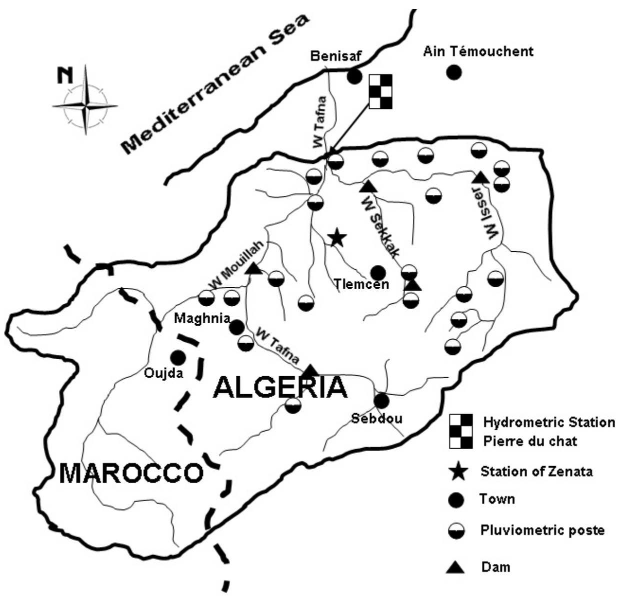

Figure 1. Watershed of Tafna

are representative as they extend over a period of 16 years (1990–2006) for the discharge "this data series is complete and without flaw" and over a period of 11 years (1995–2006) for the pair liquid discharge, solids discharge (Q, Q_S).

The ANRH data were divided into two files: a file of the average daily liquid discharge without flaw and file a second fluid flow means instantaneous and instantaneous solid concentrations observed by the ANRH services over the period mentioned above where we have produced the file of the pair liquid discharge/solid discharge expressed as average daily discharge.

RESULTS AND DISCUSSIONS

For the Pierre de Chat Station, applications for annual and seasonal scales were conducted, given the seasonal influence on the phenomenon of bed load transport; the latter led us to establish relationships between seasonal liquid discharge and sediment loads and to estimate the contribution of suspended sediment from each season. Two groups of seasons have been made, the first treatment with the year seasons (autumn, winter, spring, summer), the second according to the division of the year into two seasons (wet season and dry season) identified through the construction of the ombrothermic diagram of the Zenata meteorological station, which is located inside the drainage basin, we preferred to use the data from this station rather than from the Pierre de Chat Station for better representation (Figure 2). The data used for the construction of this diagram comes from the National Office of Meteorology (ONM). The ombrothermic diagrams are used to determine the number of dry months and the number of wet months and therefore they identify the dry season and wet season. In effect, if the value of temperature in a given month is higher than the double of the value of rainfall in this month, it is considered as dry month (Walter 1979).

According to the ombrothermic curve, we notice that the humid season extends from November to April (i.e. 6 months) against the dry season extending from May to October (6 months). According to Figure 2, it is evident that the wettest month is November with an average rainfall of 44.7 mm and the driest month is July with 3.8 mm of rain per month while the coldest month is January with an average temperature of 10.8°C and the hottest month is August with 26.6°C.

More than 5840 data on daily average liquid discharge and 1000 pairs (Q, Q_S) were selected over the period 1995–2006. It should be noted that the series of daily mean water discharge is a continuous series without gaps, but the series of pairs (Q, Q_S) should be as long as possible but not necessarily continuous. The liquid flow rates are registered at the Pierre du Chat gauging station and solid concentrations are obtained after analyses of water samples collected at this station in the laboratory of ANRH, these samples are daily with multiplication of the number of samples during floods.

Figure 3 shows the relationship between annual and seasonal sediment loads based on discharge rates. It is interesting to note that the cloud of points takes the form of a power relationship:

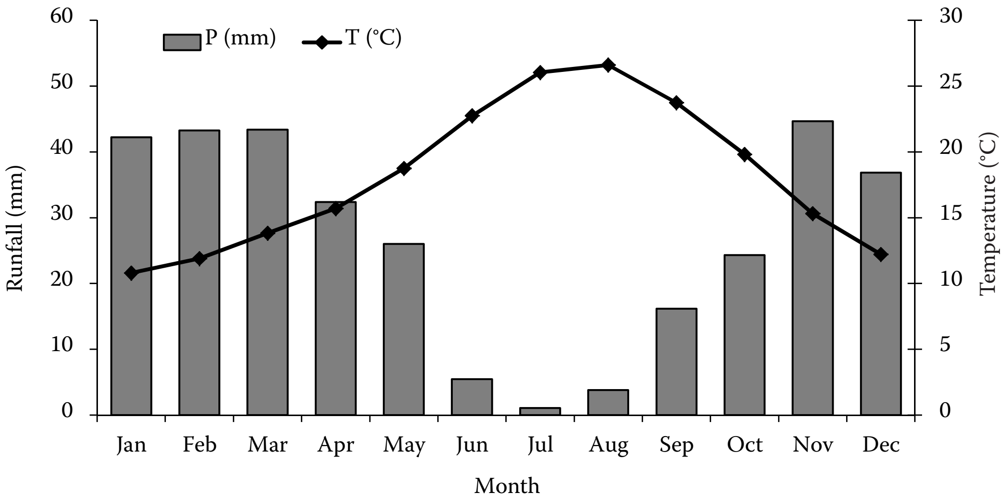

Figure 2. Ombrothermic diagram – Zenata Station; period 1980–2010

$$Q = K \times Q^{A} \qquad (2)$$

where:

K, A – coefficients

Table 1 summarizes the different relationships and correlation coefficients.

Using the distribution of statistical observations in classes, we were able to trace the flow duration curves (cumulative frequency of mean daily liquid discharge) (Musy 1998), so then each file of mean daily liquid discharge is classified and we determine the experimental frequencies of their discharges.

For the periods considered the curves obtained are illustrated in Figure 4. When plotting the cumulative frequency curves we observed that these curves stick to axes; they are all perfectly normal because wadi Tafna like most Algerian wadis (rivers) is not permanent and is very ir-

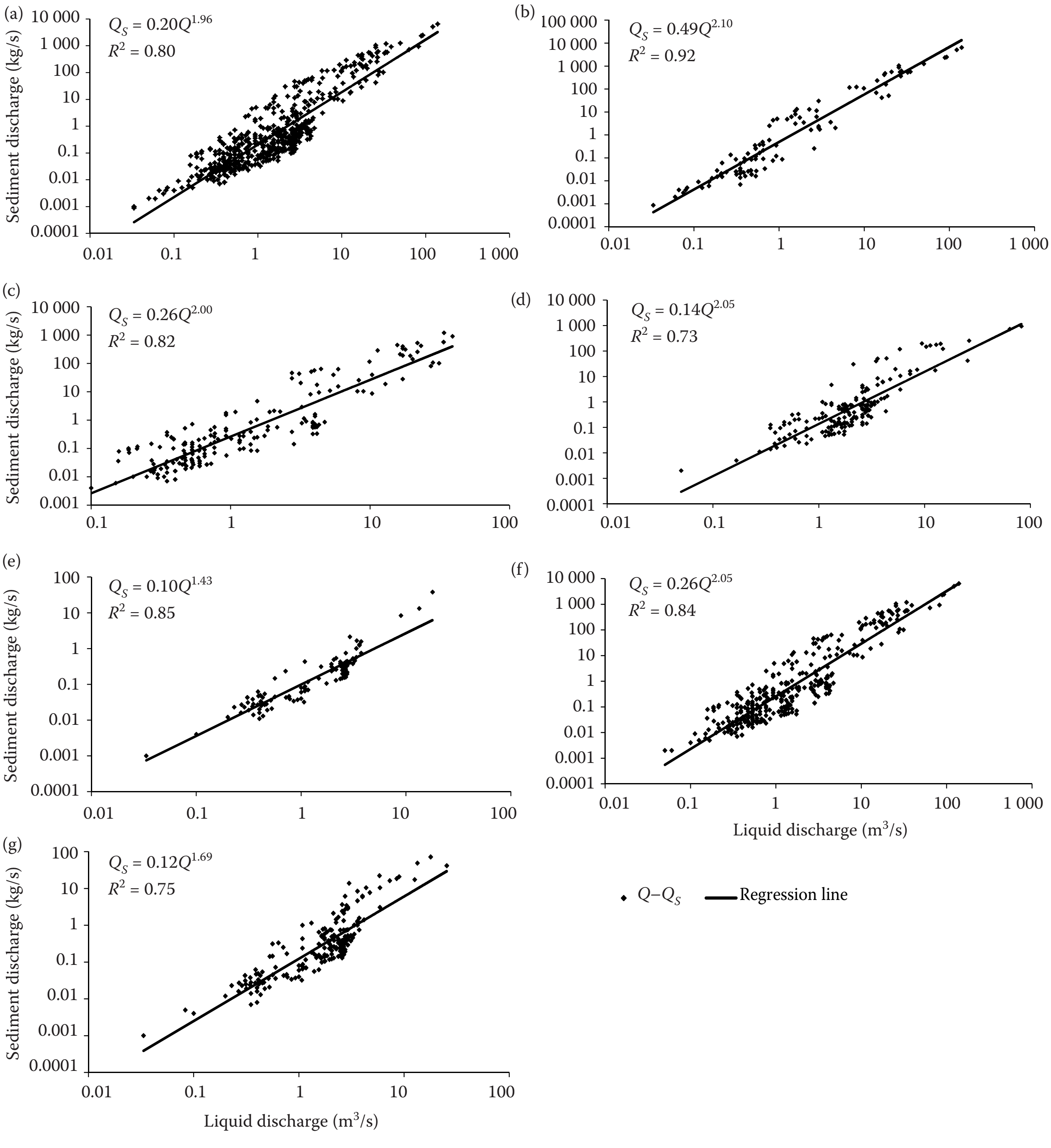

Figure 3. Correlation between annual and seasonal solids flow and liquid flow: (a) annual, (b) season of autumn, (c) season of winter, (d) season of spring, (e) season of summer, (f) wet season, (g) dry season

Table 1. Relationships and correlation coefficients of models $Q_S = f(Q)$

Period	No. of points	A	K	Correlation coefficient (%)	Relation
Annual	592	1.96	0.20	89	$0.20Q^{1.96}$
Fall	355	2.10	0.49	96	$0.49Q^{2.10}$
Winter	302	2.00	0.26	90	$0.26Q^{2.00}$
Spring	252	2.05	0.26	91	$0.14Q^{2.05}$
Summer	215	1.43	0.10	92	$0.10Q^{1.43}$
Wet season	606	2.05	0.26	91	$0.26Q^{2.05}$
Dry season	516	1.69	0.12	87	$0.12Q^{1.69}$

A, *K* – coefficients

Table 2. Means and standard deviations (SD) of mean daily liquid discharge_

Period	Size	Average (m^3/s)	SD
Annual	5400	1.75	17.90
Fall	1464	0.90	3.69
Winter	1440	3.99	24.84
Spring	1452	1.26	4.24
Summer	1440	0.42	3.72
Wet season	2892	2.60	24.14
Dry season	2940	0.70	3.69

regular; its flow is low, sometimes well dry but can exceptionally reach phenomenal flows (1040 m^3/s registered in the period 1991–2006) especially during floods, for this reason that we have borne the abscissa axis in logarithmic scale for better visibility of curves.

Table 2 summarizes the means and standard deviations of monthly average flow rates for each period. Mean and standard deviation gives us an idea about sample, standard deviation measures the dispersion of data around their mean. If the standard deviation is low, there is a concentration of data around the mean (Bowker 1965). So for our case the liquid flows are more concentrated around their average in autumn, spring, summer and dry season (standard deviation < 4.24) and more dispersed around their average annual in winter and wet season (standard deviation > 17.9).

The model $Q_S = K \times Q^A$ combined with the flow duration curve following the steps listed above in section 2.2 allows us to assess the annual average suspended sediment load (annual mean suspended sediment discharge). The results obtained are shown in Table 3.

All results (correlations of liquid discharge – solid discharge, liquid flow frequency study and estima-

Table 3. Solids inflows in the Tafna River

Period	Annual	Fall	Winter	Spring	Summer	Wet season	Dry season
Daily water discharge average (m^3/s)	2.08	1.20	4.43	1.54	0.88	2.91	1.07
Specific concentration (g/l)	31.60	8.68	88.55	2.46	0.23	93.07	0.58
Sediment discharge suspended (kg/s)	65.82	10.41	392.16	3.78	0.20	271.18	0.62
solid contribution (104 t/period)	207.60	8.21	309.20	2.98	0.16	427.59	0.98
Solid annually input (10^6 t/year)	2.08		3.2055			4.2857	
specific degradation (t/km^2/year)	301.45		464.56			621.11	

tion of suspended sediment yield) were obtained by a specially developed computer program.

The results of adjustment models: solid discharge – liquid rate are fairly significant, since the correlation coefficient varies between 86% and 96% (Table 1) for all applications. The correlation coefficient for the model annually is significant; it is 89% (Table 1). Using the seasonal scale, the cor-

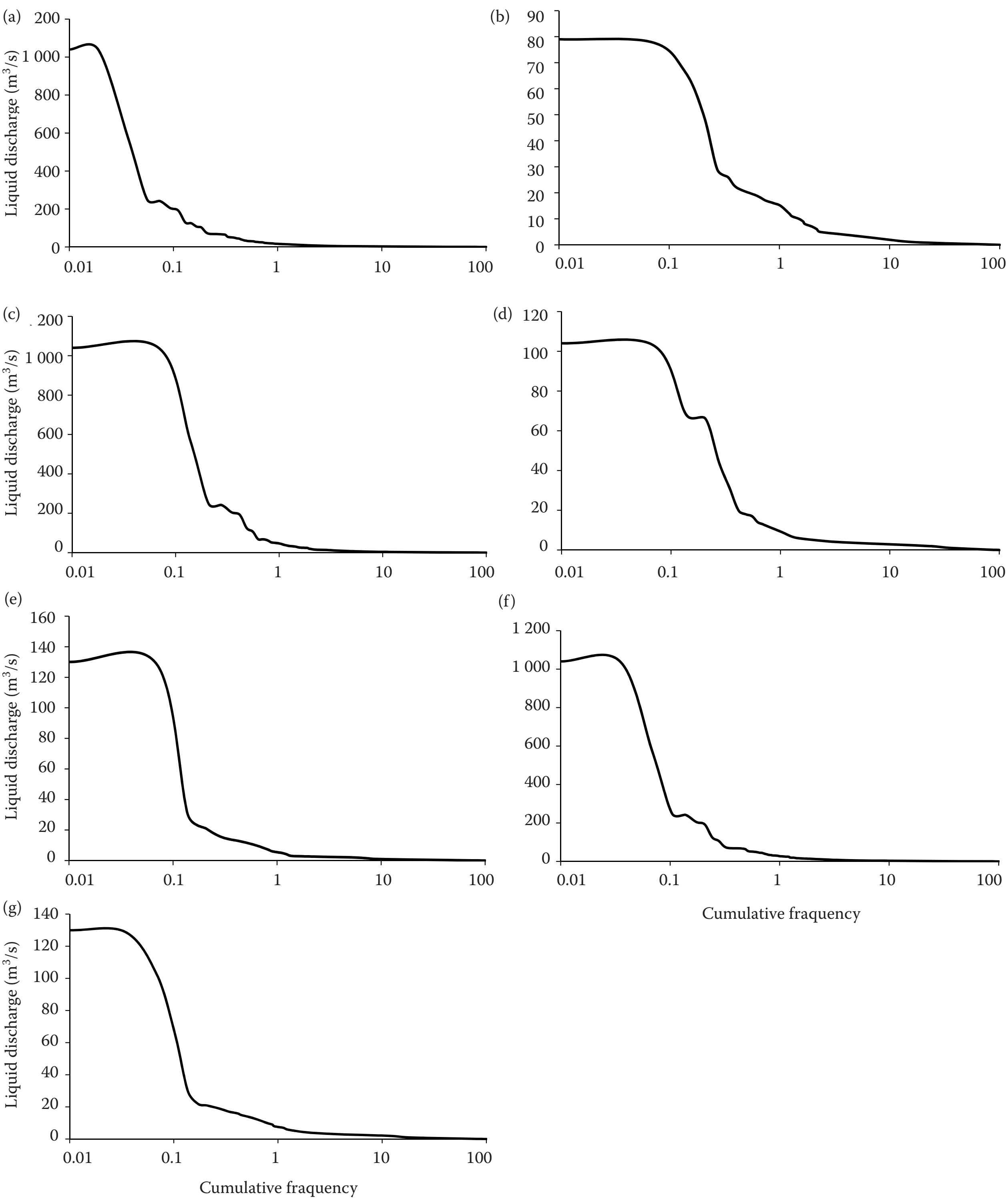

Figure 4. Cumulative frequency curve of mean daily liquid discharge, Station of Pierre du Chat (1991–2006): (a) annual, (b) season of autumn, (c) season of winter, (d) season of spring, (e) season of summer, (f) wet season, (g) dry season

relation coefficient is much larger for the seasons: autumn, winter, spring, summer and humid season since it is 96, 90, 91 92 and 91%, respectively.

We note that the lowest coefficient is stored during the dry season (87%); this may be due to the irregular supply and the intervention of major flood events during this season. Overall, the seasonal influence on the phenomenon is visible in this study. On the scale of the two seasons (wet and dry season), but the significance is very important that we have obtained correlation coefficients of 91 and 87%. This confirms the seasonal influence on the phenomenon of bed load transport. The relationship of water discharge – solids discharge generally remains significant.

Specific degradation at the catchment area of the Tafna seems very important as it is subjected to physical and climatic conditions that vary widely (between 301 and 621 t/km^2/year). It is clearly superior to results found in 1994 in an earlier study (Bouchelkia & Benhadj 1994) on the same watershed (between 197 and 255 t/km^2/year) using previous data (1970–1990). These results are well above the suspended sediment yield that we found in the catchment of Wadi Mouillah (Bouchelkia *et al*. 2011) (between 17.73 and 28.41 t/km^2/year in the period1974–1999) located within the basin of Tafna. These results are higher than the result found by Terfous *et al.* (2001) for the watershed of Mouillah (126 t/km^2/year in a study period from 1977 to 1993), but it should be noted that their estimate does not account for frequency rates liquids, and even it is far from the value obtained by Megnounif *et al.* (2003) for specific degradation in one sub-basin in Tafna using data on five years of observation (1120 t/km^2/year).

It is noted that in winter flows are most important Solid (3.20 × 10^6 t) in this season because the liquid discharges are more important, more regular and more frequent floods than in the other seasons.

CONCLUSION

This estimation approach will allow the projector and the manager to better estimate the sediment transport and predict losses in capacity. This approach was applied to quantify the suspended sediment at the Pierre du Chat Station located at the basin outlet of Tafna during the period 1990–2006. The estimate was based on the average daily traffic as well as liquids means that for couples liquid flow rates – solid discharge (model for $Q_S = f(Q)$) recorded during the period in question. The obtained results showed that the sediment yield in winter is the most abundant and regular.

The results demonstrate that the catchment area of the Tafna is very important from the aspect of erodibility, since the maximum value of solids contributions is 6.21 × 10^6 t/year. Considering the results of our previous study on the same problem shows that the degradation of this basin has intensified in the last twenty years well as liquid intake decreased (drought and construction of two dams Hammam Boughrara and Sekkak); this accentuation is probably the major change undergone by this basin in this period, in particular the fires of forests. The results in an application different from each other, any time the extent and nature of the work will be predetermining the choice of the application. A comparison of these with the field measurements and experimental, we will make the best choice.

The results of this study can be used as a simple and directly applicable tool for estimating solids contributions in all Algerian catchments.

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