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Modelling the Soil Loss in the Watershed of the Chaddad Wadi in Terms of Both Rockiness and Soil Slaking Indexes

Naima Azaiez Arif[1,2,3]

[1]King Khalid University, Abha, KSA
[2]Preparatory Institute for Literary Studies and Human Sciences of Tunis I (IPELSHT), Tunis, Tunisia
[3]Research Laboratory: "*Biogeography, Applied Climatology and Environmental Dynamics*" (BICADE), Faculty of Arts and Humanities of Manouba, Manouba, Tunisia
Email: azaieznaima@yahoo.fr, nazaiez@kku.edu.sa

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Abstract

Currently we are at a phase where morphogenesis is gaining more prominence and dimension regarding the pedogenesis. The numerous multidisciplinary studies on the soil showed that the erosive action as well as the various problems that result from it, bring out a very serious state of soil degradation in the semi-arid field [1]-[9]. Several attempts have established to set empirical and experimental methods for a quantitative estimation of soil loss caused by diffuse erosion. In this perspective, this research intends to track soil losses in the watershed of the Chaddad wadi, the average-flowing stream of the Nebhana wadi belonging to the lower semi-arid field. The main stream and its tributaries drain an area of 26.5 km^2 from the eastern slopes of Ejhaf mountain (517 m) and Fartout mountain (476 m), as well as the southern slope of Ediour mountain (405 m). The dividing line of the waters with the Khalfallah wadi and Bel Assoued wadi is caused by rows of hills with an altitude ranging between 220 m and 306 m such as the hills of Sidi Salah and those of Es-Souida and Ain Fres. The Wischmeier Equation will be improved by two corrective parameters: the rockiness on the one hand and the soil slaking index on the other, aiming to develop and optimize the potential of this empirical model. This application allowed overcoming some of the limitations that came with the Wischmeier equation, which is primarily designed for an application within different physical conditions on the scale of a land plot. This research is an opportunity to make a detailed contribution to the potential sensitivity of the watershed to water erosion. A good demarcation of the physical anthropogenic framework of the erosive action will provide substantial support in terms of soil protection and the stabilization of watersheds emitting sediments.

Keywords

Drainage Density, Index of Soil Slaking Crust, Sheet Erosion, Stoniness Index, USLE

1. Introduction

The soil degradation remains a persistent problem in countries characterized by highly aggressive rainfall, including Tunisia, which is searching to set up a system to manage soil under threat. This rising threat is reflected in the scope of the degradation that has far exceeded the top stratum of the soil to reach the soft bedrocks, including the continuous shrinking of arable lands. It is also reflected in a reduction of water retention power in most hillside reservoirs. It is in this context that we wanted to conduct a study on the watershed of the Chaddad wadi's tributary of the average flowing stream of the Nebhana wadi, located on the margins of the bioclimatic levels: the average semi-arid and the lower semi-arid (**Figure 1**). For decades, this watershed has known an increased land steppe formation and intensified degradation.

A simple observation of the watershed's stream system in 2017 showed that the watershed has considerable erosive potential. The drainage density of 13.8 km/km^2 is no more than a warning to take the necessary measures in order to reduce the loss of the arable stratum. To take part in this attempt of anti-erosive control, we proposed the application of the Wischmeier Equation. Widely applied all over the world, this method has shown good results in the United States, Europe and especially in Morocco. In Tunisia, it was applied by Cormary and Masson [10], and Ben Cheikha [11]... but it was criticized by the majority of geomorphologists in that it is not suitable to be applied outside the field for which it was designed. As a result, we have thought of optimizing the results and it is by adjusting this equation to the specificities of the watershed studied by choosing two corrective parameters: the rockiness and the soil slaking indexes.

2. Physical and Anthropogenic Framework

1) Topography

The water stream of the Chaddad wadi originates on the northwest ridge line that demarcates the Ejhaf depression. It crosses the southern end of the Souar corridor which is bounded to the West by Fartout mountain and to the East by the Diour mountain.

It is characterized by a rugged topography to the north-west, where the mountain ridges on rise in succession with very narrow intramountain corridors whose slopes are divided into multiple interfluves. Towards the South and South-west, topographical units become less rugged and more aerated, notably, minor mountain ridges, hills and plateaus less than 300 m of altitude.

2) Morphometric Data and Hydrological Indexes

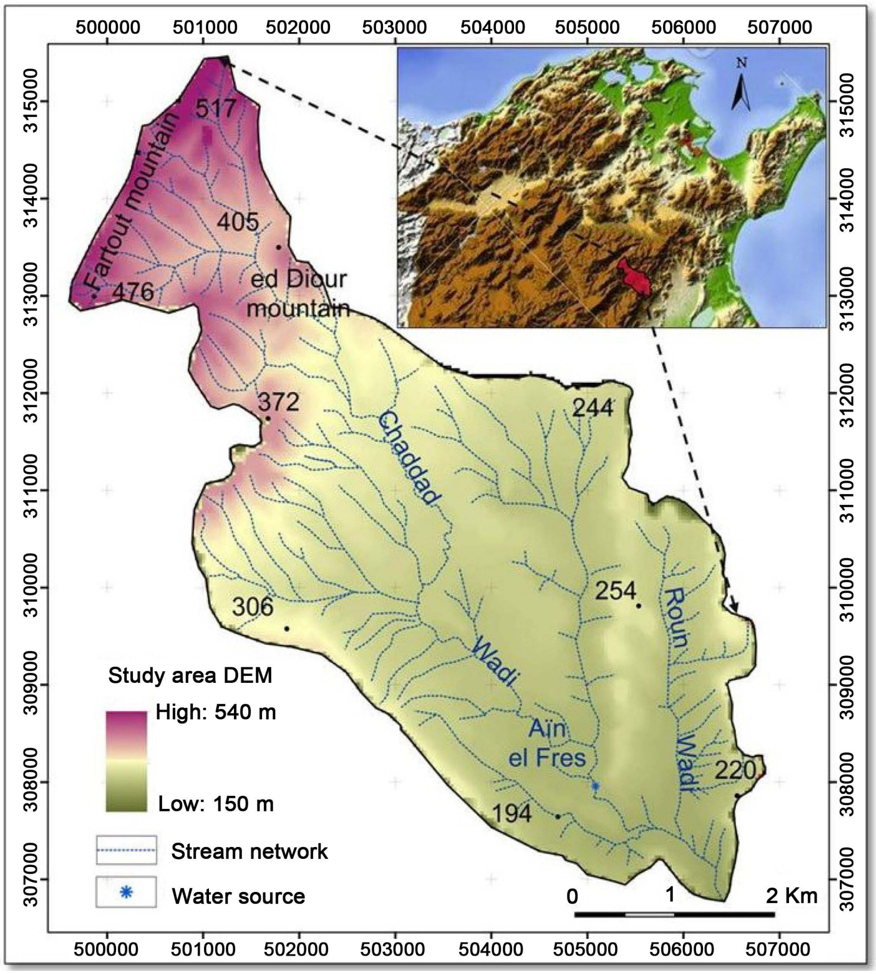

Figure 1. Location map of the study area.

Referring to the hypsometric trend curve and the specific drop, this watershed shows a fairly elevated relief of 108.11 m, with an average altitude of 230 m, while its form is relatively stretched out given the compactness index of 1.55 and the form of the equivalent rectangle (Table 1 and Figure 2).

Compactness coefficient is used to express relationship of a hydrological aspect of each sub-basin to that at circular basin having the same area as the hydrologic basin, in order to distinguish the most sub-basin which can record the shortest rainwater concentration time.

The watershed has an average slope of 8.95%. The lowest are the most widespread, with 72% of the total area characterized by slopes inferior to 6%, while 20% of the area shows a slope ranging between 6% and 14%.

The average slopes of 14% - 30% constitute 6% of the total area, while the highest slopes, ranging between 30% and 82%, are very poorly represented and make only 2% of the total surface of the watershed (Figure 3).

As previous studies on water erosion have pointed out, the slope acts not only by its rigor but also by its length and especially, by its form. The convex slopes, particularly without a sufficiently thick colluvial mantle, are considered the most

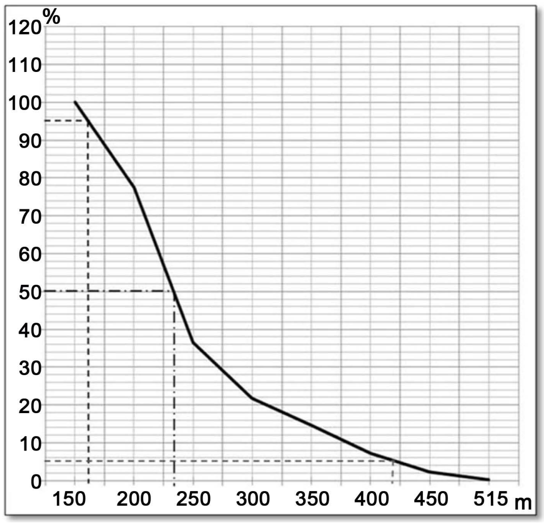

Figure 2. Hypsometric curve of Chaddad wadi basin. Source: Personal work based on the topographic maps of Jbibina and Fkirine Mountain at 1/50,000.

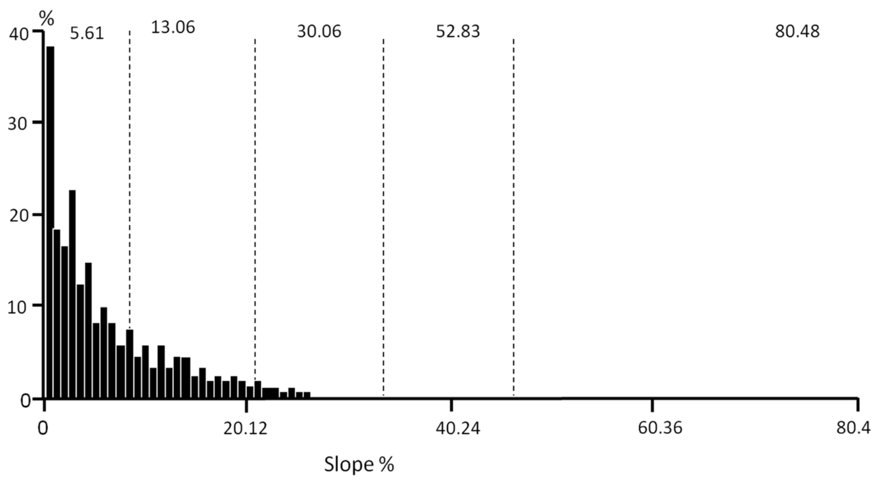

Figure 3. Slope frequency in Chaddad wadi basin. Source: Personal work based on the results of the Arc GIS.

Table 1. The morphometric and hydrological characteristics of the catchment area of wadi Chaddad.

Area Km^2	Perimeter Km	Compactness indice (Kc)	The rectangle equivalent		Specific height difference (m)	Concentration time
			Length (L in Km)	Width (l in Km)		
26.547	28.674	**1.55**	**12. 152**	**2.1845**	108.11	4 Hours and 29 minutes

privileged areas for opening multiple mountain trickles that furrow the soil to give birth to fields of ravines. These convex slopes tend to disperse water streaming in different directions by contrasting stretches of land with the adverse effects of water erosion [12] [13]. This type of slope is frequently encountered in the upstream part of the watershed, on the middle and bottom of the slopes and the interfluves of Henchir el Ksaira, west of Bled Faid el Mraima as well as the slopes demarcating the corridor of theerRounwadi (in Faïd el Aïfa and Ragoubet Souida). In all of these areas, the number of category 1 incisions is extremely high. This means an erosive dynamic which is more and more increasing and controlled by a system of ravines that appeared in ex-nihilo as a result of ravine head recession or sink-holes caused by successive suffusions.

However, one should not think of an erosive manifestation that comes under natural determinism. As for man's share in soil erosion is far from being negligible, some agricultural practices are inadequate, especially ploughing in the direction of the slope and extensive courses, account for the exacerbated degradation that dates back to an ancient process of brittleness thus expressing the multiplicity of factors that played a decisive role in its favour. For example, during heavy autumnal rainfalls, we witness a rapid transformation of the plough furrows into real ravines [1] [14] [15]. These forms of erosion, although less numerous, they can shape certain slopes, which even have a soft slope, into real soils of badlands. Morphometric and hypsometric conditions and spatial repartition of slopes do not provide information on a watershed that is suitable to the concentration of the water streaming as the driving force of water erosion. The concentration time of the water streaming is estimated at 4 hours and 29 minutes, a result obtained by the application of the two formulas of Giandotti and Passini. For an area of 26.547 km^2, this concentration time is considered relatively short to cause a concentration of the water streaming.

However, the averages are misleading, despite their importance. A thorough characterization of the sub-watersheds clearly shows four distinct groups (**Figure 4** and **Table 2**). The first group includes the highly heaped sub-watershed 2, the second group incorporates the third and fourth groups, which are relatively heaped in form. The third group concerns the first and sixth group, whose

Table 2. Estimated morphometric and hydrologic parameters in different subbasins of Chaddad wadi.

Subbasins Number	Area (Km^2)	Perimeter (Km)	Compactness indice (Kc)	Rectangle Equivalent		Specific difference in altitude (m/km)	Average Altitude (m)
				Length (L in Km)	Width (l in Km)		
BV 1	8.511	16.473	1.58	7.0211	1.211	103.87	309.66
BV 2	2.955	7.109	1.157	2.228	1.573	131.16	240.5
BV 3	5.231	10.909	1.33	4.212	1.242	92.97	206.4
BV 4	3.701	9.232	1.33	3.582	1.0332	56.2	183.33
BV5	4.492	13.768	1.81	6.149	0.73	33.42	176.76
BV6	1.654	7.186	1.56	3.053	0.51	44	171.86

Source: Topographic maps of Jbibina and Fkerine Mountain at 1/50,000 and DEM obtained from Arc Gis application.

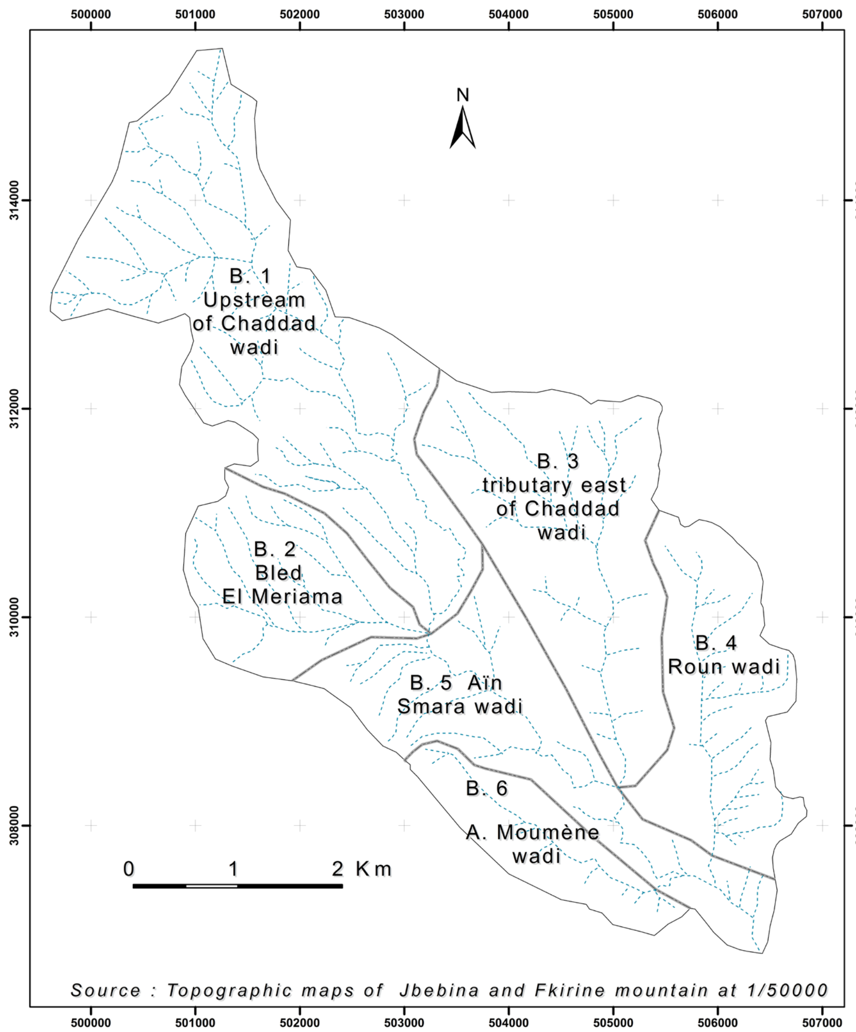

Figure 4. Different sub-basins of Chaddad wadi and its boundary. Source: The topographic maps of Jbibina and Fkirine Mountain at 1/50,000.

forms are relatively stretched out. The last group involves the watershed 5, whose form is very stretched out Knowing that the outflow in the first five basins takes place on a plastic substratum with the exception of watershed 2, which is predominantly clayey and sandy (Continental Mio-Pliocene).

The objective of this classification is to define the sediment-emitting areas and to determine the share of the different factors that come into play in the erosive dynamics. It all depends on the method and objective of the present study, all of these aforementioned data will be taken into account within a global approach in order to be able to outline as much as possible the causes that are at the origin of soil losses.

3) Predominant Outcrops of Soft and Waterproof Rocks

The majority of outcrops are soft, but mostly plastic and with a very low permeability which reminds us of a watershed strongly favorable to the concentration of the water streaming, especially following saturation or after the formation of a slaking crust on soils with a sufficiently fine texture. It is proving that more than 70% of the watershed area is covered with either Cretaceous marls or Eocene and Oligocene clays. While the remaining 30% are clayey and sandy or marly chalky soil alternations. As for the most spread surface formations in the study area, they are mainly crust and chalky deposit (Figure 5).

The edges of the glacis thin strips are lined with a colluvial deposit coming from the crumbling calcareous crust. Higher up the slopes and down the rock walls of the ridge, the tables and debris sheets stretch out over a thin, coarse, intensely stripped soil all around the heaps of stones, while the erosion plains are covered with a soil that has slightly changed into mostly alluvial soil, clayey and alluvial soil, alluvial and sandy soil (Figure 6).

4) Land Use and Watershed management

Sometimes land use plays a decisive role in the current dynamics not only in a positive but also a negative way. In this watershed, only 22.56% of its area is covered with a matorral and bush wood (Figure 7).

The matorral is shaped by young Aleppo Pine trees associated with clusters of Lentiscus trees, rosemary, acacia and a few wild olive trees. 14.3% are olive-growing and cereal lands, 26.78% of the watercourse lands. The remainder of

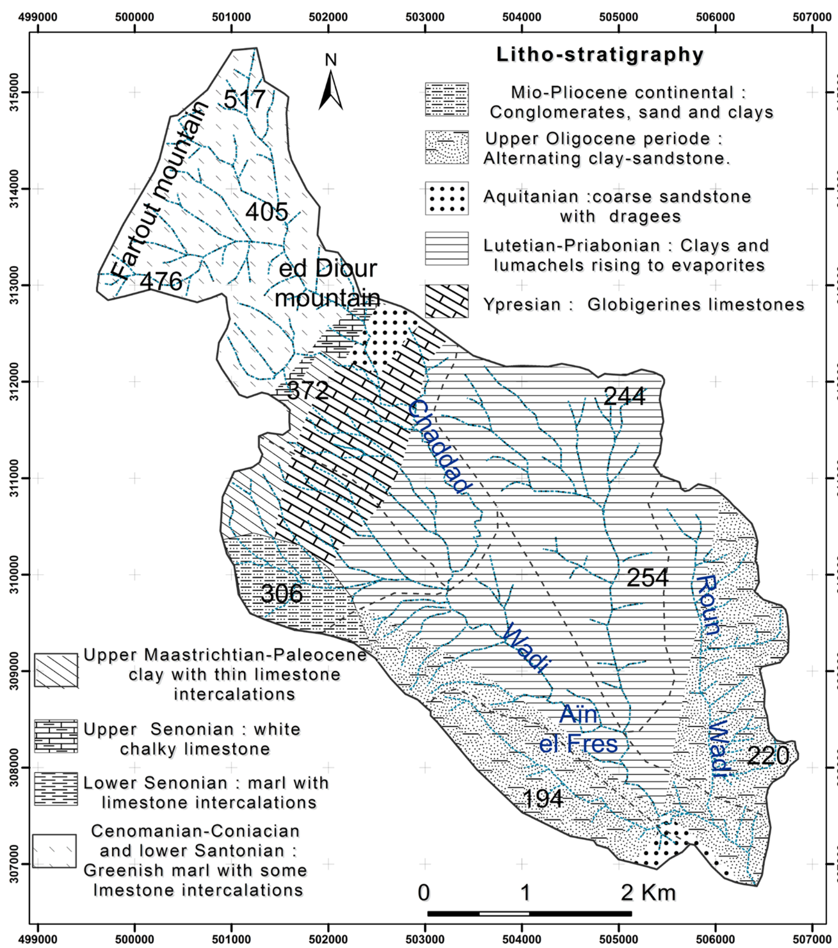

Figure 5. Geological map of Chaddad basin. Source: Geological maps of Jbibina and Fkirine mountain at 1/50,000.

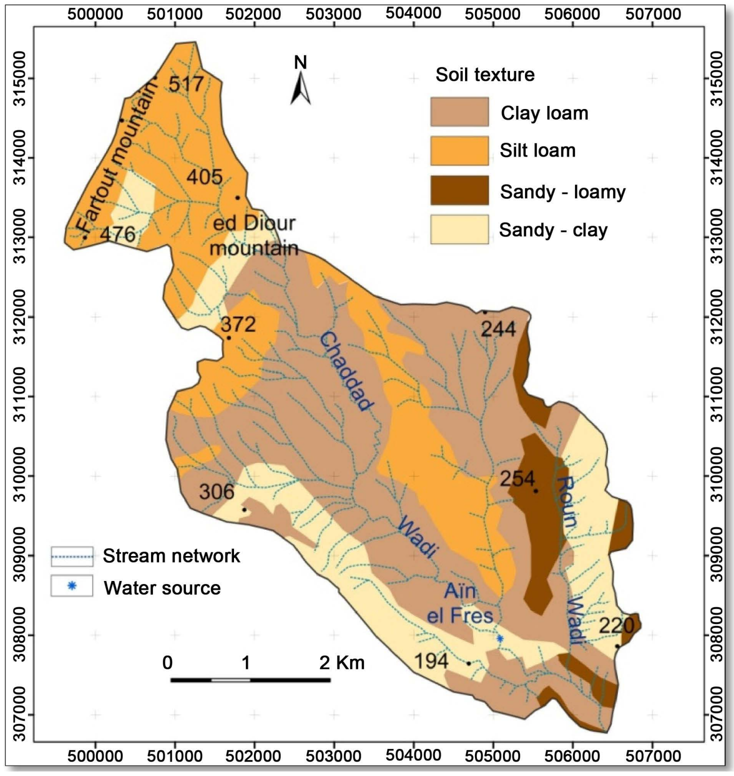

Figure 6. Soil texture repartition in Chaddad wadi. Source: Agricultural maps of Kairouan and Zaghouan, 2004 and results of granulometric analysis.

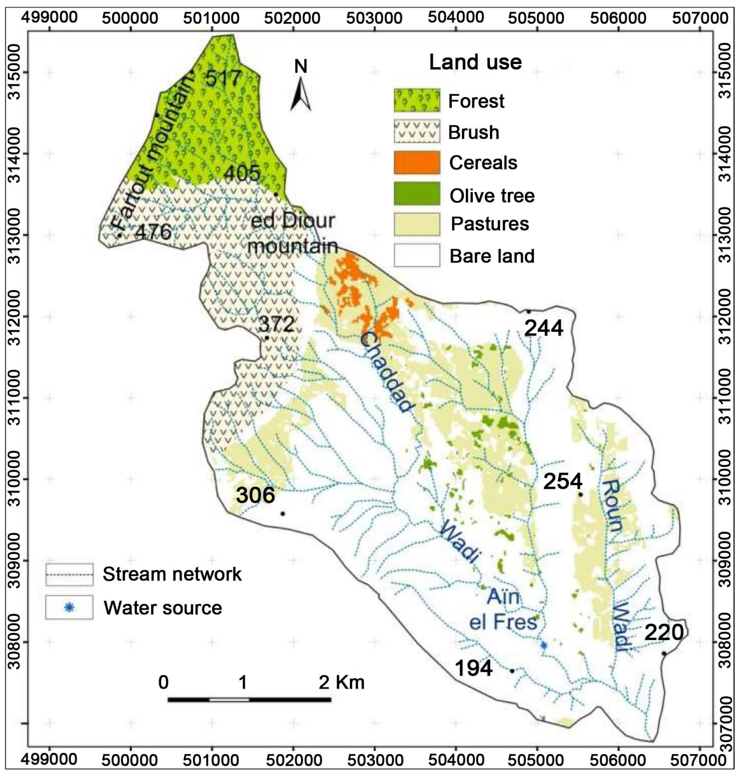

Figure 7. Land use map of wadi Chaddad basin. Source: Google Earth pro 2017 Satellite Images and Governates Agricultural map of Kairouan and Zaghouan, 2004.

the watershed (36.36%) is bare land and rocky escarpments. Given that more than half of the land (51.28%) remains disposed for the aggressiveness of autumnal rains that heavily fall on an extremely dehydrated soil weakened by the opening of numerous desiccation cracks and which can form proliferation zones for the water streaming. In some areas the peasant is at the head of degradation processes. He is responsible for the qualitative and quantitative deterioration of vegetation cover. The phenomenon of steppe formation has become a reality for several decades. Land clearing, overgrazing based on extensive stock farming, trampling of herds, drought, dwindling water reserves in the soil and the formation of the slaking crust are all at the origin of the difficulty of regenerating herbaceous formations. The anti-erosive developments that mark the landscape show an awareness of the scope of the erosive phenomenon but, unfortunately, a lack of good knowledge of the key factors contributing to its spread. For slope works, the mechanical banquettes are practically the most common, if not the only, State intervention techniques. The majority of studies carried out on water erosion in the Tunisian semi-arid field, have highly focused on the State's commitment to this policy concerning the C.E.S. work, largely based on the bulges of banquettes, sometimes without taking into consideration some lithological aspects unfavourable to these works [13] [16] [17] [18].

At the level of the Chaddad wadi watershed, the banquettes have been installed on the average course of the wadi. They only cover 13.98% of its total surface. In contrast, the high drainage density (13.8 km/km^2) and the hydrographic density (161 $drains/km^2$) prove that the erosive dynamics associated with water erosion remarkably remains a spectacular phenomenon.

This very complex situation is far from being limited only to slope and land use, although they are considered as the two major factors. The lithology and the degree of permeability on the one hand and the C.E.S. developments, the slaking index and the rockiness index on the other hand seem to have an effect in this dynamic (**Figure 8**).

3. The Types of Erosion and the Processes That Control the Erosive Dynamics in the Watershed of Chaddad Wadi

1) The Action of Rain Erosion on Slaking Soils

Raindrops are the first step in water erosion. They are of paramount importance if they fall on non-clayey-humic soils, loose and characterized by the absence of the organo-mineral bonds typical of advanced and accomplished pedogenesis. The presence of aggregates of weak cohesion is linked to the lack of sufficient organic substances [19] [20]. It is through the mechanism of "Splash" that the soil clods burst to let the fine particles scatter. On the peripheries of the gushing out zone, fine particles radically move by rewatering to clog the surrounding surfaces [1] [6] [9] [16] [17] [21] [22]. The reliefs associated with this rain process consist in the formation of the slaking crust on the one hand and the appearance of whitish areas on the other, however that sanding seems to be more intense.

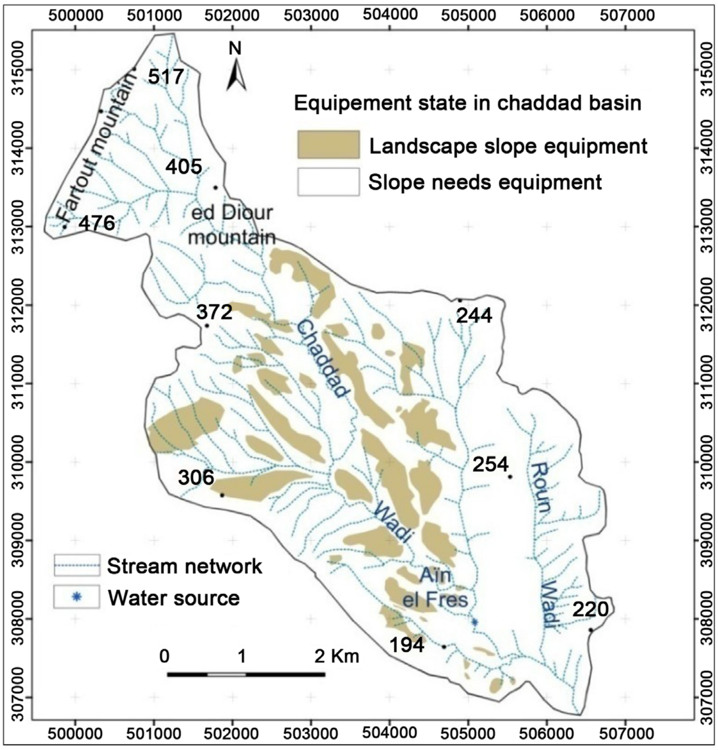

Figure 8. Distribution map of conservation water and soil equipments in wadi Chaddad basin. Source: Google Earth pro 2017 Satellite Images and Governates Agricultural map of Kairouan and Zaghouan, 2004.

The threat related formation of a slaking crust is more important especially if one considers the low degree in the organic material content that did not exceed 3% in most of the analyzed samples. Indeed, the presence of the organic fraction has shown a good structural stability of soils with a sufficiently developed vegetation cover. However, the development of a hard and very dense crust considerably reduces the infiltration, especially when it is associated with very intense autumnal rains. The spaces affected by the slaking will play the role of micro-impluviums and from which a streaming wave of water will be caused, which will trigger the different processes of diffuse erosion starting with furrows and small trenches [2] [4] [14] [15] [23].

2) Erosion Linked to Diffuse Water Streaming

The streaming wave increasingly provides rigorous erosive power in the areas of breached slopes and on convex slopes, but also on the piedmonts and in the erosion plains [15] [23] [24] [25]. The previously mentioned slopes located below the micro-impluviums will experience a selective stripping of their fine elements, more and more accentuated stripping and they will be gradually dissected into furrows and trenches, but also into very ramified ravines, notably, in the Roun wadi sub-watershed and the erosion plains of the average course of the Chaddad wadi.

Taking into consideration our objective of this research, several types of erosion will be excluded, notably gullying with its multiple degrees, as well as undermining and landslide located on the banks, although they are frequently encountered in the Chaddad wadi watershed. Indeed, these most spectacular processes are largely at the origin of soil degradation, but they do not fit with the quantification by the Method of Universal Equation of Loss in Soil. As a result, the focus will be only on the processes whose erosive power does not exceed the soil stratum between 15 and 20 cm in depth.

4. Methodology

1) Definition of the Equation Parameters:

The USLE empirical model that predicts average soil losses caused by sheet erosion [8] [9] [24] [26] [27] [28] [29] was elaborated in 1957 by Wischmeier and Smith. It is based on a multiplicative equation of five parameters and is expressed as follows:

$$Xa(\text{in Tonne/hectare/year}) = LS * R * K * C * P$$

- **The LS-factor index**

It is an index that encompasses the combined effect of the slope length and value. It is very difficult in terms of its application since the slopes in nature are not homogeneous [11] [19]. The spatial repartition of the LS-factor is directly obtained on Arc Gis based on DEM and the slope map by the "Raster Calculator" function (**Figure 9**).

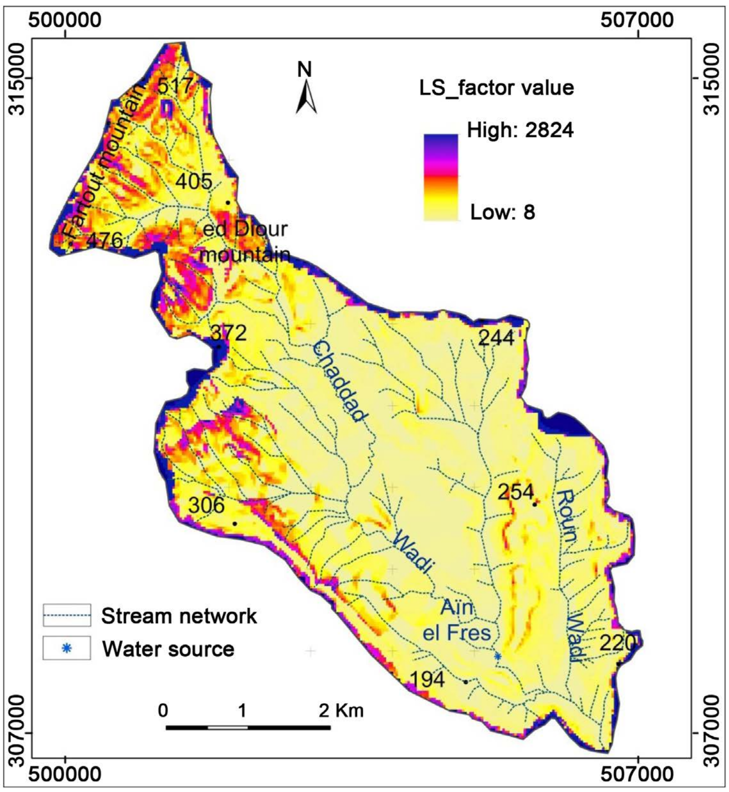

Figure 9. LS factor layer in Chaddad wadi basin. Source: Topographic maps of Jbibina and Fkerine Mountain at 1/50,000 and orthophotos, 20,000.

- **The potential rainfall erosivity index: R-Factor (in $MJ\cdot mm\cdot ha^{-1}\cdot h^{-1}\cdot year^{-1}$)**

To estimate the rainfall aggressiveness index, it was not possible to reckon the intensity of the downpours due to the lack of instantaneous recordings. As a result, the Fournier index—p^2/P and Fournier's modified index expressed through logarithmic language were applied for 5 stations very close to the watershed.

Thanks to a geoprocessing carried out under Arc Gis, the spatial repartition of rainfall erosivity at the watershed level was obtained according to the Fournier formula modified by the application of interpolation (Figure 10). The average annual erosivity index is around 31.25 ($MJ/ha^{-1}/h^{-1}/year^{-1}$). It peaks in its upstream part (37.9) and gradually weakens toward the South-East where the rainfalls become less erosive (25.9).

- **The soil erodibility index: K-Factor ($tonne/ha^{-1}\cdot MJ^{-1}\cdot mm^{-1}\cdot ha\cdot h$)**

This index expresses the vulnerability of the soil where its ability to be eroded by rain and which depends on the physical and chemical characteristics of the soil (granulometry, structural stability, porosity, organic matter content and permeability) [18] [26] [27] [28] [30]. In fact, the granulometric analysis of the samples taken allowed us to know the five necessary parameters of the Wischmeier equation, which is expressed in the following:

$$K = 2.8\times10^{-7}\times M1,14(12-MO)+0.0043(b-2)+0.0033(c-3)$$

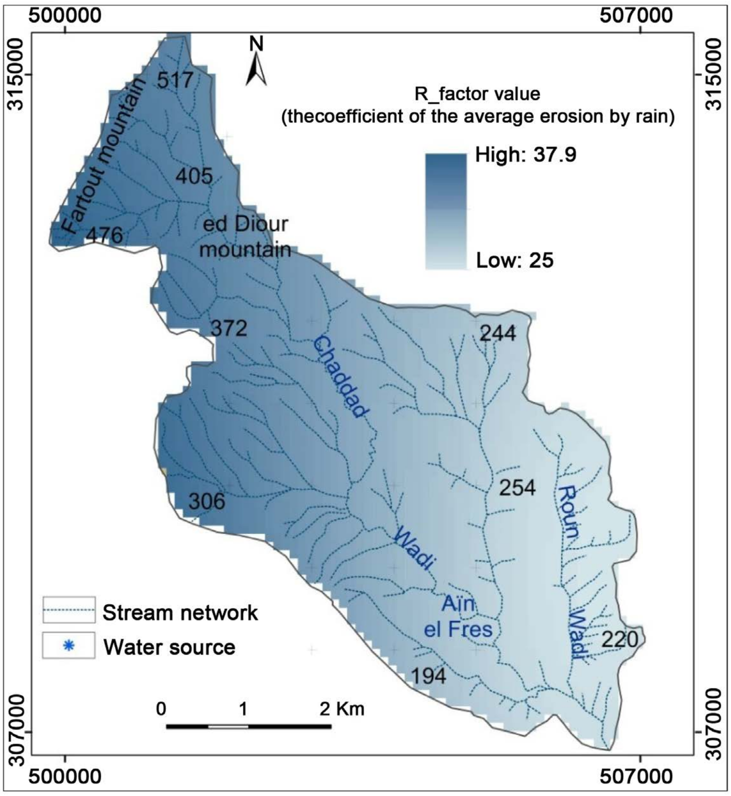

Figure 10. R factor layer in Chaddad wadi basin. **Source:** The pluvial data obtained from National Institute of Meteorology from 1953 to 2017.

The following map highlights the most eroded soil types. The erodibility index ranges from 0.1 for the most sensitive soils to 0.010 for those soils with diminished sensitivity. As a result, the soil having clayey and clayey-alluvial texture are most susceptible to water erosion. Certainly, the erosive potential of the soil is more realized with the proliferation of inclination (value and length) and the aggravation of water streaming (Figure 11).

The Bled Faid Mraima areas, the wadi Roun's sub-watershed, the South-Eastern piedmonts of "Ragoubet" Sidi Salah and the Ain Smara area constitute the center of accelerated morphogenesis controlled by hypodermic outflow to give birth to suffosion tunnels, which with the torrential rains turn into real ravines (Photo 1).

- **The land use index and cultivation practices (C-Factor):** it is an index that encompasses the effects of the natural vegetation cover as well as the effects that cause farming and different cultivation practices [28] [29]. It varies depending on the rate of recovery, the vegetative stage of the plants and the methods of ploughing. The implementation of this index was facilitated by the research of Masson and Cormary [10], who elaborated a classification specific to Tunisia (Figure 12). The C-index varies from 0 in areas with a very unfavourable type of land use for erosion, located in the far North of the watershed that coincides with a young forest, and 1 in areas whose type of land use is more favourable to water erosion and to ravine development. The map below was developed on the basis of this principle.

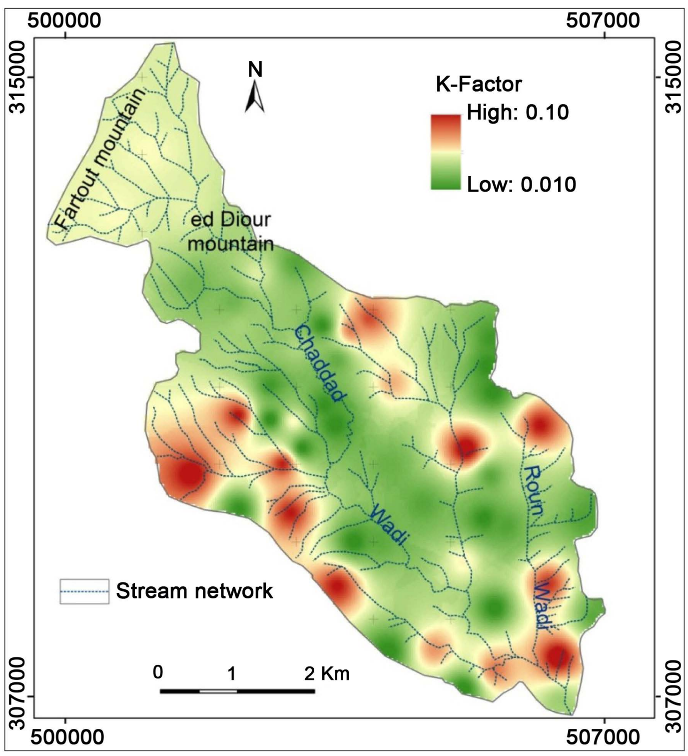

Figure 11. Improved K-factor layer in Chaddad wadi basin. Source: Agricultural maps of Kairouan and Zaghouan, 2004 and results of grain-size analysis.

Photo 1. Holes and tunnels suffusion turn into real ravines. Source: Shooting date, October, 2016.

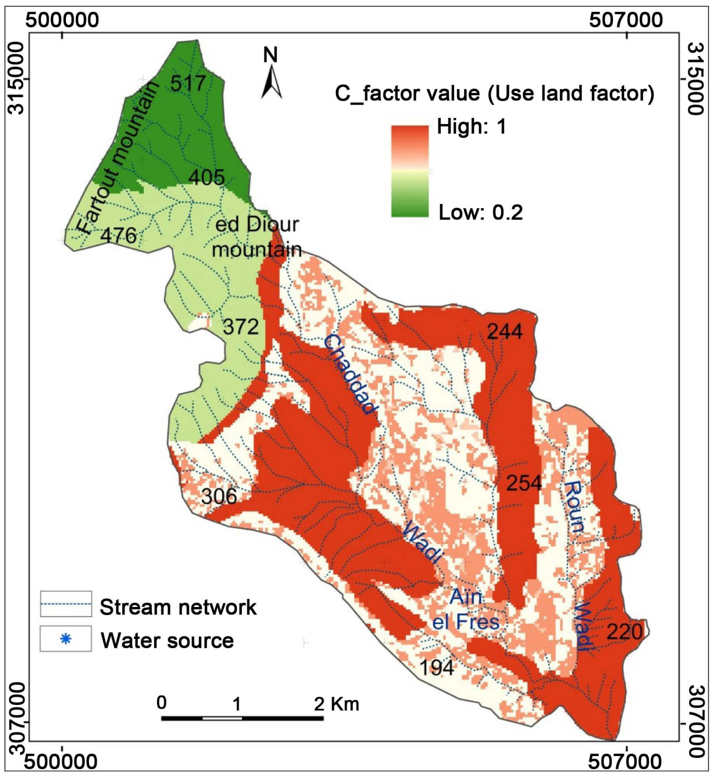

Figure 12. C factor layer in Chaddad wadi basin. Source: Google Earth pro 2017 Satellite Images and Governates Agricultural map of Kairouan and Zaghouan, 2004.

- **The index of conservation and development (P-Factor):** This index allows us to quantitatively estimate the effects of each development and each work on the decrease of soil loss. It is through resorting to the values assigned by Colinet and Zante [31] [32] for the various protection works that the map of the spatial repartition of the P-factor was developed. The index varies from 1 in areas deprived of development such as the upper waters flow of the Chaddad wadi, its downstream flow, notably the corridor of the Roun wadi located further East. It then reaches its lowest level on the average flow of the Chaddad wadi, which represents less than 14% of the watershed total surface and this is linked to the installation of mechanical banquettes. It is appropriate that a precision in this sense be added to better understand the allocation of the P-factor by making a diagnosis regarding the functional state of these banquettes (Figure 13). Some of these are damaged due to the opening of gaps on the one hand and the lack of maintenance by the peasant society on the other.

An evaluation diagnosis should have been executed on the different anti-erosive works [13] [17] [18] [33]. Thus, in the absence of an inspection of entry, the modelling obtained from this factor will have less accuracy. To overcome some of the limitations that are associated with the application of the USLE equation outside its designed framework, it was recommended that the approach be perfected by adjusting the formula with local indexes that take into account different local factors which are in effect.

2) Adjustment of the USLE Equation to the Local Specificities

Initially, the USLE empirical model was set based on observations and measures executed over years in multiple plots in the United States, so its application in another different physical framework necessarily requires the integration of other local factors that affect the speed and the modalities of water erosion. The adjustment of the equation to the local specificities of the Tunisian semi-arid field is essentially based on the introduction of two adjustment parameters: the rockiness index (Figure 14 and Figure 15) and the soil slaking index (Figure 16).

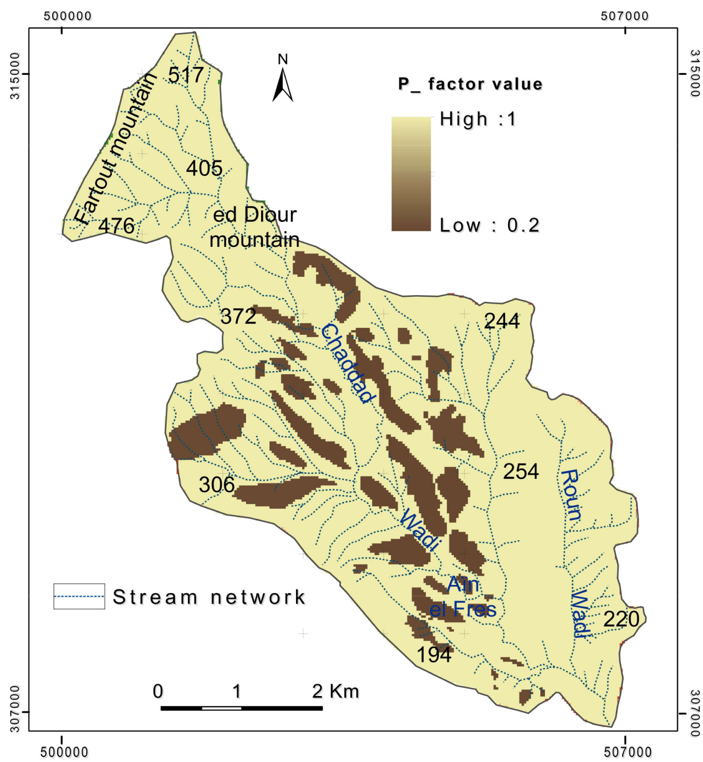

Figure 13. P factor layer in Chaddad wadi basin. Source: Google Earth pro 2017 Satellite Images and Governates Agricultural map of Kairouan and Zaghouan, 2004.

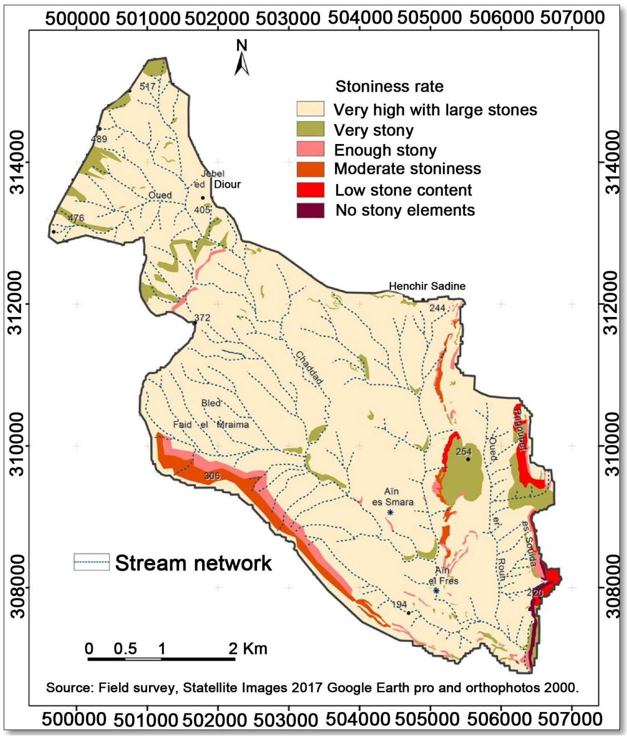

Figure 14. Distribution map of stones and rocks throughout the Chaddad basin. Source: Google Earth pro 2017 Satellite Images and Governates Agricultural map of Kairouan and Zaghouan, 2004.

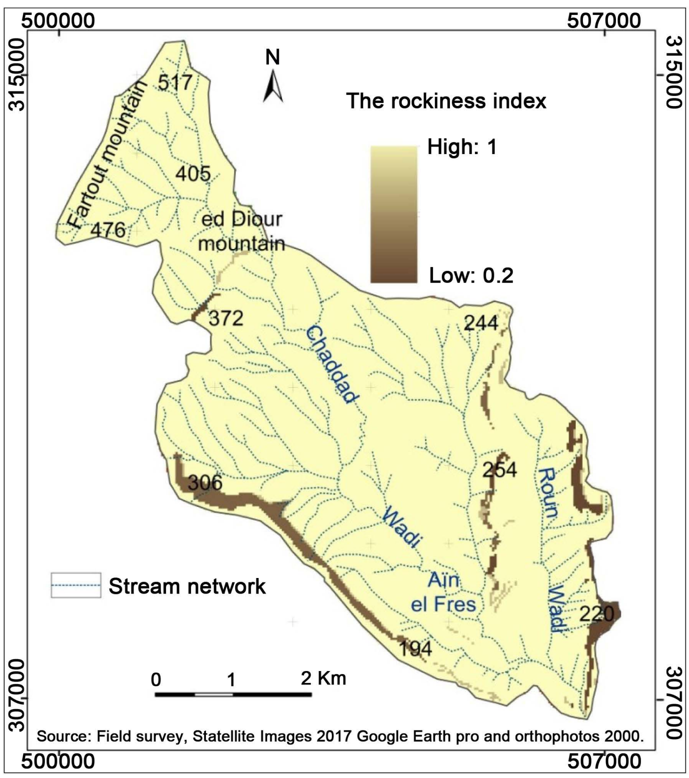

Figure 15. Rockiness index layer of Wadi Chaddad basin. Source: Google Earth pro 2017 Satellite Images and Governates Agricultural map of Kairouan and Zaghouan, 2004.

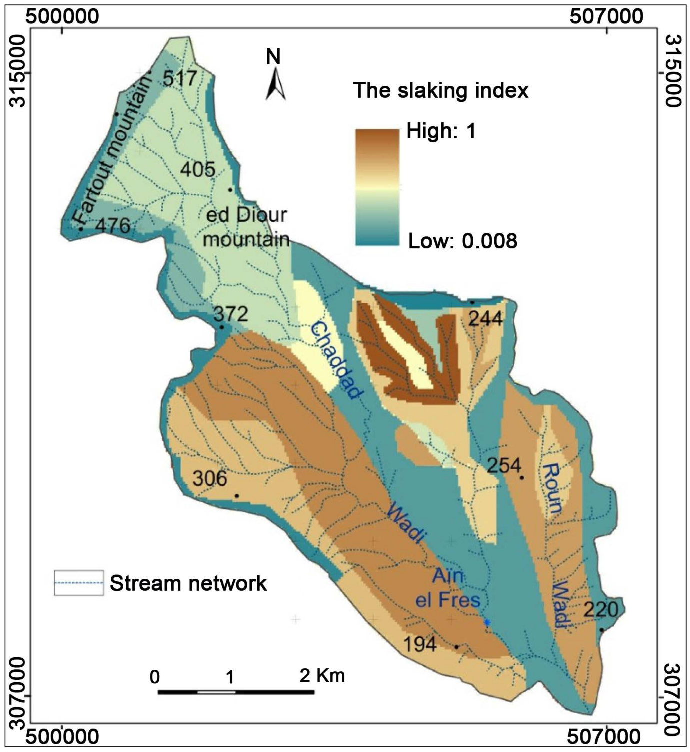

Figure 16. Distribution map of soil slaking index throughout the Chaddad basin. Source: Agricultural maps of Kairouan and Zaghouan, 2004 and results of grain-size analysis.

In this research, however, some precision in some concepts will be necessary not to confuse rugosity with rockiness. In fact, the term rugosity is more general and broader. It depends on the soil clods (structure), its work, its residues, but also its gradient between the upper part of the sedimentary crust and the bottom of the puddles in the case of a slaking soil. Thus, rugosity also refers to and encompasses all factors related to the state of the surface (linked to use, the impact of downpours on soil structure, trampling of cattle and the density caused by agricultural machinery).

Therefore, it would be more appropriate, in this case, to use the concept of rockiness (pierosity) which will enable us to estimate the interception of water streaming by pebbles and boulders scattered on the impluviums. This choice is justified by the fact that the study on rugosity is of extreme complex and requires a diagnosis of the very meticulous condition of the surface based on several fieldworks carried out during different seasons.

The integration of two parameters (rockiness and sedimentary crust) showed more performance when applying the equation. The result was improved by first comparing the losses obtained for the results of losses issued from the implementation of the USLE equation without adjustment.

Then, a second comparison was possible with the losses obtained from the isotopic analysis conducted on three samples also possible with the modelling results in the El Ogla watershed and its tributary collected from three different sites of the Chaddad wadi watershed.

The comparison East of el Mssine wadi, roughly located in the same bioclimatic semi-arid field. Indeed, the South-East and South-West slopes are the most covered by debris sheets. They coincide with the front of the cretes and their sandstone backs.

Due to the inclination of Oligocene-Miocene sandstone on the one hand, their low resistance and poor consolidation on the other, these outcrops are rapidly dislocated into detached blocks of heterometric size [19] [34]. Further upstream the surface becomes marly-calcareous bearing in mind that the chalky soil of the Ypresian forms a structural sharp rise quite resistant, thick and less favorable to the processes of weathering. This explains the small stretches area of debris slopes supposed to promote a definite protection against the concentration of water streaming in the northwestern part (**Figure 14**).

As for the soil slaking, it appears very difficult to assess or even accurately demarcate the slaking soils in the Chaddad wadi watershed in so far as the sampling that was followed for the granulometric analyses was not thorough. But also, a more significant fieldwork was not performed. As a result, it has been significantly useful to jointly leverage the results of the available analyses and the nature of the underlying parenting materials in order to further refine our database for the development of the susceptibility map of the watershed to soil slaking (**Figure 16**).

Given that the PH-index, as being an amplifier parameter of soil slaking, was not included in this executed modelling on the Chaddad wadi watershed, due to the lack of the necessary measures. Subsequently, it is through the generalization of the reckoning results that we were able to obtain the spatial repartition of the following homogeneous units (**Figure 16**). Once all these strata of the different factors were finalized, a multiplication was carried out under Arc Gis. It was possible through geoprocessing to insert the Wischmeier formula, including the two corrective indexes to obtain the soil loss map that requires a thorough interpretation to determine the effect of each factor in the current soil degradation.

5. Results and Discussion

1) Estimated Rate of the Soil Loss

The specific loss of soil is about 39 t/ha/year. It is quite considerable, but highly variable between seasons, depending on the frequency and intensity of the downpours. At the level of the Chaddad wadi watershed, the loss varies from 0 in the least sensitive areas to 80 t/ha/year in the intensely eroded areas (**Figure 17**).

Based on the modelling results, 5.9% of the watershed's soils show losses of more than 40 T/ha/year. The upstream part located in the North constitutes the center of the highest losses, although it has the densest and most developed natural vegetation cover, formed by Aleppo pines and other associated species. In these areas, soil degradation takes on a dimension in connection with nature particularly related to the slope, the permeability and to the morphometric conditions. In the downstream part, the loss becomes more and more an issue of

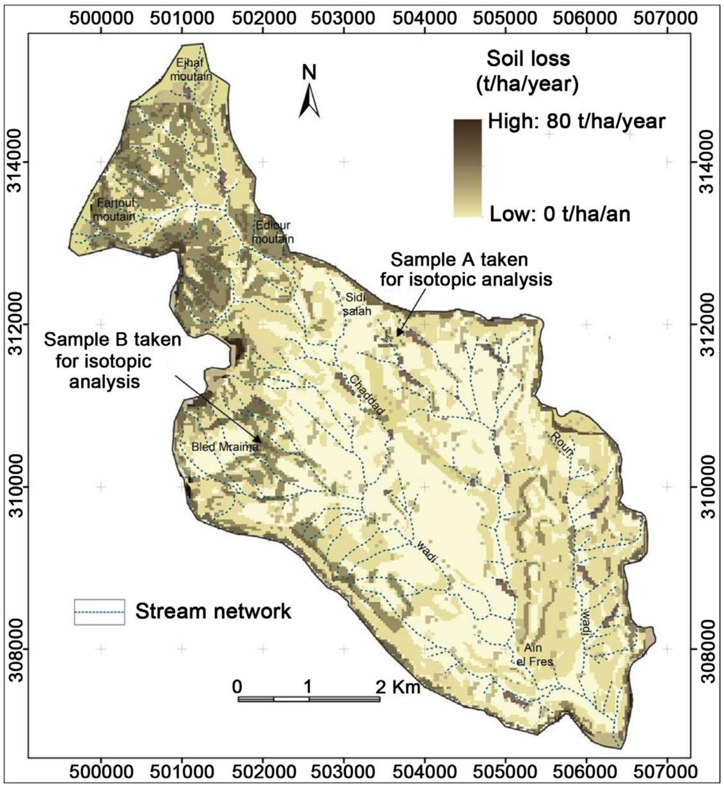

Figure 17. Amount of adjusted soil loss in study area by application USLE model, soil slaking index and rockiness index.

human concern, tightly linked to land use, without neglecting the effect of lithology and the degree of the slaking crust development.

The whole downstream part is completely devoid of its natural vegetation cover, even in the riparian field, the result of vegetation clearing executed during the colonial period, but also due to extensive cattle raising. Soil loss is less noticeable on reverse sides and interfluves. It does not exceed 2 t/ha/year, considering that it can reach 5 t/ha/year only on the slopes that are under cultivation. This lowest loss rate concerns 33% of the lands of the Chaddad wadi watershed, while the average losses ranging from 5 to 20 t/ha/year concerns 36% of the total area and the 24.1% of the land has a loss in the range of 20 to 40 t/ha/year.

In fact, the results deriving from the modelling show a considerable erosive potential at the level of the Chaddad wadi watershed (Figure 17). The situation is all the more serious when one considers the impact of the linear erosion, the undermining and that related to landslide and to suffosion. In contrast, the results are still to be discussed. The master piece of the USLE equation is the spatial quantification of soil losses to specify the emitting sectors.

The key challenge of this model is to exceed its structural limits linked first to its total independence of diffuse water streaming, but also to its insufficiency in determining the weight of the different factors and their intrinsic interactions. The main drawback of this equation is that it does not consider the interactions between the factors. It is only presented in the form of a product and "*calls out* *factors by their statistical weight without taking into consideration their causative liaison*" [33] and their temporal variability.

2) The Weight of Different Factors in Soil Degradation

Having obtained a quantitative estimation of soil loss and the repartition of erosive risk, it was recommended to know the intrinsic relationships between the different factors and indexes in order to determine the effect of each on the current erosive dynamics controlled by diffuse water streaming. Despite the complexity of the intervening factors, it was possible to apply a key component analysis. This factorial analysis enabled us to pinpoint the factors that manifest themselves in a combined way. The most important correlation is the LS-factor and the slaking index (0.846). The latter is positively correlated with the rain erosivity factor (0.833). The morphometric indexes are also well correlated with the rain erosivity and the soil erodibility. As for the adjustment factor of the rockiness, it is only correlated with the development P-factor (0.776). The loss of soil has decreased on the slopes covered with pebbles and debris even in the absence of developments (**Table 3**).

3) Discussion

The estimation of soil losses always remains an ambitious goal, but at the same time a fact that escapes any precise quantification due to the multiple facets of erosion and its high spatial-temporal variability. As a result, the losses

Table 3. Correlation between the different measurable factors in the Chaddad watershed.

indexes	Slaking	Stoniness	Density of drainage	Compactness index	Length of equivalent rectangle	(C) Occupation	(K) Soilerodibility	(P) Factor	(R) Rainfall erosivity	(LS) factor
Slaking	1.000	0.319	−0.155	−0.004	−0.699	−0.183	−0.603	0.544	0.833	0.846
Stoniness	0.319	1.000	−0.064	0.489	−0.759	−0.925	0.233	0.776	0.230	−0.023
Density of drainage	−0.155	−0.064	1.000	−0.037	0.337	0.146	0.306	−0.441	−0.396	−0.231
Compactness index	−0.004	0.489	−0.037	1.000	−0.605	−0.689	0.759	0.610	0.125	−0.452
Length of equivalent rectangle	−0.699	−0.759	0.337	−0.605	1.000	0.732	−0.004	−0.963	−0.729	−0.290
(C) Occupation	−0.183	−0.925	0.146	−0.689	0.732	1.000	−0.437	−0.731	−0.079	0.143
(K) Soilerodibility	−0.603	0.233	0.306	0.759	−0.004	−0.437	1.000	0.071	−0.487	−0.879
(P) Factor	0.544	0.776	−0.441	0.610	−0.963	−0.731	0.071	1.000	0.700	0.124
(R) Rainfall erosivity	0.833	0.230	−0.396	0.125	−0.729	−0.079	−0.487	0.700	1.000	0.577
(LS) factor	0.846	−0.023	−0.231	−0.452	−0.290	0.143	−0.879	0.124	0.577	1.000

obtained in the present research remain preliminary, given the difficulty of having a total quantitative assessment of soil loss that takes into consideration other erosion processes (gullying, undermining, landsliding, etc.). Despite this disadvantage and the limitations that are associated with the present modelling [9] [19] [26] [27], the advantages are not entirely absent. In spite of a few points of inadequacy, the advantage of this study is that it is being added to other efforts invested within the quantification framework of the soil losses to provide a new explanation to the problem of soil degradation. A validation of the results is obtained through a comparison of those attained by means of the isotopic method, at least in three previously selected sectors (Table 4).

In the same validation framework, the maximum loss obtained could have been less important if the input parameters adjustment was not executed. If the two indexes of soil slaking and rockiness have not been taken into consideration, the maximum loss will not exceed 57 t/ha/year, although the spatial repartition remains roughly the same (Figure 18 and Table 4).

However, the validation was also possible by comparing losses in other watersheds such as those of el Ogla wadi [31], the watershed of Jannet wadi [35], the Sebkhat el Moknine watershed in the Central Sahel, [24] and the watershed of el Mssine wadi [19].

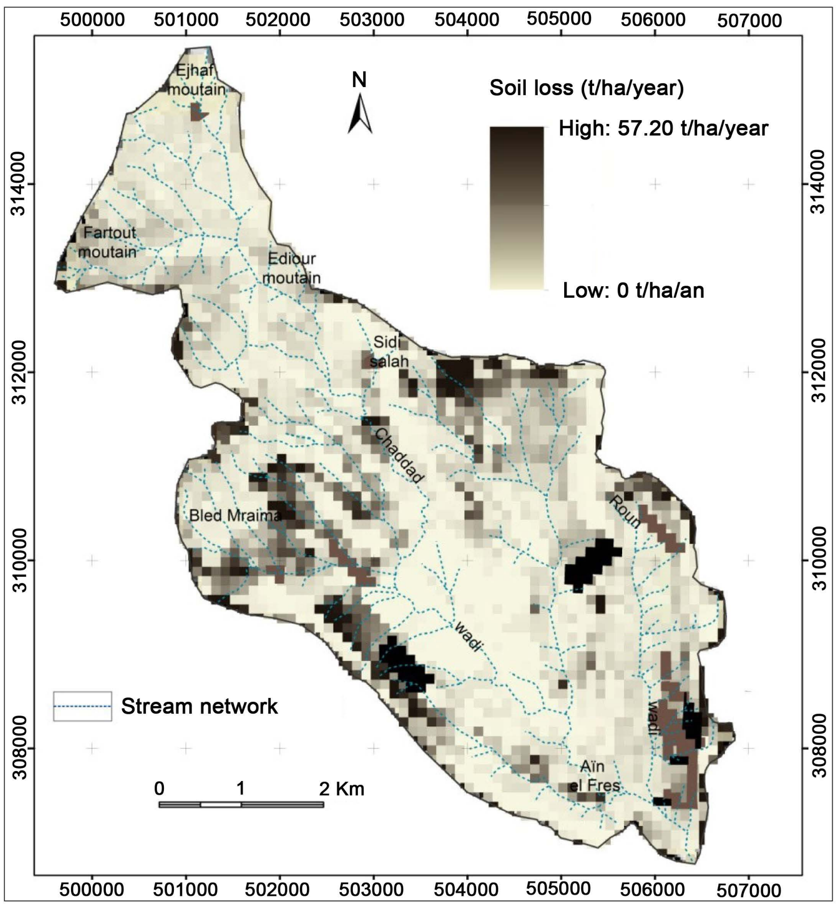

Figure 18. Amount of the unadjusted soil loss in study area by application USLE model.

Table 4. Validation of results through a comparison of sol losses between the three models (USLE, adjusted universal equation and isotopic method).

	Soil loss from unadjusted USLE model	Soil loss from adjusted USLE model	Soil loss from isotopic analysis	Observations
Sample A	28.5 t/ha/year	12.1 - 20 t/ha/year	18.9 t/ha/year	In both sampling areas, the loss of soil obtained from USLE equation without adjustment is largely overestimated compared to the results of isotopic analysis.
Sample B	57.1 t/ha/year	49.5 t/ha/year	51 t/ha/year	

6. Conclusions

At the end of this study on the quantitative estimation of water erosion, it is proving that the Chaddad wadi watershed hides a significant erosive potential. An erosive crisis has occurred, despite the efforts made by the government in terms of the slopes. This has prompted us to anticipate a new conception of soils and water conservation strategies more adjustable to the recent socio-economic changes that take into account the real tendency towards steppe formation. Such a situation could be irreversible in several areas with specific lithological conditions: soils of low consistency and very favorable to high-risk slaking. In other respects, the purely technical intervention did not have any remarkable stimulating and beneficial impacts and it could not put an end to the dysfunctioning of the ecosystem in its totality. The main objective of this study is to find an improved adaptation of the USLE equation to the local conditions in order to obtain a quantitative estimation of soil losses closer to reality. It owes its importance to the fact that it has successfully integrated the two parameters concerning the rockiness and soil slaking indexes as two adjustment factors that have the definite impact on water streaming and the erosive dynamics.

As for comparing the results of quantifying soil losses with other watersheds, we have chosen the example of el Mssine wadi located in the medium semi-arid bioclimatic layer. The estimation of maximum soil loss without adjustment to the equation is around 62 tonnes/hectare/year compared to 57.20 tonnes/hectare/year in the Chaddad wadi watershed. In prospect, it would be desirable to anticipate the validation of the results in the same watershed through the application of other experimental methods that start from field measurements and comprehensive sampling.

The methods used (empirical and experimental) remain numerous throughout the world. We have cited the one based on the simulation of rains at the plot level and that based on the isotopic analyses. Both methods yielded considerable quantification results at all levels (annual average, seasonal average and even at the level of the downpours). Based on the different studies that dealt with the qualitative and quantitative soil degradation, it would be possible to implement participatory projects of interest that will be sustained, both by the government and the local peasant structures. The establishment of surveillance stations will create an updatable database that can meet the requirements of soil loss modelling and both the annual and seasonal follow-up of the erosive dynamics, notably in a context marked by the ongoing climatic and the socio-economic changes.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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