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Erosion and dam siltation in a Rif catchment (Morocco)

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Abstract In the Rif region (northern Morocco), various check dams were constructed in the 1990s, but high siltation rates led to their total infilling in a few years. The objective of this work was to assess the processes generating soil particles, and their accumulation, in the Abdelali check dam. A bathymetric survey was carried out to quantify the volume of sediments and the total erosion rate. Further, fallout ^{137}Cs was determined to estimate soil loss in selected areas, and to identify the main sources of sediment. The radiotracer led to the identification of different sediment sources; erosion rates appear to be a function of vegetative cover, topography, and/or land use. Based on the two methods, it was possible to assess the contribution of rill and bank erosion; it appeared to represent about one third of the total accumulated sediments. The combination of these techniques proved to be a suitable approach for establishing catchment sediment budgets with a view toward promoting strategies for better soil and water management.

Key words Abdelali; bathymetry; caesium-137; check dam; erosion; Morocco; Rif; sedimentation; siltation

INTRODUCTION

The Rif territory in northern Morocco is under threat of desertification due to erosion, which accelerates the degradation of ecosystems. In this small region, intense rainfall events on highly erodible soils and poorly vegetated slopes supply high sediment loads to downstream catchments. The transport and accumulation of sediment seriously damages such water-related structures as canals and reservoirs, and degrades water quality. Besides, devastating floods also damage roads and bridges, and are a permanent risk for the population. In the region, a total of 20 check dams were recently built by the government with the aim of improving rural development. Unfortunately, total siltation of the dams occurred shortly after they started functioning, in most cases in just five or six years. Among the reasons for these failures were: (a) unsuitable locations for the check dams; (b) their disproportionate initial small volume in relation to the catchment area; and (c) erroneous estimations of siltation rates calculated from empirical equations.

In the Msoun basin (eastern Pre Rif), three check dams were totally filled with sediment in less than seven years. One of the check dams, in the Abdelali catchment, was selected as a case study to assess the erosion and sedimentation processes in the area. The deposited materials originated from different erosive processes such as overland flow, and rill, gully and bank erosion. The analyses of some sediment characteristics could provide valuable information on the specific degradation processes ongoing in the catchments during the time of dam operation (Foster & Walling 1994; Navas *et al.*, 1998). The objective of this study was to apply a combination of techniques to identify the main processes of sediment delivery, and to estimate the erosion rates responsible for the siltation of the Abdelali check dam. A bathymetric survey was carried out to estimate the volume of sediment that had accumulated in the check dam. In order to find the source areas of the sediments, and to classify them according to different degrees of erosion, the ^{137}Cs radiometric technique was applied in some representative areas of the catchment. The combined use of both methods helped establish the relative contributions of the different erosive processes that led to the siltation of the Abdelali check dam.

THE STUDY AREA

The Abdelali catchment is located in the southern part of the East Rif (Fig. 1). The climate is semiarid, with an average annual rainfall of 479 mm. The catchment is close to the city of Aknoul, and has a surface area of 240 ha. In the catchment, highly fragile soils cover Cretacious outcrops composed of marls, limestone, and clays with gypsum. Approximately 70% of the catchment surface is covered by shrubs and natural or replanted forests of conifers and evergreen oaks; the remaining surface area is heavily cultivated for cereals (Fig. 2). Overgrazing and deforestation have rapidly increased the amount of exposed soil subject to erosion.

The mountainous landscape displays sharp relief, with most of the slopes above 35%. The local geology is characterized by the presence of the Aknoul and the

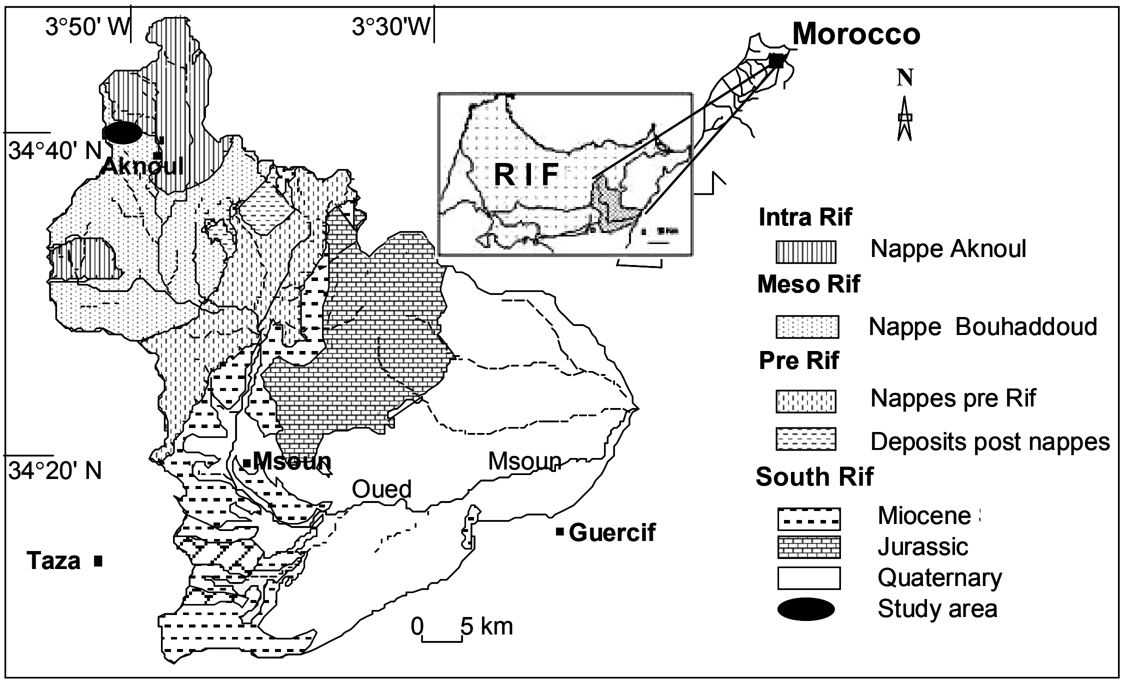


Fig. 1 Location and geology of the study area.

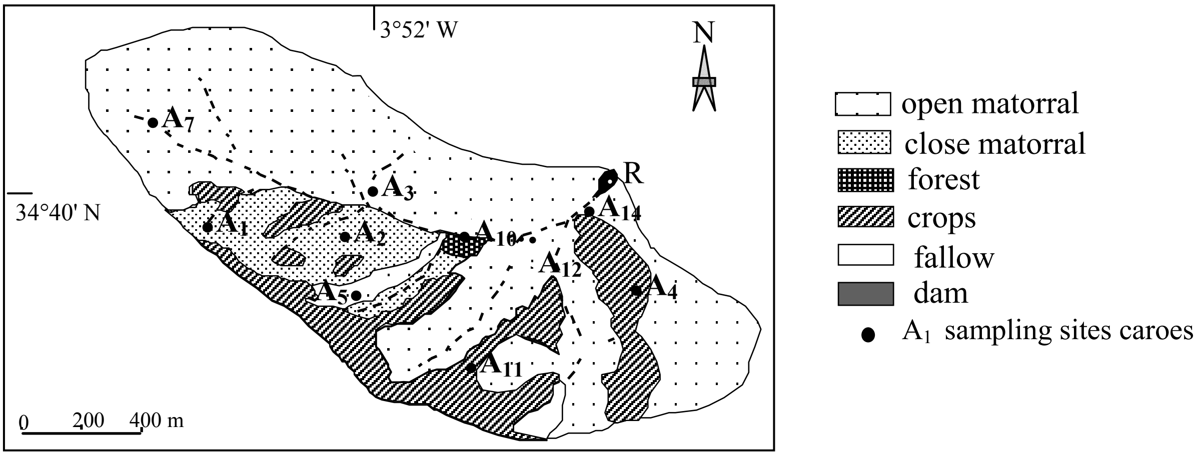
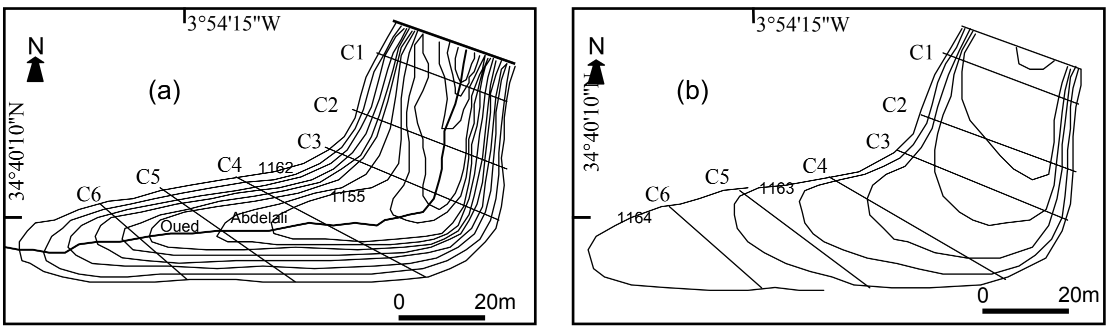


Fig. 2 Land use and sampling sites in the Abdelali catchment.

Bouhaddoud nappes (Leblanc, 1975). The latter occupies most of the catchment. The contact between both nappes consists of Triassic formations of various thicknesses, composed of gypsum and saline clays.

METHODS

The total volume of sediment that accumulated in the Abdelali check dam was estimated by means of a bathymetric survey. The bottom topography of the reservoir behind the siltated check dam was measured using an electronic theodolite and GPS. The current topographic map, and the previous one generated prior to the construction of the check dam, were integrated into a GIS file. The contour lines were transformed in a digital elevation map (DEM) of the catchment to estimate the volume of sediment in the siltated section (Fig. 3). To calculate the total weight of the sediment, the bulk density of the accumulated material was measured in several samples. Thus, an average erosion rate, for the period between 1991, the year the check dam was built, and 1997, when it was fully siltated, can be established for the whole Abdelali catchment.



C*x*, situation of the transects.

Fig. 3 Topography of the Abdelali check dam. (a) prior to dam construction (1991), (b) after dam construction.

The ^{137}Cs technique was employed to help identify the different sources of sediment that contributed to the siltation of the check dam. In other studies, this radiotracer has been used successfully, in diverse environments around the world, by Richie *et al*. (1974), Walling *et al*. (1986), Martz & de Jong (1987), Loughran *et al*. (1990). Works by Navas & Walling (1992), Quine *et al*. (1994), and Bouhlassa *et al*. (2000) confirm its potential utility in identifying sources of erosion and sedimentation in semiarid regions.

In order to obtain estimates of the relative contributions from the different sediment sources in the catchment, a soil survey was carried out to identify the main morphoedaphic units. Thus, land uses and soil types on different lithologies and slope gradients were taken into consideration to establish a soil sampling scheme designed to obtain representative results.

Samples were collected using a 6-cm drill core to a depth of 35 cm. The dry samples were sieved, and the <2 mm fraction was analysed for ^{137}Cs by gamma spectrometry. Soil redistribution was assessed by comparing the measured ^{137}Cs at the various sample sites with the reference inventory for the area which is 370 mBq cm^{-2} (Faleh *et al*., 2004). To calibrate the ^{137}Cs data, various models were available in the literature (Mitchell, *et al*., 1980; De Jong, *et al*., 1983; Frederick & Perrens, 1988; Walling & Quine,1990; Walling & He, 1999). The erosion rates were estimated by applying the proportional model for cultivated soils and the model developed by Walling & Quine (1990) for uncultivated soils.

RESULTS

Since the inauguration of the Abdelali check dam in 1991, sediment began to accumulate very rapidly, and by the winter of 1996–1997, it had completely siltated. The volume of sediment estimated from the bathymetric survey amounted to 52 000 m^3. The total weight of the sediment deposited in the check dam is some 67 000 t (Table 1, Fig. 4).

The sediment filling the dam was supplied by different processes, such as overland flow, and rill, gully, and bank erosion. Interpretation of the bathymetric survey indicated an average erosion rate, for the whole catchment, of around 40 t ha^{-1} $year^{-1}$. This rate does not take into account sediment deposited within the catchment, nor suspended sediment exported out of the catchment during floods. Further, this average rate does not reflect differences in the siltation rate related to variations in precipitation and discharge, as the catchment is ungauged and lacks a rain gauge. Therefore, it wasn't possible to correlate the infilling-rate variations with the hydrological cycle of the Abdelali River. Despite these limitations. this average erosion rate is viewed as a consistent value for the catchment.

Table 1 Results from the bathymetric survey of the Abdelali check dam.

S (ha)	V (m^3)	B (t m^{-3})	M (t)	D (t ha^{-1})	E (t ha^{-1} $year^{-1}$)
240	51 692	1.3	67 200	280	40

S: surface area of the catchment; *V*: volume of the sediments; *B*: average bulk density;
M: sediment weight; *D*: degradation specific; *E*: erosion rate.

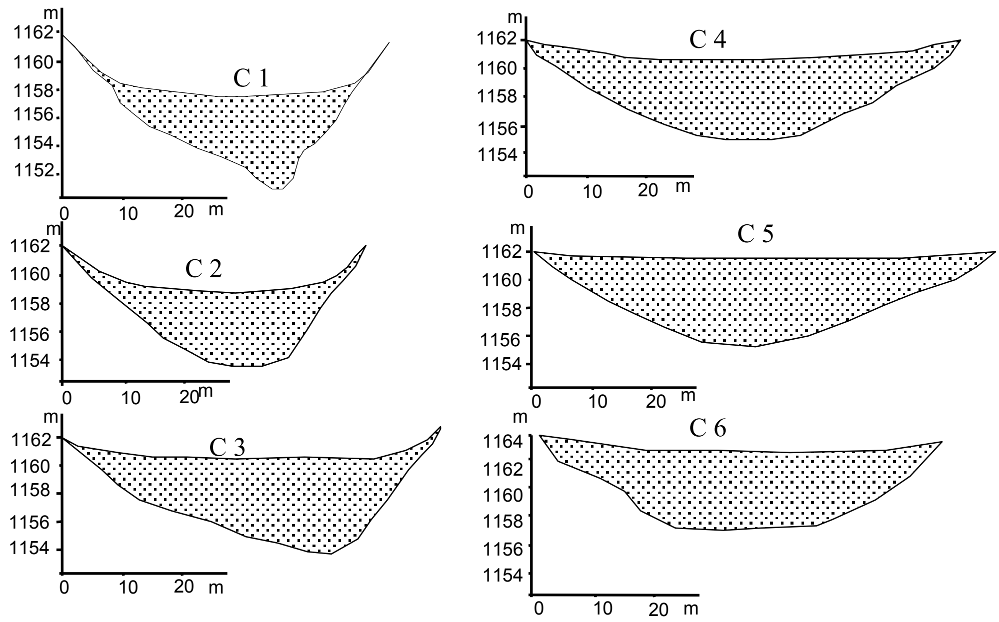


Fig. 4 Cross-sectional profiles of the Abdelali check dam impoundment.

Taking into account the diversity of soils, geomorphic elements, land use, and vegetative cover, the ^{137}Cs technique was applied to provide information on the source areas of the sediment, and to assess the relative contribution of overland flow to the infilling process.

A classification of the source areas supplying sediment was made after calculation of the aggradation and erosion rates estimated for the period between 1963 and 2001 (the year of the soil survey) (Table 2). The areas corresponding to sampling sites A_1, A_3, A_5, and A_{11}, appear to contribute most of the sediment. The soils have almost lost their surface horizons, and the erosion rates are very high, ranging between 24 and 42 t ha^{-1} $year^{-1}$. The areas corresponding to sampling sites A_2, A_4, A_7 and A_{10} display a partial loss of their surface horizons, and the erosion rates are lower, with values ranging between 4 and 16 t ha^{-1} $year^{-1}$, hence these areas contribute less to the sediment load.

Table 2 Classification of sediment sources according to erosion rates in the Abdelali catchment.

Sources of sediments	Site	Land use	Slope (%)	*I* (mBq cm^{-2})	*E*/ *A* (t ha^{-1} $year^{-1}$)
Main (erosion: intense)	*A11*	Cereal crops	20	88.1	41.8
	A5	Matorral light	42	88.5	34.4
	A3	Matorral light	18	135.7	27.5
	A1	Matorral dense	42	165.5	23.6
Secondary (erosion: middle–low)	*A4*	Cereal crops	5	190.3	15.9
	A7	Matorral light	12	211.5	13.5
	A2	Matorral dense	18	222.6	12.5
	A10	Matorral light	8	287.6	4.1
Reference site	*A12*		5	370.2	0.0
Aggradation	*A14*	Matorral light	8	435.4	8.4
	R	Check dam	–	578.8	28.8

I: inventories; *E*: erosion; *A*: aggradation.

Table 3 Grain size and erodibility for various lithologies in the Adbelali catchment.

Parent materials	*OM* (%)	Clay (%)	Silt+fine sand (%)	Sand (%)	Gravels (%)	Structure code	Permeability code	*K*
Clays	3.1	7.2	60.4	12.0	13.4	3	5	0.38
Marls-limestones	2.2	10.3	53.9	32.1	3.9	3	3	0.35
Marls	1.5	7.9	57.2	15.8	18.3	3	4	0.37

OM: organic matter; *K*: erodibility.

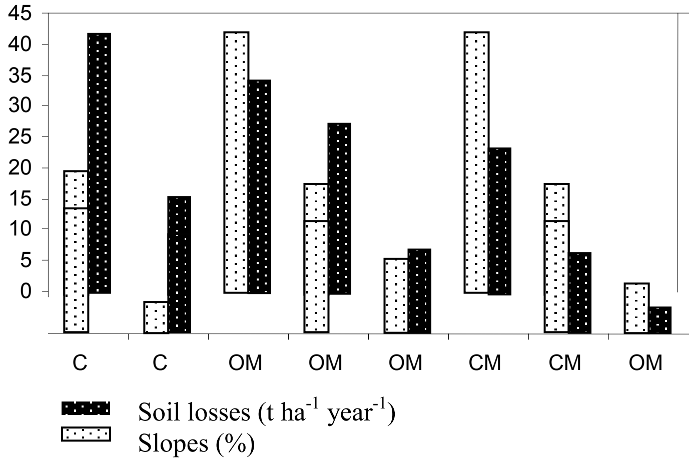


Fig. 5 Erosion rates based on slopes and land use at the head of the Abdelali check dam. (C: cereal crops; OM: open matorral; CM: close matorral.)

The quantified soil losses do not show any clear relation with lithology. The reason may be due to the relative homogeneity of materials and their very similar erosion potential (Table 3).

The soils cultivated for cereals on steep slopes (>20%) supply most of the sediment relative to the cultivated soils on lower slopes (5%) (Fig. 5). The areas of open "matorral" (bushy Mediterranean type vegetation composed of various shrubs) show diverse contributions to the sediment load, with the highest erosion rates (34 t ha^{-1} year^{-1}) on steep slopes (42%) whereas less steep slopes (8%) have much lower erosion rates (4 t ha^{-1} year^{-1}). The protection of the soil surface by a more dense vegetative cover, such as that provided by the close "matorral", tend to reduce erosion rates (24 t ha^{-1} year^{-1}) for the same slope (42%). Therefore, it appears that vegetative cover and topography are the key factors controlling erosion in the catchment. Thus, the distribution and importance of the source areas of sediment mainly appear to be related to land use and slope gradient.

An attempt to estimate an average rate of erosion by overland flow, for the whole Abdelali catchment, was made. A classification of the surface areas based on land use and slope was carried out, and an average erosion rate based on ^{137}Cs measurements estimated. Thus, for the whole catchment, an erosion rate of 28 t ha^{-1} year^{-1} was obtained. As the total erosion rate derived from the bathymetric surveys was some 40 t ha^{-1} year^{-1}, by subtraction, around 12 t ha^{-1} year^{-1} can be assigned to gully and bank erosion. Therefore, erosion by overland flow appears to be the main process in the catchment contributing at least some 70% of the sediment accumulated in the check dam.

The effect of overland flow is less visually noticeable than bank and gully erosion because cultivation and grazing are spread throughout the catchment and this type of erosion is a continuous process. On the other hand, gully and bank erosion only tend to occur for short periods of time, in localized areas in the catchment. Hence, although these processes appear to be more visually obvious in the catchment, they actually supply less sediment.

CONCLUSIONS

The combination of bathymetric surveys and radiometric techniques has proven to be a useful methodology to study erosion and sedimentary processes at the catchment scale. This combined approach permitted a measure of total erosion, the identification of sediment sources, and a means of estimating the relative contributions of the different erosion processes/sediment sources within the catchment. The combined approach also allowed an assessment of the relative importance of physiography, vegetative cover, and land use on the rate of soil erosion.

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