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SILTING RATE OF THE ZIT EMBA DAM AND QUANTIFICATION AND SPATIALIZATION OF WATER EROSION USING THE USLE MODEL (EXTREME NORTH-EAST ALGERIA)

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ABSTRACT

The Zit Emba dam (in the far north-east of Algeria) was impounded in 2001. With a capacity of 117,39 hm³, siltation is monitored solely by bathymetric surveys (2004 and 2014). The first company obtained a volume of silt of 0,8 hm³. The second survey estimated the amount of silt at 4,7 Hm³. However, the silt removed is estimated at 20% of the total silt. As a result, 5,6 Hm³ of sediment landed in the reservoir. In other words, a specific degradation equal to 1300 t/km²/year. However, this siltation monitoring does not allow us to locate the most degraded input zones. We therefore chose the USLE (Universal Soil Loss Equation) to quantify and spatialise hydric erosion in the watershed. To compare the bathymetric measurements with the soil losses obtained by the USLE, we subtracted the equivalent of silt transport (25%), giving a ratio of average annual soil losses (289.103 t/year) to estimated average annual solid transport (485.103 t/year) equal to 60%. This approach enabled us to validate the results obtained by the model, and to locate and quantify the degraded and very degraded surfaces (17,5 km²), or 3.6% of the total surface area of the watershed. They produce 77.103 t/year, representing 26% of annual soil losses. Developing these vulnerable areas will inevitably extend the lifespan of the Zit Ema dam, at a lower cost.

KEYWORDS

Zit Ema Dam, Siltation, USLE, Bathymetry, Watershed, Algeria

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1. Introduction

Due to the aggressiveness of rainfall and the degradation of plant cover in the Maghreb, and particularly in Algeria, water erosion remains the major phenomenon threatening agricultural land and hydraulic infrastructures (dams). This phenomenon has been exacerbated by man's actions over the centuries, particularly during the colonial period, when the rural population was forced onto poor, fragile land. Soil load per hectare and cultivation practices remain major obstacles to soil protection measures in catchment areas. In fact, the Ministry of Agriculture, Rural Development and Fisheries (MADRP) estimated in 2011 that around 14 million hectares of mountain areas in the north of the country are suffering serious degradation as a result of water erosion, and that silting up of dams is a direct consequence. The example of the watershed area of the Ighil Emba dam, which has a record rate of specific erosion equal to 5000 t/km²/year, illustrates this situation. At present, around 100 hm³ of silt is deposited annually in all Algerian dams. However, the Zit emba dam, which is located in the extreme south-east of the wilaya of Skikda, is far from being subject to this rate of erosion, as it benefits from continuous and dense plant cover in places, which provides it with fairly effective protection

to counteract the aggressiveness of the rains. Extensive agriculture (cereal growing) also occupies the lower-lying areas that are less exposed to the erosive energy of run-off. This situation has not prevented continuous monitoring of water erosion through regular bathymetric surveys. However, this quantification of erosion does not make it possible to locate the most dangerous input zones for the dam, hence the usefulness of this work which proposes the application of the USLE model (Universal Soil Loss Equation) which makes it possible to quantify and spatialise water erosion in the watershed.

2. Presentation of the study area

The Zit Emba dam, impounded in November 2000, is located on the Oued Hammam, a tributary of the Oued Kiber Ouest (Fig.1), in the extreme North-east of Algeria, 2 km south of the town of Bekkouche-Lakhdar, Wilaya of Skikda. Its watershed is drained by two tributaries, the Mouggar and El Hammam, which meet at the dam reservoir. L'oued Mouggar drainant les flancs nord des djebels El Grar et Aslouge est s'écoule suivant une direction sud/ouest –nord/Est. Il traverse les monts du Mazouz en vallée étroite pour atteindre la retenue. Oued el hammam draine le flanc nord de djebel Dabar à l'extrême sud-est du bassin versant et travers le système collinaire avant la confluence avec l'oued Mouggar. Ce réseau hydrographique est limité au nord et au sud par les éléments de la chaîne calcaire (Fig. 2) qui a conditionné l'individualisation du bassin versant (Fig. 1). The morpho-structural evolution has conditioned the distribution of relief in the watershed (Fig 2 and Tab 1). In fact, the south-west is characterised by mountainous units made up of very resistant massive limestone, with very steep high slopes. These reliefs represent the highest peaks in the catchment area (Djebels Taya 1208 m, Grar 1078m).

At the eastern edge of the watershed, the mountains are clearly south-west north-east in orientation, with the ends of the chains extending eastwards out of the watershed (Djebels Boudba, El Mkrase, Bezioun and Meharem).

On the northern fringes, the mountainous relief is made up of massive limestone, sandstone and calcareous marl (Fig. 2). It has moderate altitudes not exceeding 600m (Djebels Bouzourlech 483m, Moulmdefa 572 m, Chebabik 447 m and Meharem 414 m). Other hilly units can be observed within the catchment area, compartmentalised from south to north, sometimes deeply dissected by the secondary hydrographic network.

The majority of the watershed is sub-humid. The climate is conditioned by its geographical location, its proximity to the sea on the one hand, and the distribution of relief in the watershed and neighbouring areas on the other. The Mediterranean climate is characterised by hot, dry summers and relatively mild, rainy winters, with average annual rainfall of around 600 mm, which is highly irregular.

Table 1. Morphometric characteristics of the Zit Emba watershed

Lambert coordinate			
X(km)	911,45	Maximum altitude x (m)	1208
Y(km)	385,3		
Z(m)	58		
Area (km ²)	485	Index of compactness	1,20
Perimeter (km)	94	Drainage density (km/km ²)	2,8
Minimum altitude (m)	58	Length of talweg (km)	35
Average altitude (m)	376		

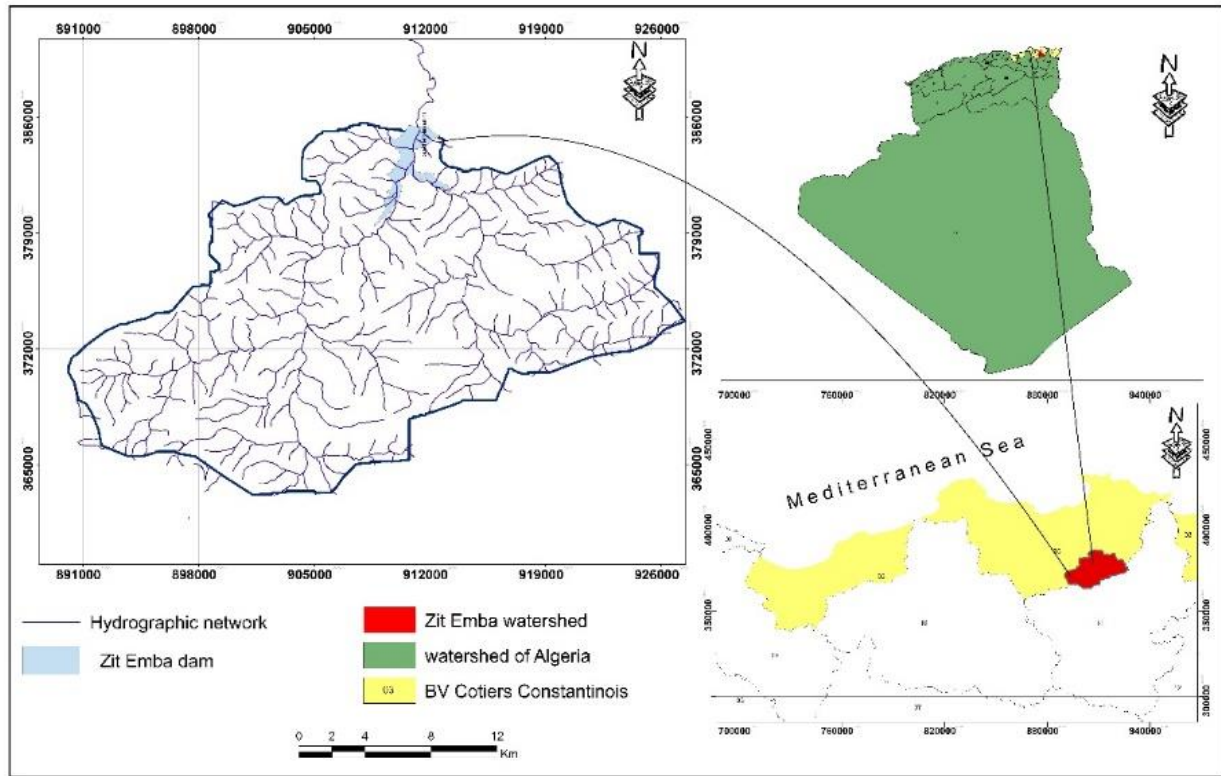


Fig. 1. Location of the study area.

3. Morpho-geological context

3.1. Geology

The extract from the structural map by JM. Vila (1980), in the part covering the Zit Emba watershed, shows a stack of thrust sheets whose erosion and tectonic and neotectonic activity have largely eroded the overlying sheets (recent sheets), leaving the underlying sheets exposed. As a result, the different units (windows and klippen) are outcropping side by side (**Fig 2**). In addition, the uplift of the elements of the limestone chain unit to the north and south has led to the individualisation of the Zit Emba watershed by erosion.

From north to south, the arrangement of the thrust sheets in the watershed is as follows :

- Kabyle base, limestone chain
- Kabyle Flysch nappes
- Numidian nappes
- Ultra-tellian nappe
- Constantine neritic sheet

This 1:500 000 structural summary is only a schematic diagram of the overall layout of the thrust sheets in the far north of Algeria. In fact, Vila has focused more on the ancient flysch nappes beyond the Numidian flysch, hence the wide outcrop of other flyschs, particularly the Mauretanian flysch. However, old geological maps (Hammam El Meskoutine, Guelma, Mondovi and Ain Berda) at 1:50,000 scale show a different extension of the Numidian nappe and the overlying clay formations. These outcrops largely determine current external geodynamics. As a result, the lithological map of the catchment area is based on these detailed maps.

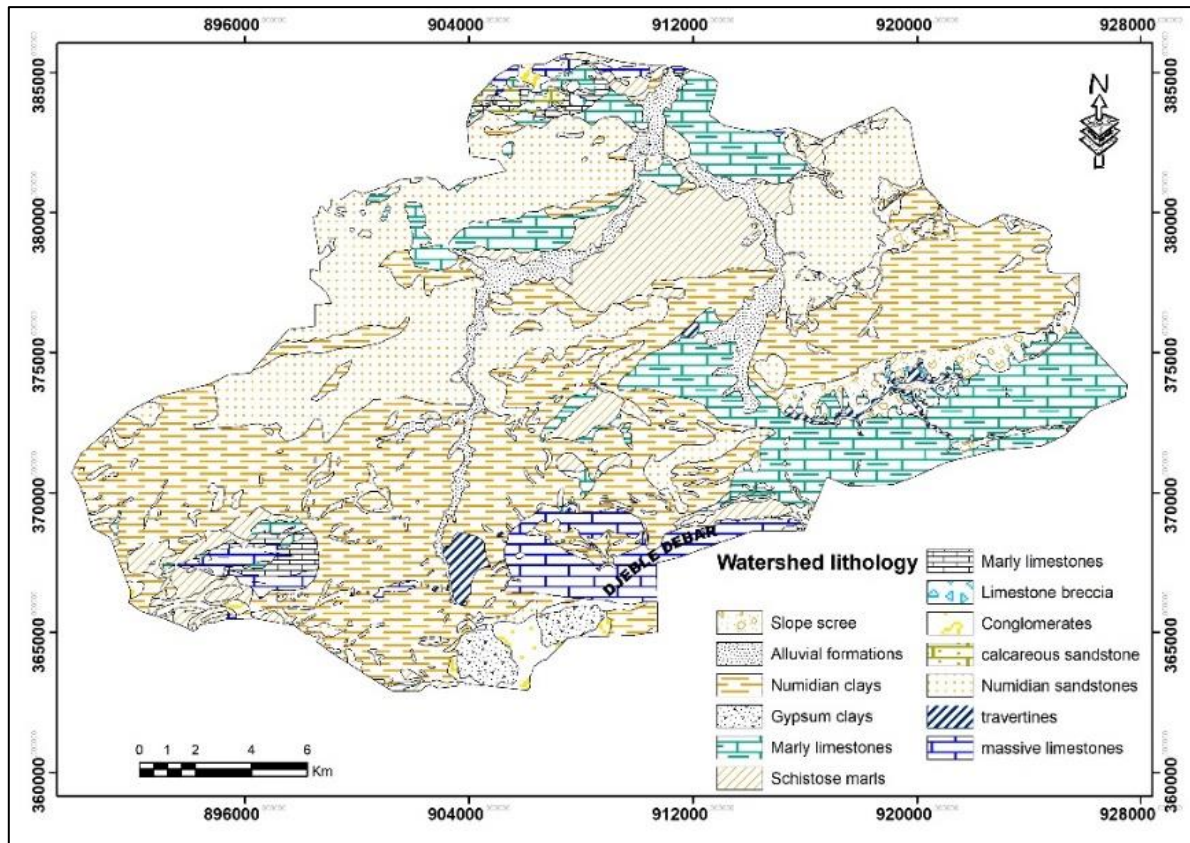


Fig. 2. Lithological map of the Zit emba watershed

3.2. Watershed lithology

A reading of the 1:50 000 geological map (Dalloni et Savornin 1937) shows that most of the surface of the watershed is covered by the Numidian flysch, the sandstone layer of which has been dismantled. In fact, because of its rigidity, the sandstone layer has been crushed, making it easier for erosion to dismantle it. As a result, the Numidian nappe is only represented, over large areas, by a thin layer of Numidian clay. As a result of this situation, only the underlying nappes were represented in the synthesis drawn up by JM VILA (JM. VILA 1980). The virtual absence of faults on these old maps has also made it difficult to interpret the role played by tectonics and the omnipresent neotectonics in shaping the current relief. Nevertheless, the east-west orientation of the Jurassic outcrops to the north and south of the watershed has led to the identification of the Zit Emba watershed. In addition, recent and current erosive activity, in places, has led to the outcrop of other nappes over limited and discontinuous areas.

We have therefore adopted a classification of outcrops by lithological group, taking into account their resistance to erosion (Fig 2 and Tab 2), from the least resistant to the most resistant formations, as follows :

- **Slope scree and limestone breccia**, covering an area of 19 km² (4% of the watershed), cover the foot of the Numidian and limestone reliefs to the south-east of the watershed.

- **Alluvial formations** occupy the beds of the two main tributaries as well as their banks, in places represented by the low and medium terraces, covering an area of 20 km². These clay-loam-sand formations with gravelly passages are subject to linear erosion, particularly during floods.

- **Numidian clays** cover vast areas (176 km², or 36,3% of the watershed), particularly in the southern part of the watershed. Of modest thickness, they represent the base of the Numidian flysch nappe. Because they are used to grow cereals, these formations are subject to moderate water erosion.

- **The gypsum clays** occupy very small areas (6 km², or 1,2%) at the southern end of the watershed.

- **The marly limestones** occupy the extreme south-eastern part of the watershed, as well as a few limited and discontinuous areas. These slightly reinforced formations have a moderate relief and are therefore exposed to active erosion.

- **The schistose marls** occupy a large area in the north (41 km²), bounded by two major tributaries to the watershed, and a smaller area at the foot of the Grar massif in the south-west of the catchment. These laminated formations show a certain resistance to erosion, but are easily sintered.

- **The marly limestones** are resistant formations, as the marly passages are thin to very thin. Their surface area is very small (5 km²) but they appear as protrusions (relief) in the extreme north-west and south-west.

- **The conglomerates**, with a very limited surface area, follow the southern limit of the watershed area.

- **Numidian sandstones** occupy the north-western part of the watershed basin over large areas (110 km²), extended to the north by calcareous sandstones with very limited areas. They are highly resistant to water erosion and therefore constitute a low input zone.

- **The travertines** are represented by a spot located in the extension of the active fault delimiting Djebel Debar to the south, at the origin of the hot spring generating the accumulation of travertines covering an area of 5 km².

- **The massive limestones** are represented by the elements of the limestone chain, notably Djebel Debar and its western extension Djebel El GRAR, as well as Djebel Moulemdefa and Djebel Taya, covering an area of 22 km².

Table 2. area of lithological formations in the Zit Emba watershed

Lithology	Area (km ²)	Area (%)
Slope scree	18	3,7
Alluvial formations	20	4,2
Numidian clay	176	36,3
Gypsum clay	6	1,2
Calcareous marl	72	14,8
Schistose marl	41	8,4
Marly limestone	5	1,1
Calcareous breccias	2	0,3
Conglomerates	7	1,5
Calcareous sandstone	2	0,4
Numidian sandstone	110	22,7
Travertins	5	0,9
Massive limestone	22	4,6
Watershed	486	100

4. Materials and methods

4.1. Materials

To meet the requirements of the factors making up the Universal Soil Loss Equation (USLE) model, we collected and critically analysed the data, images and cartographic documents needed to quantify each factor. However, because of the unrepresentative distribution of rainfall stations across the watershed and the gaps in the data from certain stations, we also used CHIRPS (Climate Hazards Group Infrared Precipitation with station Data) data (1981-2023), as well as the map of average annual rainfall developed up by the ANRH national water resources agency (2005). The soil map drawn up by the Bureau National des Etudes Forestières (1993), according to the French classification (CPCS, 1967), enabled us to deduce the K factor (soil erodibility). The length and slope (LS) of the slopes were extracted from the DEM image (30m resolution) covering the catchment area. We used the WorldCover site to draw up the land cover map (10m resolution) of the catchment for the year 2021-2022. In addition, by reading the Google image, we were able to note the absence of development in the Zit Emba watershed. Finally, data from two bathymetric measurement campaigns. (ANBT 2004 and 2014), can be used to confirm the validation obtained in the field.

4.2. Methods

It has been established that monitoring the silting up of dams using hydrometric stations is necessary but not sufficient. This is because measurements taken at the station level do not allow us to locate the areas of input. To make up for this shortcoming, it is essential to use models that quantify and spatialise water erosion at catchment level.

Several models have been adopted to quantify and spatialise water erosion in the Mediterranean basin and North Africa, including the USLE by Wischmeier and Smith (1978) and its modified (MUSLE) and revised (RUSLE) versions, SWAT by Arnold et al (1998) and EUROSEM by Morgan et al (1998). Because of the satisfactory results obtained in the In the north of Algeria, we apply the USLE to the Zit Emba watershed area. It is an erosion model developed to calculate the long-term average loss of sheet and gully erosion under specific conditions. The model is a multiplicative function of the form: $A = R K L S C P$ with : A: amount of soil loss, R: rainfall erosivity, K: soil erodibility, L: slope length factor, S: slope gradient factor, C: crop management factor and P: conservation practice factor. In order to monitor the silting up of the Zit Emba dam and understand the reduction in its capacity over time, the Agence Nationale des Barrages et des Transferts (ANBT) carried out bathymetric measurements after the dam was impounded (November 2000), in 2004 and 2014. In this way, the loss of dam capacity can be correlated with the soil losses determined by the USLE.

5. Results and discussion

5.1. Available data

5.1.1. Calculation of the R factor

The kinetic energy of rain makes a major contribution to the uprooting of soil particles. It is linked to the intensity of the rain and depends on the size and speed of the falling drops. For this reason, estimating the climatic aggressiveness factor using the formula of Wischmeier and Smith (1978) requires knowledge of the kinetic energy and average intensity of rainfall over 30 minutes.

Due to the absence of 30-minute rainfall intensity measurements in our watershed, to evaluate the R factor we use the equation developed by Rango & Arnoldus (1987), which is as follows:

$$\text{Log } R = 1,74. \text{Log } \Sigma P_i^2/P + 1,29$$

$P_i(\text{mm})$: monthly rainfall

$P(\text{mm})$: annual rainfall.

Because of the inconsistencies mentioned above, we calculated the R factor (rainfall erosivity) using three data sources in order to ensure that the spatial distribution of the R factor in the watershed was reliably representative. We therefore adopted the following three approaches:

- **Calculating R from available station data**

Taking into account the length and gaps in the series as well as the geographical distribution of the rainfall stations, we have drawn up a list of stations considered to be more or less representative of the climate in the Zit Emba watershed and its surroundings (Tab 3).

Table 3. Erosivity factor of rainfall R calculated from rainfall stations (1978-2010).

Stations	Z(m)	R	P (mm)
El kerma	15	91,6	605,9
Ain berda	55	88,5	611,4
Azzaba	91	99,9	605,4
Bouati mahmoud	150	101,4	662,2
Guelma	150	77,6	536,8
Bouhegouf	154	89,8	539,7
Nechmeya	270	84,0	564,1
Medjez amar	295	83,8	592,1
Bouhadja	300	79,0	533,9
Hammam nbail	460	92,7	660,9
ZIT Emba	58	90,1	557,9
Bordj sabat	525	81,5	545,5

However, the limited number and uneven distribution of stations within the watershed have distorted the spatial distribution of R (Fig 3). Nevertheless, the values obtained, ranging from (85-98 MJ. mm/ha.h.yr) remain acceptable.

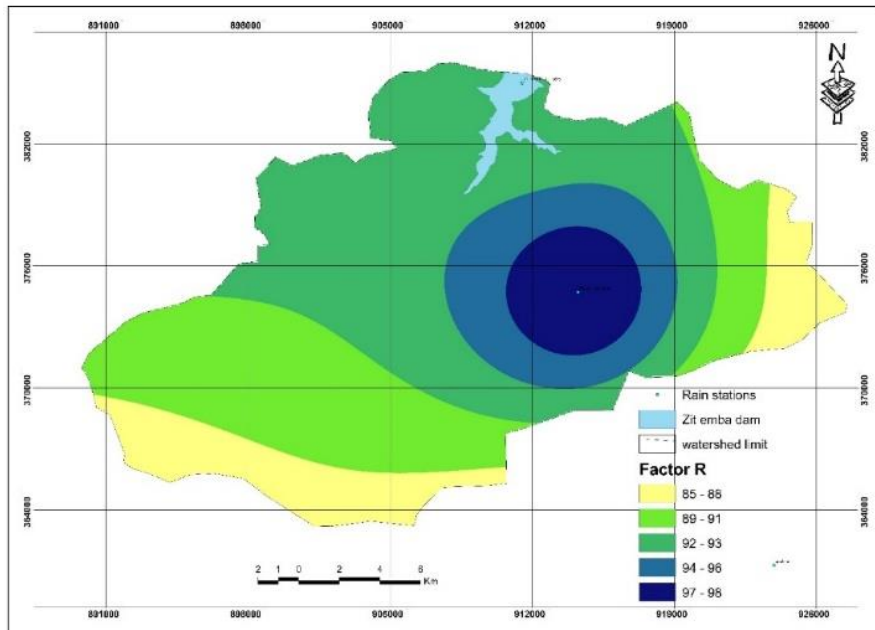


Fig. 3. Rainfall erosivity map R for the watershed

- **Calculation of R from CHIRPS data (1981-2023)**

The CHIRPS data obtained in the form of monthly rainfall rasters enabled us to obtain annual rainfall rasters (Fig 4). This makes it possible to apply the formula of Rango & Arnoldus (1987).

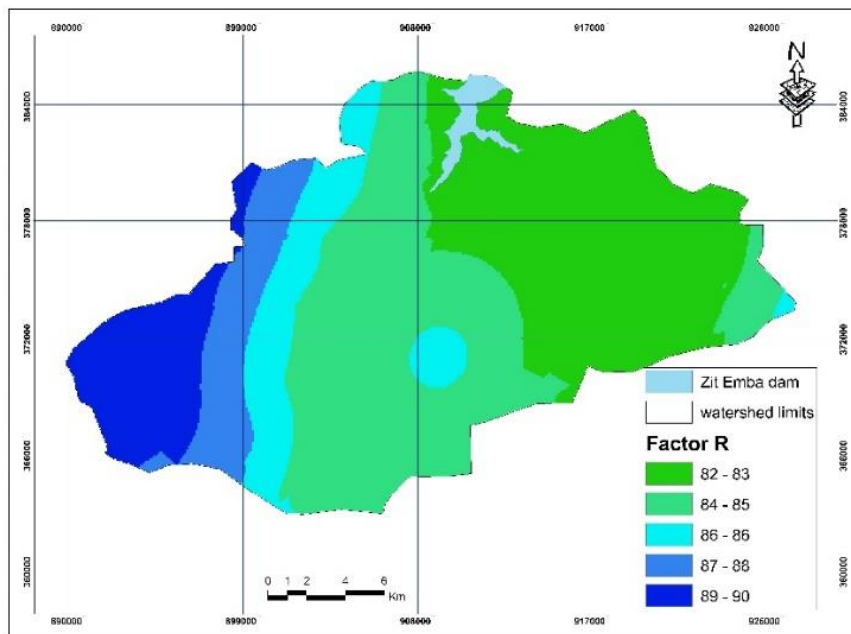


Fig. 4. Rainfall erosivity map R for the watershed

This map shows slightly higher R values (90-106). However, the spatial distribution bears no relation to the topography of the watershed. This distribution forms bands from north to south and is similar to the distribution of rainfall in northern Algeria.

- **Calculation of R from the ANRH annual rainfall map (1965-2002)**

The map of average annual rainfall in northern Algeria is based on a series of rainfall measurements over 37 years. We used it to calculate the R factor (Fig 5) by applying the following formula:

$$R=0.15 \cdot P \text{ (D. Hernando, G.M. Romana región de madrid).}$$

To spatialise the values of the R factor, we used the IDW (Inverse Distance Weighting) method.

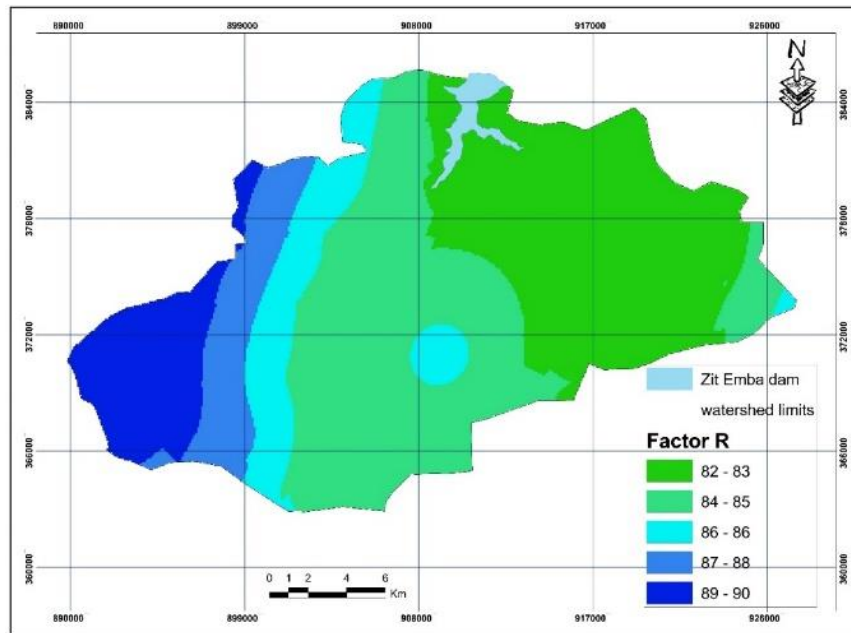


Fig. 5. Rainfall erosivity map R for the watershed

This map shows values similar to those obtained on the basis of station data and has the advantage of a spatial distribution of R that matches the morphology of the watershed. Indeed, the distribution of rainfall erosivity is clearly conditioned by altitude and exposure, hence its adoption for calculating land loss in the Zit Emba watershed.

5.1.2. Soil erodibility factor K

The K factor is a determining factor in the Wischmeier and Smith (1978) equation because it shows the vulnerability of the soil to water erosion through the determination of three characteristics, namely texture, soil organic matter content and soil permeability (Tab 4). These are determined on the basis of the 1:50,000 soil map of the Zit emba watershed and physico-chemical analyses of the soil profiles carried out, and enable the following equation to be applied:

$$K = [2.1 \cdot 10^{-4} (12 - MO) M^{1.14} + 3.25 (S-2) + 2.5 (P-3)] \cdot 0.1317 / 100$$

With:

K: soil erodibility factor in t.ha.H/ha.MJ.mm

MO : percentage of organic matter.

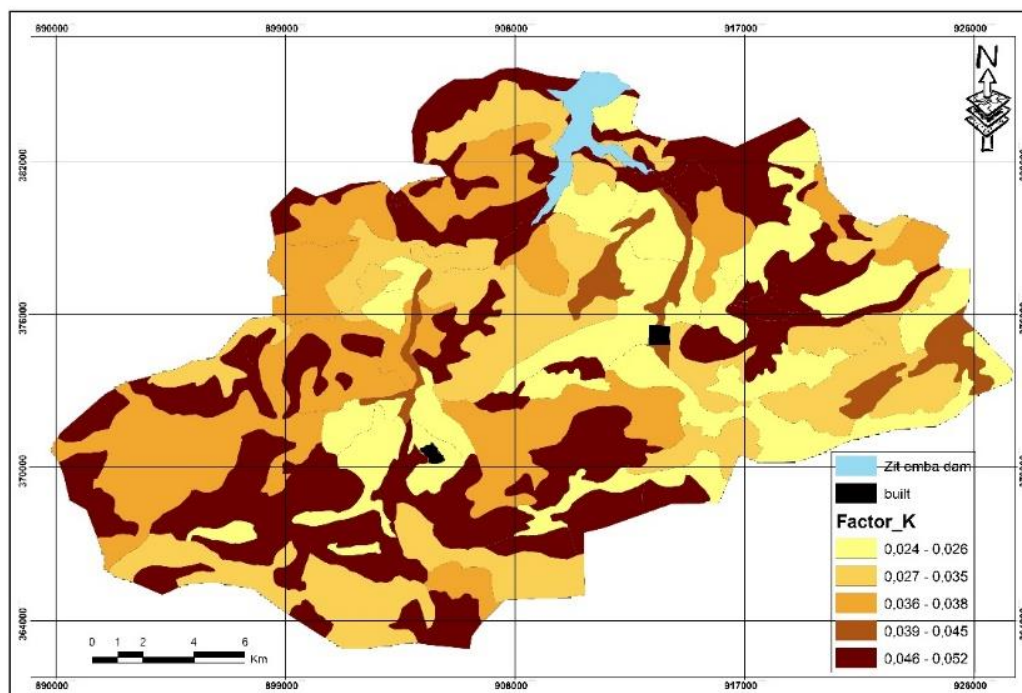
S : structure code (1 à 4) : 1 : Very fine; 2 : fine ; 3 : medium and coarse; 4 : very coarse.

P: permeability class, permeability code (1 to 6): 1 rapid; 2 moderate to rapid; 3 moderate; 4 slow to moderate; 5 slow and 6 very slow.

M: (% fine sand + % silt) (100 - %A).

Table 4. Determinants of the K factor

soil class	subclass	(lemon +SF) (%)	clay (%)	MO (%)	Structure code	permeability	F K	K metric	Area (ha)	Area (%)
little evolved	litho sol	60	10	1,2	3	2	0,38	0,050	3019,15	6,21
	rego sol	60	35	1,6	2	5	0,32	0,042	684,30	1,41
	alluvial	60	30	1,2	3	4	0,34	0,045	907,71	1,87
	colluvial	60	30	1,2	3	5	0,36	0,048	12237,72	25,18
vertisol	vertisol	41	56	2,09	2	6	0,18	0,024	988,44	2,03
calcimagnisique	redzine	55	37	1,79	2	4	0,26	0,034	3083,70	6,34
	brown limestone+br own calcium	48	48	2,7	2	5	0,20	0,026	7844,83	16,14
brunifié	brown soil	56	24	4,03	3	4	0,29	0,038	10190,98	20,96
	leached soil	62	26	1,96	3	5	0,40	0,052	532,30	1,10
iron sesquioxide	non-leached red soil	44	22	2,55	3	4	0,25	0,032	6743,86	13,87
	leached red soil	41	41	2,5	2	5	0,19	0,026	1305,48	2,69
	non-leached brown soil	57	30	2,89	2	4	0,27	0,035	1072,01	2,21

**Fig. 6.** Soil erodibility map of the watershed (K)

A reading of the K-factor map (Fig 6) reveals the predominance of the sub-class of less developed soils, representing 25% of the total surface area, followed by brown soils with 20% of the surface area of the watershed and calcareous brown soils with 16%, with K-factors of 0,048, 0,038 and 0,026 respectively. Other soils with the highest K values (0,052) occupy very limited areas (1%). It should be noted that this mosaic represented by the K factor map is broadly superimposed on the soil map of the watershed.

5.1.3. LS factor:

At the origin of the erosive energy of surface runoff, the LS factor is a topographical factor determined essentially by the arrangement of the morphological units making up the watershed. It is represented by the multiplicative effect of the length of the slopes by the degree of their inclination. It is extracted from the DEM image (30m) using the equation established by Wischmeier and Smith (1978). In this work we apply the equation proposed by Foster (1977), which takes the following form:

The L factor:

$$L = \left(\frac{\lambda}{22.13} \right)^m$$

$$m = \frac{F}{1+F} ; \quad F = \frac{\sin\beta/0.0896}{3(\sin\beta)^{0.8}+0.56}$$

λ : length of slope (m),

m : exponent of the length of the slope

β : slope in degrees.

The equations used to calculate L in ArcGis 10.8 are as follows:

$$m = "F" / (1 + "F")$$

$$F = (\sin("slope_degree" * 0.01745) / 0.0896) / (3 * \text{Power}(\sin("slope_degree" * 0.01745), 0.8) + 0.56)$$

$$L = \text{Power}(("FlowAcc" + \text{Cell Size} * \text{Cell Size}), ("m" + 1)) - \text{Power}("FlowAcc", ("m" + 1)) / \text{Power}(\text{Cell Size}, ("m" + 2)) * \text{Power}(22.13, "m")$$

The S factor

The S factor stands for the angle (gradient) β which represents the effect of slope on water erosion. It is considered as the average angle of the largest slope of all the meshes. (McCool et al, 1987, 1989).

The equation used to calculate S in ArcGis 10.8 is as follows :

$$S = \text{Con}(\tan("slope_degree" * 0.01745) < 0.09, (10.8 * \sin("slope_degree" * 0.01745) + 0.03), (16.8 * \sin("slope_degree" * 0.01745) - 0.5))$$

Finally, LS is obtained by multiplying the L factor by the S factor (Fig 7). The result is represented by the map below.

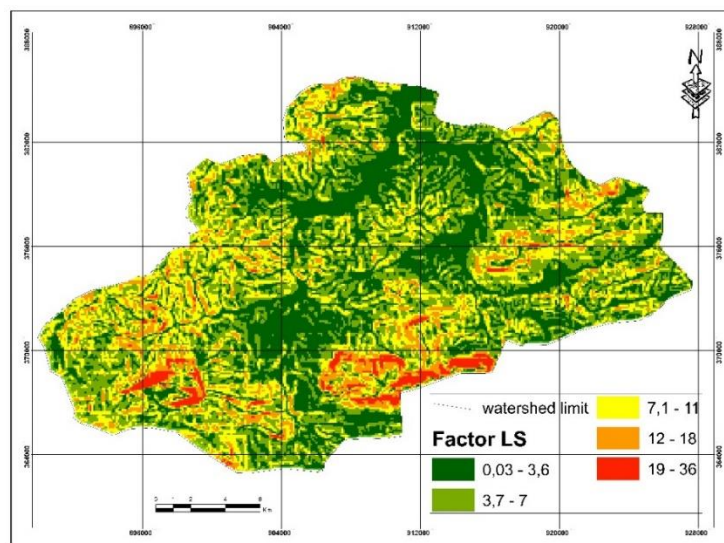


Fig. 7. LS factor map

The Topographical Factor (LS) map (Fig N°7). shows the distribution of values for the defined classes, with the lowest values following the valleys of the two main tributaries that occupy the centre of the watershed. On the other hand, the highest values are spread over the more rugged peripheral areas.

5.1.4. Land cover factor C

The land cover map used to spatialise the values of factor C is based on the WorldCover 2021-2022 project (10 m resolution) and refers to the land cover map drawn up by the Bureau National d'Etudes pour le Développement Rural (National Bureau for Rural Development Studies) at a scale of 1:50 000 surveyed in 2008. However, this map is too oriented towards development, resulting in a legend that does not meet the objectives of this work. We therefore adopted the WorldCover map with minor adjustments, resulting in a legend that shows soil cover rates instead. In fact, it is the rate of vegetation cover that conditions the interception of rainfall and the slowing of surface runoff, hence the attenuation of the erosive energy of rainfall and runoff.

The values of factor C adopted in this work refer to observations made in the field (BNDER report), where water erosion remains fairly moderate overall. Also, work carried out under different climates (Biélers et al. 2011), showing the predominance of moderate to low erosion, mentions the relative effectiveness of each type of plant cover. The hierarchy of this effectiveness is adopted in this work. The values adopted (Wischmeier & Smith 1978) range from 0,001 to 0,4. The table below (Tab. 5) summarises the values of factor C, according to the land use considered, as follows:

Table 5. Land use classes according to the C factor

Land use	C factor	Area (km ²)	Area (%)
Maquis dense	0,001	94,06	19,35
Forest	0,003	131,04	26,96
Degraded maquis	0,004	1,14	0,24
Body of water	0,01	7,02	1,44
Built	0,1	2,80	0,58
Farmland	0,2	113,43	23,34
Rangelands	0,4	136,51	28,09

It should be noted that the area occupied (Fig 8) by forest and dense maquis reaches 225,1 km² (46,31%). Rangelands and farmland cover 28% and 23,34% respectively of the total surface area of the watershed.

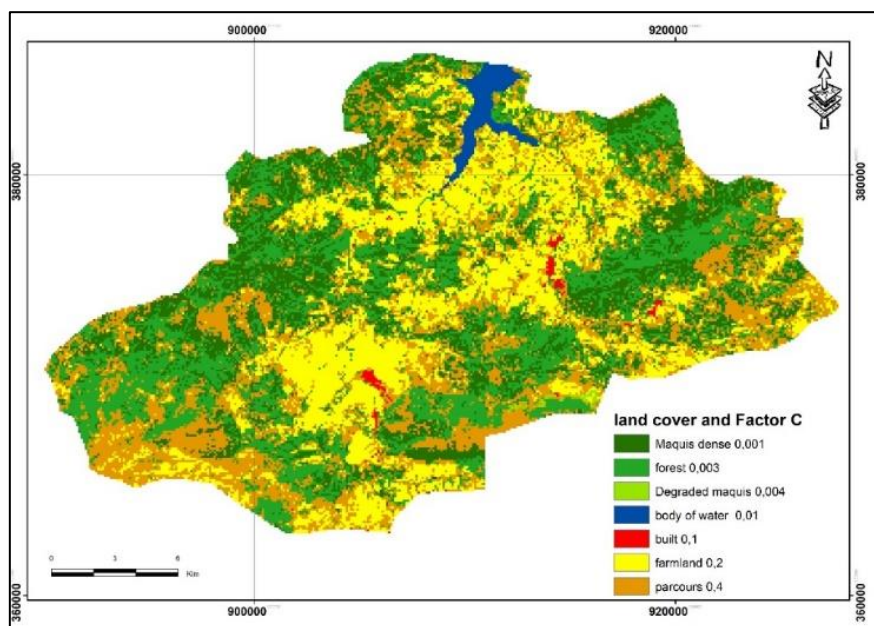


Fig. 8. Land use map and C factor for the Zit emba watershed (C)

5.1.5. Facteur des pratiques culturales P

This parameter is used to estimate the role of erosion control measures (banks, alternating strips, ridging,...) in reducing soil loss in the watershed. The values of the P factor vary according to the type of development and the steepness of the slope. This value reaches its maximum (1) if no anti-erosion works are carried out. This is the case in the Zit Emba watershed (Shin, 1999).

5.1.6. Annual soil losses (A) in the Zit Emba watershed

The soil loss map (A) (Fig. 9) is the result of the multiplication of active factors, at the origin of erosive energy (R, LS) and passive factors showing a certain resistance to this erosive energy (K, C, P). The spatial distribution of this product (A) shows the degree of sensitivity of the different zones making up the watershed to water erosion, giving rise to the following soil loss classes :

- **low soil loss (< 5 t/ha/yr):** this class covers the majority of the watershed, with the area affected by this class of erosion reaching 367,08 km² or 75.5% of the watershed. The land corresponding to this class belongs to two different categories, namely cultivated land, occupying the lower altitudes around the main valleys (Fig. 9. and Tab. 6) and areas covered by forests and dense scrubland higher up than the previous category.
- **average soil loss (5- 15 t/ha/year):** this class covers 83,2 km² or 17.11% of the total area. It has a fairly rugged topography and a fairly varied land cover, ranging from cultivated plant cover (cereal crops) to degraded scrubland and grazing areas. With the first class, low and medium soil losses represent 92,6% of the watershed. It is this aspect that characterises the Zit Emba watershed (Fig. 9 and Tab.6).
- **Fairly high soil loss (15- 25 t/ha/an) :** This class covers 18 km² or 3,78% of the watershed It is represented by small, discontinuous areas (Fig. N°9).
- **high soil loss (25- 50 t/ha/yr):** this class covers 12 km² or 2,53% of the watershed. It is represented by small, discontinuous areas on the high ground, particularly in the southern part of the watershed. The soil is poorly covered (rangeland) (Fig. 9).
- **Very high soil loss (>50t/ha/year) :** this class occupies a negligible surface area corresponding to degraded areas that do not benefit from any protection and are subject to aggressive climatic conditions (R) due to their altitude (1200 m).

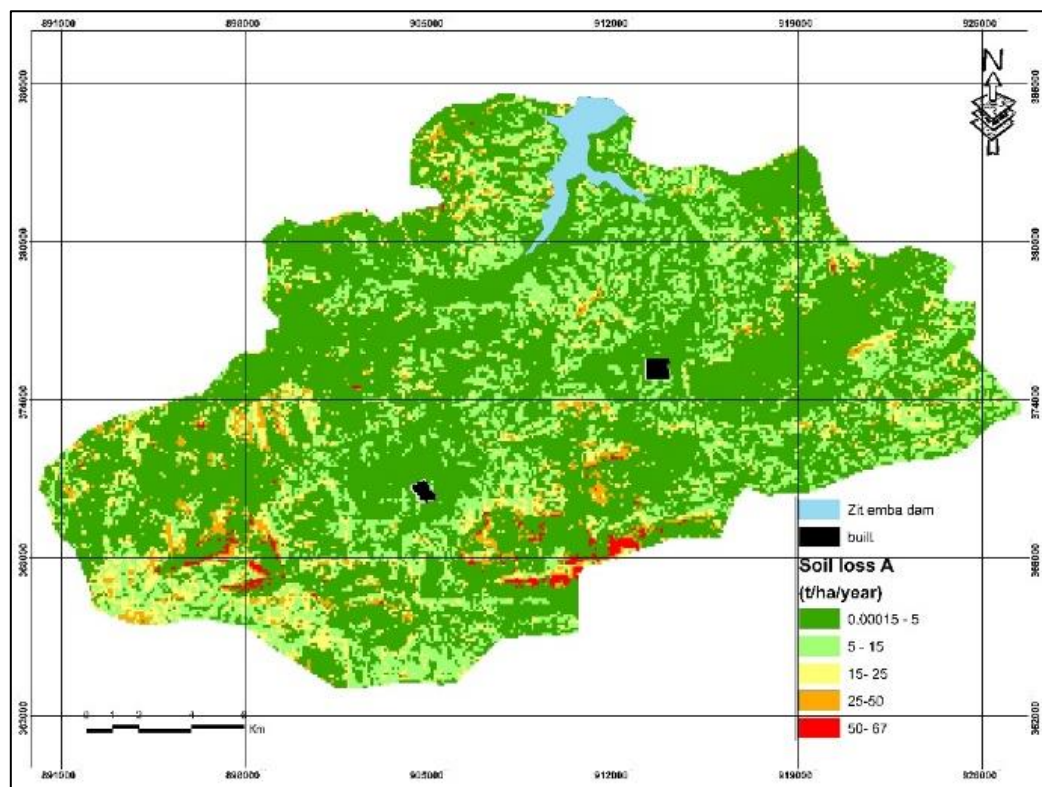


Fig. 9. Soil loss map of the Zit Emba watershed (A)

Table 6. Distribution of soil losses in the watershed

Soil losses (t/ha/yr)	Erosion class	Area km ²	%
<5	low	367,0	75,50
5-15	average	83,2	17,11
15-25	Fairly high	18,3	3,78
25-50	high	12,3	2,53
>50	Very high	5,3	1,09
watershed		486,1	100

5.1.7. Average annual soil losses by erosion class

Tables 6 and 7 show the annual soil losses (t/year) in relation to the specific degradation and surface area of each erosion class. The low erosion class, because of its low specific degradation (2.5t/ha/yr) and despite its vast surface area (75,5%), produces only 91 770 t/yr, or 32% of the sediment. On the other hand, the very severely eroded class, with a surface area of only 1,09%, due to specific degradation (58,6 t/ha/yr), produced 31 000 t/yr, or 11% of the sediment. This analysis enables us to deduce the most productive input zones in the Zit Emba watershed.

Table 7. Average annual soil losses by erosion class

Classe érosion	Specific degradation by erosion class (t/ha/yr)	Average soil losses (T/year)
low	2,5	91770
average	10	83200
Fairly high	20	36740
high	37,5	46050
Very high	58.6	30999,4
Weighted annual average	5,94	288 759,4

5.1.8. Quantification of mud deduced from two bathymetric surveys

The volumes of silt determined by bathymetric surveys (2004, 2014), carried out by ANBT, in the dam reservoir are 0,8 and 4,7 hm³ respectively. Also, taking into account the date of impoundment of the Zit Emba dam (February 2001), we deduce annual solid inputs of 0,267 and 0,362 hm³. This difference between the two companies is essentially due to the effectiveness of the bottom draining regularly carried out during major floods. The data on volumes discharged and monthly and annual rainfall over the entire period (13 years) do not show any appreciable variation, which explains the difference in solid inputs recorded by the two bathymetries. As a result, we deduced an increase in silt settling over time, hence the slower drawdown. Nevertheless, referring to studies on bottom emptying carried out in Algeria, in particular the work of (Remini B. 1999,2000, 2006 and 2017), and taking into account, the low degradation of the watershed, we adopted a low percentage of silt evacuated by bottom sluices estimated at 20% of the total silt determined by the 2014 bathymetric campaign. Thus, the total volume of mud evacuated would amount to 0,94 hm³, giving a total volume of mud that landed in the dam reservoir equal to 5,64 hm³. However, the contribution of bedload to the volume of silt determined by bathymetry can be as much as 25% of the total volume (1,41 hm³), resulting in an estimated transport of suspended sediment of 4,23 hm³ (995,37 t/km²/year). These data are used to validate the USLE model.

Table 8. Loss of capacity by bathymetry 2004 and 2014

	Initial volume 2001	Bathymetry 2004	Bathymetry 2014	Vase evacuated by bottom valves (20%)	Total estimated vase
Capacity (hm ³)	117,39	116,59	112,69	-	-
Loss of capacity 2001-2014 (hm ³)	-	0,800	4,7	0,94	5,64
Loss of capacity annuelle (hm ³ /an)	-	0,267	0,362	0,685	0,430
volume of suspended sediment (hm ³)	-	-	-	-	4.23
bed load contribution (hm ³)	-	-	-	-	1.41
Specific degradation (t/km ² /year)	-	823,00	1190,00	137,16	1327,16
Estimated drift (25%) (t/km ² /year)	-	205,75	297,50	-	331,79
Degradation S. according to TSS(t/km ² /an)	-	617,25	892,50	-	995,37

5.2. Discussion

The success of the universal soil loss equation in the United States (weichmeier 1978) led to enthusiasm for its generalisation to all continents. Its application to plots in Equatorial Africa (É. Roose, G. D. Noni, 2004) gave encouraging results, followed by other applications in North Africa, particularly in Tunisia (Cormary, Y. and Masson, J. 1964), followed by several studies in Algeria (Arabi, 1991). Following these experiments, researchers (hydrologists, geomorphologists, hydraulic engineers, etc.) attempted to extrapolate this model to watersheds in order to spatialise and quantify water erosion in addition to measuring solid transport at hydrometric stations. However, no attempt has yet been made to assess the applicability of this extrapolation to North African watersheds. In this work, we compare the results of the application of the USLE to the Zit Emba watershed with the bathymetric measurements carried out in the dam reservoir. However, because of the vegetation cover (natural and cultivated) that covers almost the entire watershed and its low level of degradation, we opted to apply the USLE. We also ensured that the chosen indices of factor C were appropriate in order to highlight the role of land use in protecting the watershed.

6. Conclusions

The Zit emba dam, with an initial capacity of 117,9 hm³, was impounded in 2001. Based on empirical formulae, the dead volume is estimated at 8,4 hm³, referring to 30 years of operation. The annual solid input is therefore estimated at 0,280 hm³.

The first bathymetric survey in 2004 confirmed the annual siltation estimate given in the dam feasibility study (0,267hm³). However, the second bathymetric survey (2014) showed a significant increase in the rate of siltation (0,361hm³). Given the absence of changes in runoff conditions (precipitation and land use), the explanation adopted remains the low rate of drawdown by the bottom sluices as a function of time, due to the consolidation of the silt. In addition, during this period, the bottom drain is regularly activated, with quantification of the liquid input evacuated without any estimate of its sediment content, hence an estimate based on measurements carried out on other dams in northern Algeria. Nevertheless, we have adopted the lowest percentage observed (20%).

This measurement of the solid input to the reservoir does not allow the location of sediment input zones in the watershed to be determined so that management actions can be taken to fix the soil in these zones. To compensate for this shortcoming, we chose the Universal Soil Loss Equation (USLE), which quantifies and spatialises erosion. The factors that determine the soil losses determined by this model are calculated according to the availability of data. For example, the R factor calculated from data from stations with measurement series exceeding 30 years (1978-2010), gives us a spatial distribution of R values in the watershed that does not conform to the distribution of landforms and their exposure. This situation is due to the unrepresentativeness of the stations, most of which are located outside the watershed, to the south, where rainfall is lower.

As a result, we extracted CHIRPS data (1981-2023) for the watershed, in the form of rasters. However, the R values obtained have no link with the topography of the catchment. However, their distribution reflects a regional configuration. This situation led us to extract the average annual rainfall heights represented by the rainfall map drawn up by ANRH (2005). This approach enabled us to obtain a distribution of R values

consistent with the morphological configuration of the watershed. In addition, the C-factor indices are obtained from the land use map (Landcover 1/10000th) drawn up in 2021. The choice of C-factor indices is closely linked to the observed effectiveness of the vegetation cover.

The average annual soil loss determined by this model is 289.10^3 t/year, or 53% of the quantity of mud determined by bathymetry in 2014. The specific degradation determined respectively by the USLE and by bathymetry is 594 and 1190 t/km²/year. If we add the quantity removed by the bottom sluices, estimated at 20% of the total silt, we obtain a specific degradation of 1327 t/km²/year. If we subtract 25% of the total quantity of silt due to bed load, we obtain a suspended solid contribution equal to 5,64.10⁶ t, or a specific degradation of 995 t/km²/year. Land loss (USLE) therefore represents 60% of the estimated suspended solids input. Given the state of degradation of the watershed (average), we consider this report to be a reliable validation of the results obtained by this model.

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