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Modelling Soil Erosion and Sedimentation in the Oued Haricha Sub-Basin (Tahaddart Watershed, Western Rif, Morocco): Risk Assessment

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Abstract

This study evaluates the annual loss of soil in the sub-basin of Oued Haricha (Tahaddart basin, Western Rif, NW Morocco). The integration of revised (RUSLE) and modified (MUSLE) soil loss empirical equations of Wischmeier and Smith in combination with GIS permits the modelling of soil erosion at the scale of parcels. The characteristics of precipitation and runoff, the soil properties, the culture system and the current working practices of soil in the sub-basin of the Oued Haricha are collected from local data. The digital terrain model is used to generate topographic factors. The combination of different RUSLE factors shows that the annual soil is 62.72 t/ha/year and corresponds to an average level of risk. The total losses calculated by MUSLE method are valued at 221,468 t/year. The rates of loss due to linear erosion are 82,652 t/year. These soil losses represent 20.33% of the total losses, and confirm that the losses on the slopes outweigh the losses due to the river system. Sedimentation module shows that the areas of high erosion (greater than 200 t/ha/year) are concentrated in the reliefs with average and high slope and occupy 38% of the total area. The deposition areas occupy the centre of sub-basin and constitute 9.12% of the total area. These deposits were concentrated on the edges of major rivers and the outlet of the sub-basin and contributed to siltation of the April 9, 1947 dam.

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Keywords

Soil Erosion, Deposition, Oued Haricha, NW-Rif, Morocco

1. Introduction

Research conducted over the past forty years have shown the value of the estimated soil loss using the accrual rate in downstream dams, reservoirs and other deposit areas [1]. Recent studies have largely involved the use of distributed and empirical models. These models consider the spatial heterogeneity of the use of watershed lands, soil properties, topography and spatial interaction processes of erosion, transport and deposition of sediments. The validation of these models is generally limited to the comparison of the predicted and measured outputs from the watershed.

The results of soil loss computations vary from one basin to another. This difference is due to variations in the physical characteristics of each basin, including the power of erosion by rain, the intrinsic susceptibility of soils to erosion, as well as the combined effect of the tilt and angle length of the slope. Human activities also play a role in sofar as natural vegetation is disturbed, and practices that control erosion can affect sediment loss.

Empirical models are integrated approaches permitting the soil erosion modelling in watersheds in response to changes in land use. The nature and extent of watershed degradation and erosion can be provided to the past, present and future conditions.

To link the eroding factors between them and quantify soil loss, several equations are developed (USLE: Universal Soil Loss Equation of Wischmeier and Smith [2]; WEPP: Water Erosion Prediction Project [3]; SWAT: Soil and Water Assessment Tool [4]; EUROSEM: European Soil Erosion Model [5]). Several computer models have subsequently emerged; some of them are based on the Universal Soil Loss Equation (USLE) and its modified (MUSLE) and revised (RUSLE) versions. GIS software is getting ready to assess these equations and thus mapping the rate of erosion and soil loss at the parcels' scale from the upstream of the basins.

This paper complements the studies already undertaken in northern Tahaddart watershed (Oued Sania sub-basin) in where the soil loss is quantified [6]-[9]. The objective is to produce modelled estimates of soil loss from empirical models for the Oued Haricha sub-basin. The applied models are based on the Universal Soil Loss Equation (USLE Universal Soil Loss Equation) with its revised (RUSLE) and modified (MUSLE) versions. These are supplemented by the deposition module for calculating the balance sheet of erosion.

2. The Study Area

The Oued Haricha sub-basin is part of the Tahaddart watershed (Western Rif, NW Morocco). It has an area of 221.82 km^2 and is characterized by an altitudinal variation ranging from 10m at the outlet (dam of 9 April 1947) to 941 m at the top of the most prominent reliefs situated in the east and in the south (**Figure 1**). The region has a Mediterranean climate tempered by Atlantic influences, with an average annual rainfall of 689.4 mm (meteorological station of dam April 9, 1947) for the periods from 1970 to 2015. The 1995-1996 hydrological year is the wettest year with 1279.5 mm precipitation, while 1994-1995 is the driest year with precipitation of 237.2 mm (**Figure 2**). December is the wettest month (140 mm) while July is the driest month (0.4 mm). The average monthly temperature recorded shows that August is the hottest month (T = 23.9˚C) and January is the coldest one (12.5˚C).

The Oued Haricha sub-basin has an elongated shape. Its compactness index of Gravelius Kc is equal to 1.44. It is drained by Oued Haricha over a length of 24.63 km. This river takes its birth in the southeast of the sub-basin and ends to the west by the dam of April 9, 1947 (**Figure 3**). The time of concentration Tc, calculated using the most widespread empirical formulas in Morocco (Formulas of Turazza, Ventura, Kripich, Giandotti, California and Passini) gives an average of 2.70 hrs. This time is relatively long, which will cause a slow gathering of water towards the outlet.

The soils type in the sub-basin of Oued Haricha studied by [10] [11], classified according to the CPCS classification system [12] are generally the low developed soils (25.66% of the total surface), lithosols (14.91%), vertisols (32.48%), brown soils (19.22%), hydromorphic soils (2.69%) and iron sesquioxides soils (2, 34%). The natural vegetation consists of matorral moderately dense and degraded in the hills (16% of the total area). The

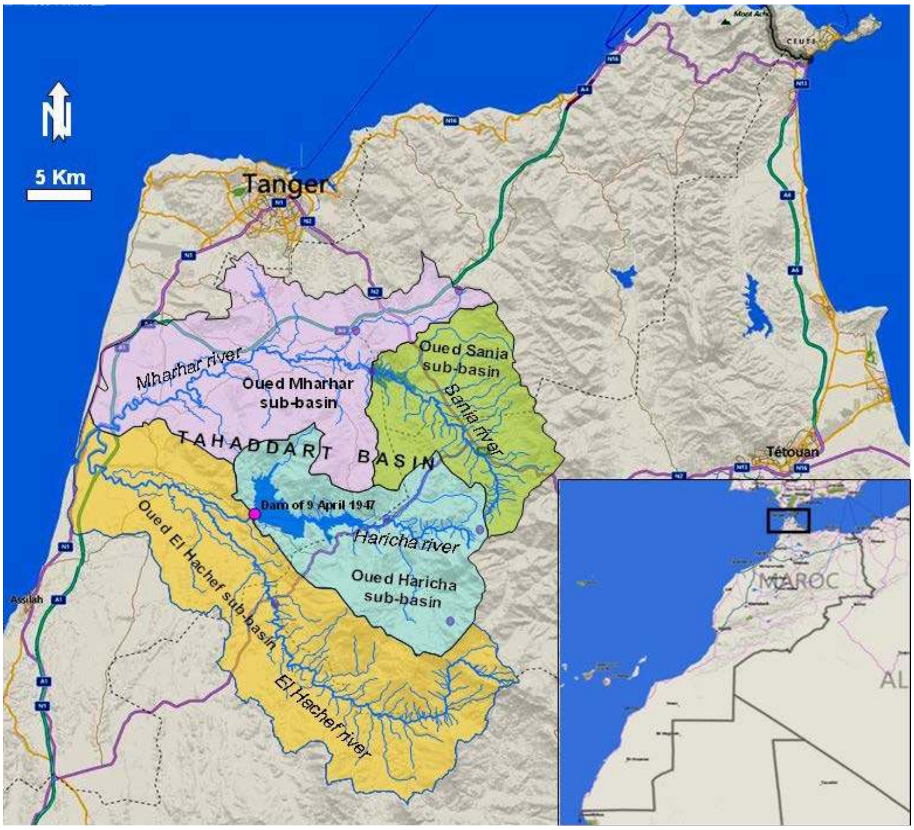

Figure 1. Situation of Oued Haricha sub-basin in Tahaddart watershed in NW of Morocco.

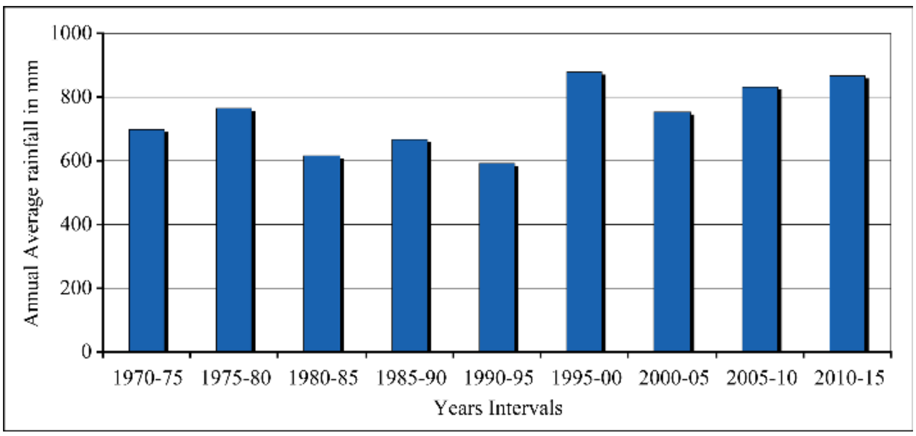

Figure 2. Annual rainfall in the meteorological station April 9, 1947 during the period 1970-2015.

Aleppo pine mixed or not with cork oak and Eucalyptus plantations dominate especially at the breakwater of the dam. These forests constitute 52% of the total area. Ligneous vegetations dominate the high and low hills of the sub-basin (5%). The valley floor is occupied by cereal (18% of the total area).

3. Factors of Erosion

The potential for erosion can be calculated after identification of individual soil factors values. The following section briefly describes each RUSLE and MUSLE factor and lists inputs for the time-invariant (average annual values) module.

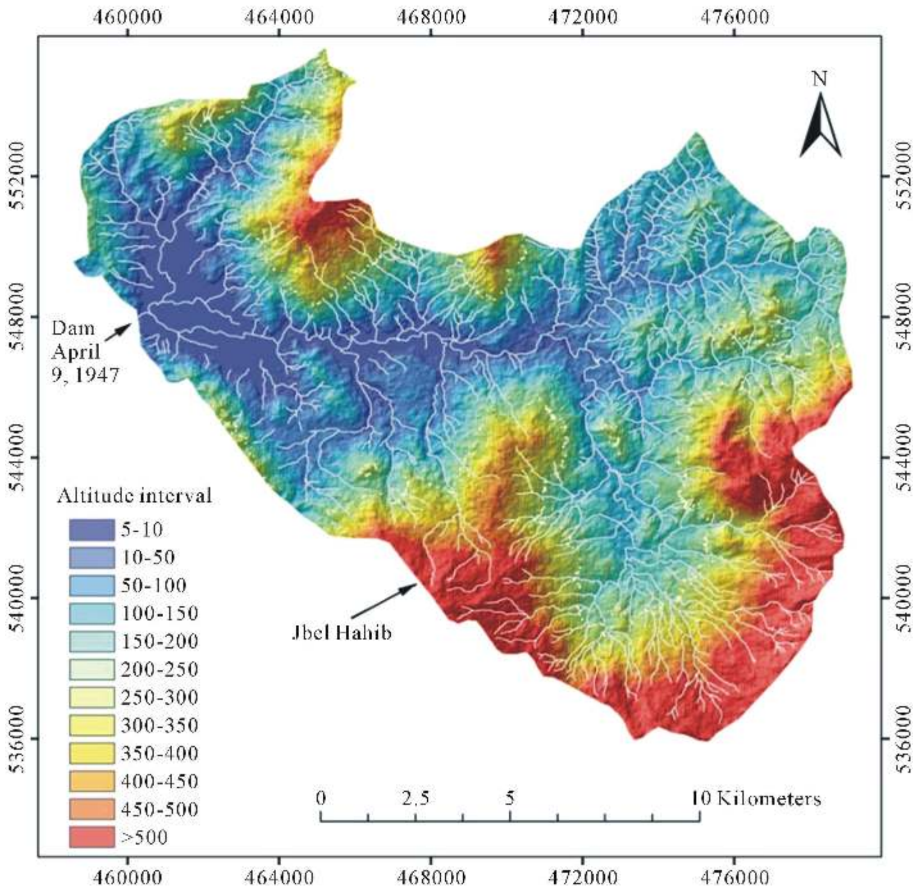

Figure 3. Morphological Unit of El Hachef sub-basin.

3.1. Rainfall Erosivity Factor (R)

The R factor for a given location is derived from precipitation records, placed on an iso-erodent map. Local R values are calculated directly from the equation of Arnoldus [13] (Equation (1)), for the meteorological stations of Ibn Battuta, Dar Chaoui, Jbel Hbib, Béni Harchane, Skarich and April 9, 1947 (**Figure 1**). The rainfall data series used are especially monthly and yearly average.

$$R = 1.753 \times 10\left(\left(1.5\log\Sigma\left(Pi2\right)/P\right) - 0.8188\right) \quad (1)$$

where:

Pi: monthly precipitation in mm.

P: annual precipitation in mm.

From the iso-erodent map, we deduce that the average erosivity for the Oued Haricha sub-basin is equal to 37.89 MJ*mm/ha/h.

3.2. Soil-Erodibility Factor (K)

The soil-erodibility factor (K) represents the influence of soil properties and characteristics of the soil-profile on soil loss during storm events on upland areas [14]. Soil texture, organic matter, structure, and permeability determine the erodibility of a particular soil. K values for various soil types were estimated using the published soil erodibility nomograph [2] [15] [16] in different soil type already mapped [10] [11] [17]. The erodibility values in the study area range from 0.12 to 0.40 Mgh/MJ/mm. **Table 1** shows that 44.47% of the soil series are characterized by low values ($K \leq 0.2$). Medium soil erodibility (0.2 to 0.3 Mgh/MJ/mm) represents 35.26% of the total area. The high values of K (0.3 to 0.4 Mgh/MJ/mm) represent 20.27%.

Table 1. K range interval and corresponding area.

K range	Area	
	Km^2	Percent (%)
$K \leq 0.1$	89.04	40.14
$0.1 < K \leq 0.2$	9.61	4.33
$0.2 < K \leq 0.3$	78.21	35.26
$0.3 < K \leq 0.4$	44.96	20.27
Total	221.82 km^2	100

3.3. Cover and Management Factor (C)

The C factor represents the effect of plants, soil cover, below-ground biomass and soil-disturbing activities on soil erosion. It is used to reflect the effect of cropping and management practices on erosion rates. The C values corresponding to each crop/vegetation condition were estimated from RUSLE guide tables [2] [5] for forests, matorrals and pastures and on the guide table of Cormary and Masson [18] for the types of culture, timing and crop rotations.

For this study, the C factor is determined from the update in the field of the crop/management map [11]. The results show that the values of the C-factor are between 0.0 and 0.70. They indicate that 22.54% of total area has a low and very low protection against erosion and 16.00% has good protection. The very good protection is dominated by land occupied by forests (52%). Other areas outside of agriculture correspond to urban areas and bare land.

3.4. Slope Length and Steepness Factor (LS)

The effect of topography on erosion is accounted for by the LS factor. Erosion increases as slope length increase, and is considered by the slope length factor (L) [14] [19]. RUSLE uses one of four equations to compute LS values. The choice of LS equation is based on existing conditions including surface cover at the site. For this study, the LS factor is calculated from the formula of Wischmeier and Smith [2] in the out-of-box functionality of ArcMap [20] following the programmatic methods in Equations [21] [22]:

$$\mathrm{LS} = \left(\mathrm{sl}/22.13\right)^{\mathrm{m}} \cdot \left(0.065 + 0.045 \cdot \mathrm{S} + 0.065 \cdot \mathrm{S}^2\right) \tag{2}$$

where:

sl: is the slope length of the site (m).

m: is a coefficient related to the ratio of rill to inter-rill erosion presented in table below.

Slope	$P < 1$	$1 \leq P < 3$	$3 \leq P < 5$	$P \geq 5$
m	0.2	0.3	0.4	0.5

S: is the slope factor.

$S = 10.8\sin\theta + 0.03$, since the average angle of the slope θ (in degrees) of the sub-basin is less than 9% and the length ≥ 5 m [22].

Figure 4 shows that 65% of the total area of the sub-basin has LS values lower than 5. The classes of LS upper than 15 are homogeneous across the sub-basin.

3.5. Support Practice Factor (P)

The P-factor describes the supporting effects of practices like contour farming, cross-slope farming, buffer strips, stripcropping, and terraces. It represents the ratio of soil loss from an area with supporting practices in place to

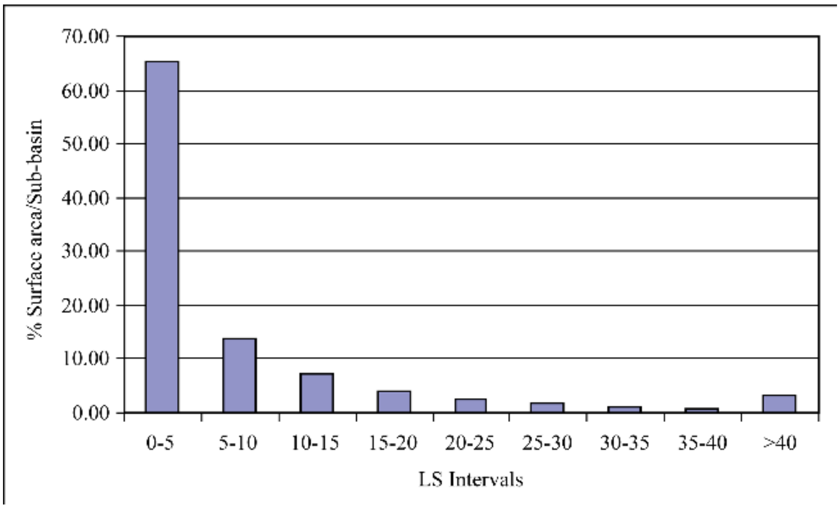

Figure 4. Distribution of the LS factor intervals in Oued Haricha sub-basin.

that from an identical area without any supporting practices. In the sub-basin of Oued Haricha, there are no support practices for soil conservation; the P factor is set to equal 1.

4. Empirical Modelling

The dataset used in this study consists of digitized maps, geo-referenced in the Moroccan projection system (Merchich Morocco, ellipsoid Clarke 1880) and projected in the Moroccan cartographic system (Lambert Conformal Conic, Zone-1). The geometric and cartographic parameters (river system, land use, climate and soil data) were extracted and listed in the GIS as vectors and raster layers (grid). Topographic parameters (slope map, contour map for each altitude, map exhibition, slopes map, slope lengths, etc.) were extracted from the digital elevation model. ArcGIS [20] was used to create relevant thematic layers and to generate a composite map for the revised (RUSLE) and modified (MUSLE) models of Wishmeier and Smith [2]. The results are presented as thematic maps.

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4.1. Erosion on the Slopes by RUSLE Model

The Revised Universal Soil Loss Equation (RUSLE) was examined as an improved method for estimating sheet and rill erosion at the Oued Haricha sub-basin. RUSLE calculates annual sheet and rill erosion from a hill slop by multiplying together several factors: the Soil-erodibility factor (K), Rainfall erosivity factor (R), Slope length and steepness factor (LS), Cover and management factor (C), and Support practice factor (P) [15] [16]. The annual average loss of long-term soil for Oued Haricha sub-basin is 62.72 t/ha/year. The spatial and statistical distribution of the RUSLE values (**Figure 5**, **Figure 6**) shows that the losses are located in the range of less than 50 tons/ha/year and constitute over 60% of the total area. Only 18% of the territory is subject to excessive erosion (over 100 t/ha/year), exceeding Wischmeier tolerance levels.

4.2. Erosion at the Outlet of the Sub-Basin by MUSLE Model

Erosion at the outlet of the Oued Haricha sub-basin is evaluated from MUSLE model (Modified Universal Soil Loss Equation) of Williams and Berndt [23]. It involves the peak flow and total volume of water runoff to predict soil erosion for an event of erosion of the water. The equation, corrected by Renard *et al.*, [16] is as follows:

$$A = C1\left(Vr.Qp\right)0.65.K.LS.C.P \quad (3)$$

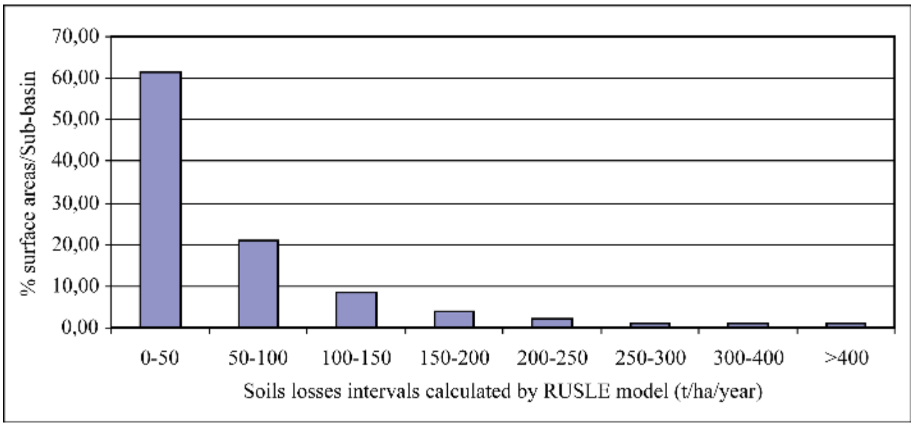

Figure 5. Distribution of soil loss by RUSLE model.

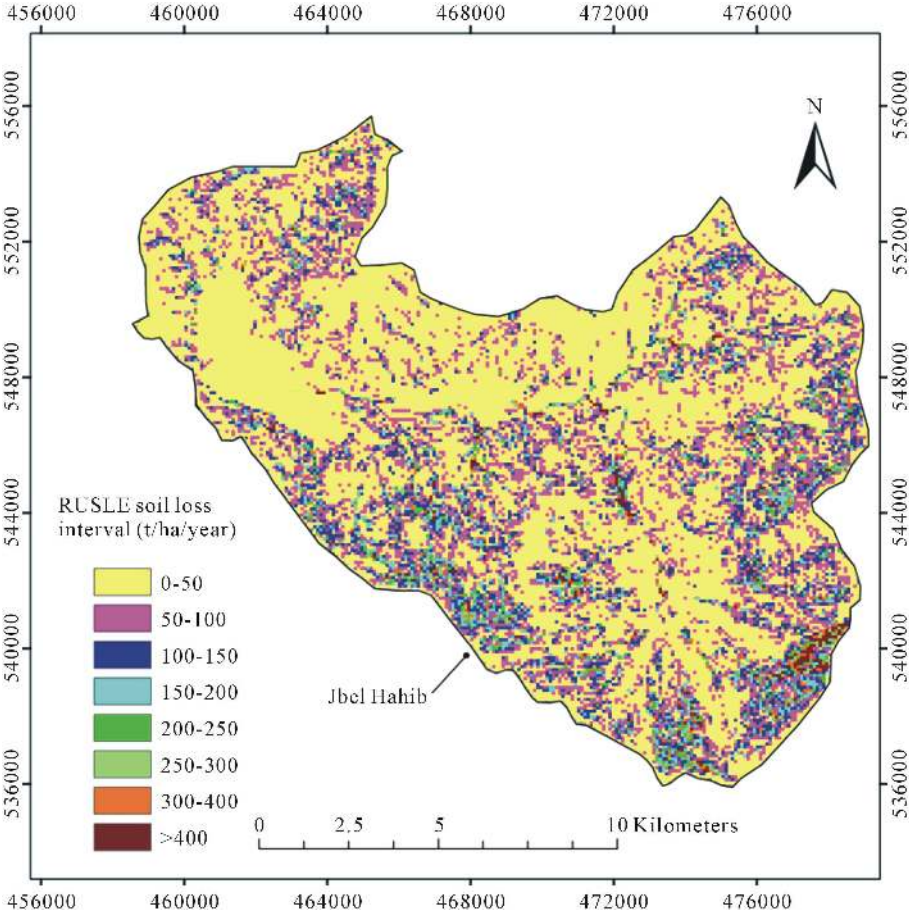

Figure 6. Distribution of soil loss by RUSLE model.

where, A is sediment yield produced by sub-basin in t/year, C1: Conversion factor equal to 9.05 or 11.8 in International Unit System. In Morocco, C1 = 9.05. Qp is peak flow rate in m^3/s. Vr is volume of runoff in $m^3/year$, determined from hydrometric stations. K, LS, C and P are respectively, erodibility, topography, crop management and soil erosion control practice factors (all dimensionless).

The average annual losses at the outlet of the Oued Haricha sub-basin are 221,468 tons. The spatial distribution of losses (**Figure 7**, **Figure 8**) shows that 22% of the sub-basin area generates low levels of sediment (less than 50,000 t/year). These are the raised lands that produce larger amounts of sediments (over 100,000 t/year).

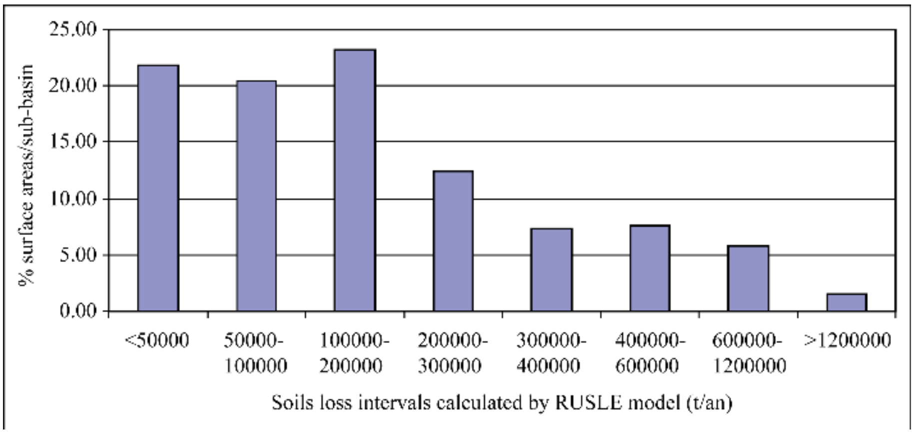

Figure 7. Distribution of soil loss by MUSLE model.

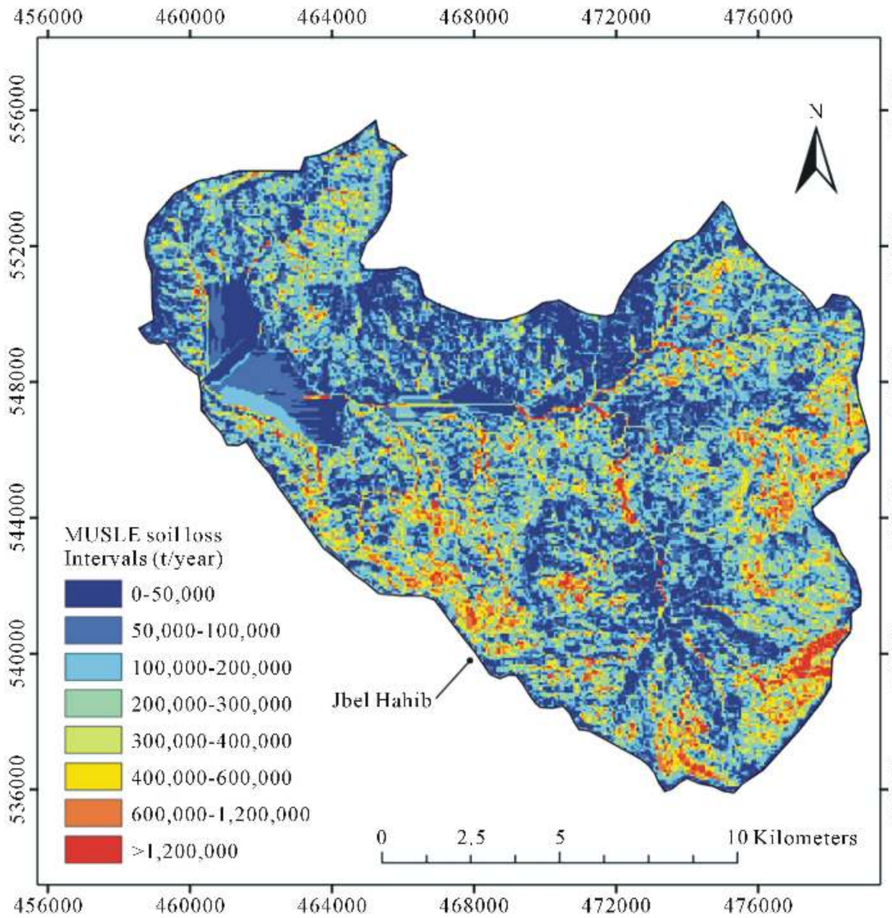

Figure 8. Loss map by Williams model.

4.3. Erosion Caused by the Hydrographic Network

The estimation of the contribution of the river system in the production of sediments occurs after subtraction of values calculated from MUSLE model to that derived from RUSLE model, since linear erosion is assumed dominant compared to other forms of erosion. The results show that the loss rates due to linear erosion are at the average of 82,652 t/year. These losses, due to hydrographic network, constitutes 20.33% of the total losses (**Figure 9**). Thus, the losses on the slopes outweigh the losses due to the river system.

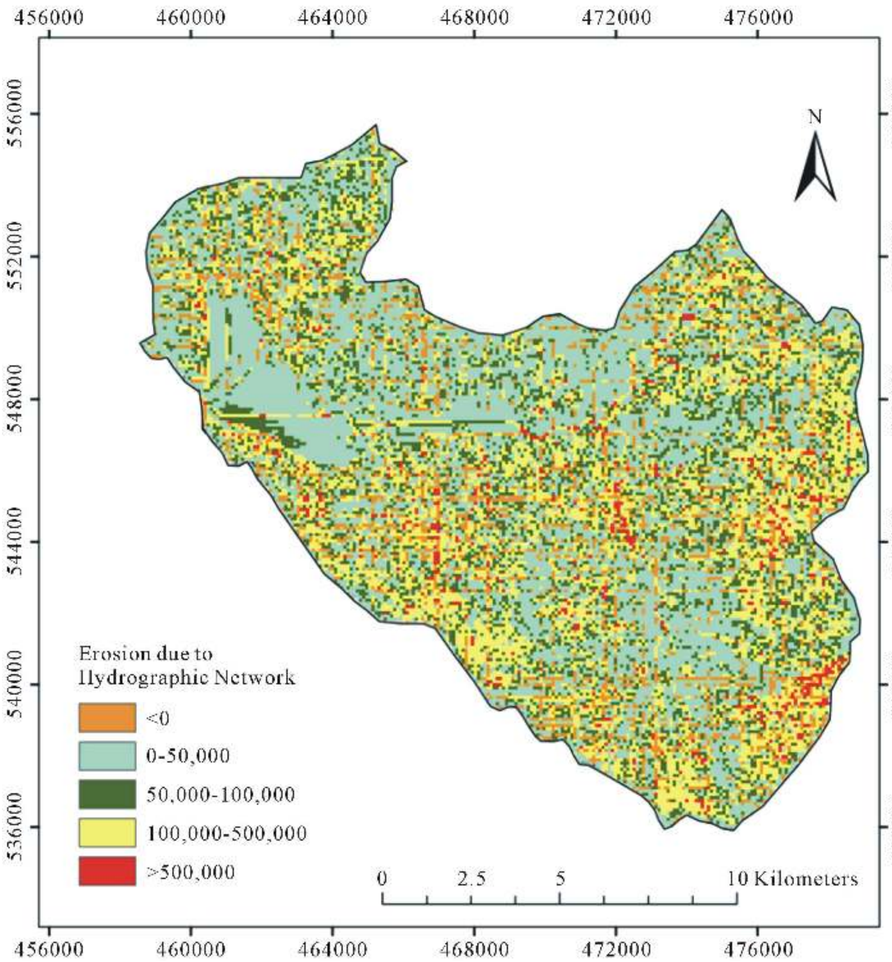

Figure 9. Map of losses related to Hydrographic Network.

4.4. Sedimentation Model

The sedimentation model (deposition) is based on the results of the RUSLE model to calculate the balance sheet of the erosion in each individual parcel. It uses homogeneous polygons resulting from the calculation of the RUSLE model to assess the net movement of the soil (erosion or deposition) in parcels or sub-basins [24] [25]. It also requires the digital terrain model (DTM) and represents an extension of the incorporation of RUSLE in a GIS environment [24].

Application of sedimentation model for in the Oued Haricha sub-basin helped to clarify the rates of soil loss and sedimentation (**Figure 10**). Calculation results of the net annual soil loss show that:

- Areas with losses from 0.0 to 50 tonnes/ha/year are concentrated at the outlet of the sub-basin in an area of 3023 ha (13.63% of the total area);
- Areas with average loss between 100 and 200 t/ha/year constitutes approximately 25% of total surface (or 5210.39 ha);
- Areas with high losses (200 to 400 t/ha/year) occupy regions with an average slope over an surface area of 5210.39 ha (23.49% of the total area);
- The regions of very high losses (over 400 t/ha/year) dominate especially on the upstream reliefs southeast sub-basin. They correspond to areas of high gradient and occupy 14.7% of the total area (3261.58 ha of total area);
- The regions of low slope correspond to areas where dominate sedimentation (or deposition) on erosion. These areas occupy the center of the sub-basin in the edges of the main rivers in a surface area of 2022.55 ha (9.12% of the total area).

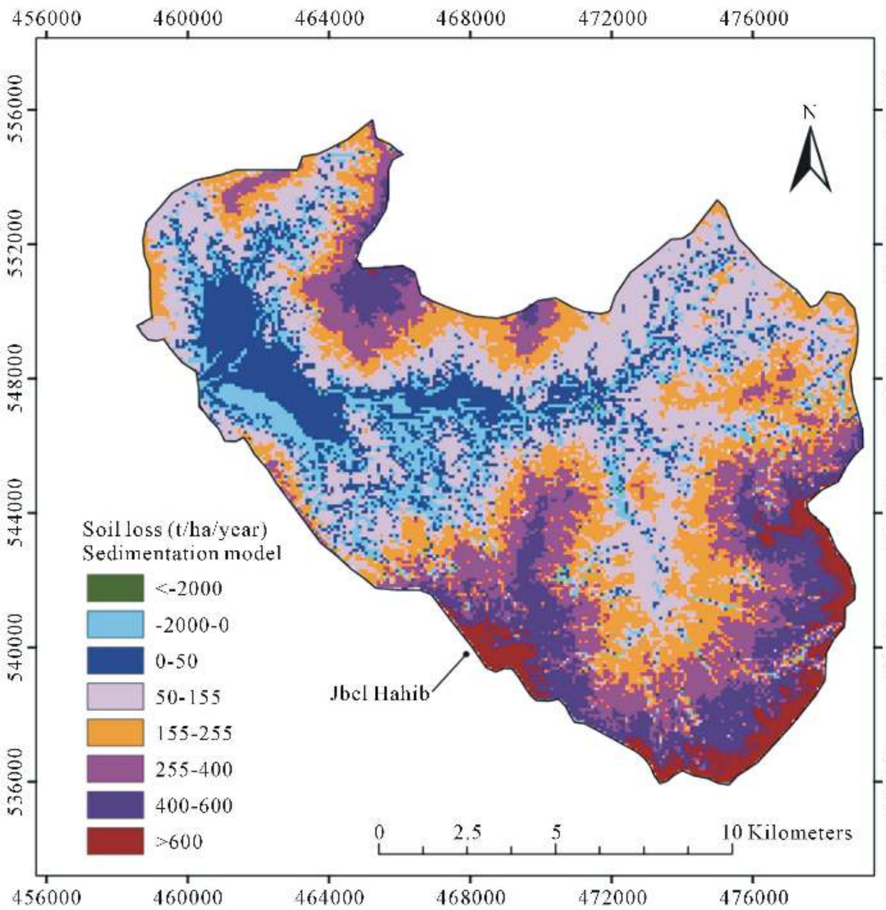

Figure 10. Map of soil losses by Deposition model.

5. Discussion and Conclusion

This study evaluates the erosion based on changes in the characteristics of precipitation and runoff, the properties of land use and practices in a mountainous area of the western Rif (NW Morocco).

The Rainfall erosivity factor (R) calculated for the sub-basin of the Oued Haricha is equal to 37.89 MJ*mm/ha/h. This value is close to the values determined in central and western Rif and the Rif foreland. In the Central Rif, R index ranges from 43 to 87.56 in the watershed of Oued Lben [26] and is estimated to 51 to 194 in Ouergha Valley [27]. In the eastern foreland of the Rif chain, this index is estimated at 56.3 in the watershed of Oued Tleta [25], and ranges from 40 to 50 mm*MJ/ha/h in the watershed of Oued Boussouab [28]. In the western Rif, Tahiri *et al.* [9] calculated a value of R = 54.75 MJ*mm/ha/h in the sub-basin of Oued Sania.

This study shows that erosion is slightly constrained by the vegetal cover. The spatial distribution of the vegetation cover index (C) shows that 22.54% of the surface has low protection against erosion. The very good protection is dominated by land occupied by forests (52%).

The distribution map of the soil-erodibility factor (K) shows that over 35% of the sub-basin area has an average erodibility. This is explained by the abundance of vertisols and lower developed soils, usually from the alteration of the bedrock constituted by marl and flysch very permeable and easily erodible. Good protection is visible on 44% of the total area.

The results of LS calculation factor of the sub-basin of Oued Haricha show that downstream and center reliefs constitute 65% of the total area where LS values are smaller to 5. They exhibit flattened morphology and show relatively low potential role of this index in the quantification of erosion.

The crossing of synthetic maps of different factors using a GIS enabled an assessment and quantification of erosion. The actual erosion by the RUSLE method is 62.72 t/ha/year with a medium level of risk. These results show that the values recorded in the sub-basin of Oued Haricha and the results of previous studies in the Prerif

[25] [29]-[32] and the Western Rif [9] are much higher than the tolerance levels (RUSLE value > 11 t/ha/year). Soil losses lower than 50 t/ha/year are more than 60% of the total area. This shows the seriousness of the specific degradation due to the type of land use, lithology, topography and especially to climate changes that promote soil erosion. Last studies show that climate is marked in northern Morocco by a predominantly negative precipitation evolution and a general tendency toward warmer and drier conditions [33]. Precipitation is likely to decrease between 10 and 20%, while temperatures are likely to rise between 2˚C and 3˚C by 2050 [34] [35].

The total loss at the outlet by the MUSLE methods is averaged to 221,468 t/year. Low rates (less than 50,000 t/year) are 22% of the area of the sub-basin and dominate the downstream reliefs and rivers. These are the raised lands that produce larger amounts of sediments (over 100,000 t/year). This highlighted the risk of these losses in siltation of the April 9, 1947 dam.

Soil losses due to the hydrographic network or linear erosion, are about 20.33%, confirming that the losses on the slopes, or sheet erosion and rill outweigh the losses due to the river system. The values calculated after subtracting MUSLE data and RUSLE using a GIS can calculate the average annual loss rate of 82,652 t/year.

Application of Deposition module helped to clarify the rate of loss of soil and sedimentation. The regions of very high losses (greater than 200,000 t/ha/year) occupy the middle slope areas and contribute to siltation of the April 9, 1947 dam. The regions of low slope correspond to areas dominated by sedimentation (or deposition) on erosion. These areas occupy the center of the sub-basin on the edges of major rivers and constitute 9.12% of the total area.

This study has identified various areas at risk of erosion and quantified the deposition. Erosion causes damage to farmland but also degrades water quality and sediment movement. To address the risk, control ways must be within the emitting runoff regions and sensitive areas accumulating precipitation. This is to reduce surface runoff and training detachments and transport capacity of runoff by limiting its speed and concentration.

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