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Impact of Land Use and Vegetation Cover on Risks of Erosion in the Ourika Watershed (Morocco)

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ABSTRACT: *Ourika watershed is located in mid-western Morocco, in the northwest of the High Atlas. This watershed, characterized by dramatic topography, sparse vegetative cover and friable substrates, is under increasing human pressure amplified by a variable and changing climate.*
The objective of this work was to map the risks of water erosion in the watershed using the RUSLE and GIS, and highlight, by mapping land uses, the role of land use and vegetation cover in the regulation of risks of erosion. The findings showed that the Ourika watershed was subject to strong climatic aggressiveness ranging from 55 to 101 MJ.mm/ha.h. Soil erodibility value ranged from 0.15 to 0.48 t.ha.h/ha.MJ.mm. Topographic factor ranged from 0 to 95. The vegetation cover factor was greater than 0.5 for 73% of the watershed area. The average soil loss obtained in the watershed was 380 t/ha/year. The results indicated that 48% of the watershed area is subject to soil loss between 50-400 t/ha/year, and 30% of the watershed area between 400 and 1000 t/ha/year. Soil loss below the tolerance level (<7 t/ha/year) represented only 4% of the area. These results demonstrated the significance of erosion in the Ourika watershed. Croplands, clear forests, shrubland and non-forest empty spaces were subject to very high risk of erosion. By contrast, dense forests, moderately dense forests and arboriculture not mixed with cereal growing, protected the soil against erosion, improved physical and chemical soil characteristics, facilitated the infiltration of water into the soil and limited runoff and the risk of erosion.

Keywords: *Water erosion, RUSLE, GIS, Ourika watershed, Morocco.*

I. INTRODUCTION

Land use and land cover are important factors in soil erosion [1]. Several authors showed that plant cover exponentially reduces both runoff and soil erosion [2-3]. Thus, in the Mediterranean region, inappropriate land use accelerates the risks of water erosion and land degradation [4]. Land uses that are manifested by inappropriate agricultural practices, deforestation, overgrazing etc. are the main causes of soil erosion [1, 5-7]. Reducing the plant cover accelerates erosion [8.] Water erosion affects soil quality by facilitating land degradation by loss organic matter-rich top soil, leading to the loss of soil productivity and land degradation.

The High Atlas is the highest mountain range in Morocco. It is divided into a multitude of watersheds that are a real water tower for the neighboring arid plains [9]. However, the mountainous areas of the High Atlas are subject to high stress with its natural environment being particularly sensitive to human activities [10]. These constraints include a particularly dramatic topography, land subject to heavy erosion, a harsh and brutal climate, sparse vegetation and an increasingly growing human impact.

The watershed of the Ourika is part of High Atlas and perfectly illustrates the problem of degradation of natural resources and raises many questions about the rationality of the management of its water and soil resources. This watershed, subject to both natural constraints and a growing human impact, is highly vulnerable to water erosion [10].

Several models are used for risk assessment of erosion depending on the research's objectives. Researchers in many countries continuously improve these models by adapting them to local conditions [11]. The RUSLE model [12] is widely used in the Mediterranean region. It is an empirical model based on the USLE model [13]. The use of remote sensing and geographic information system has made possible the efficient estimation and spatial distribution of soil erosion on large scales ([14-17]). The idea is to integrate the factors in the empirical model, RUSLE, into a geographic information system. Similarly, advances in remote sensing and geographic information system have greatly facilitated the mapping of land uses.

The objective of this work was to map land uses and the risk of erosion in the Ourika watershed, and to highlight the role of land use and vegetation cover in regulating risks of erosion. The mapping of erosion factors and identifying areas of vulnerability to soil erosion, would help assess the risk of erosion for the different land uses and vegetation cover densities in order to develop measures and conservation of water and soil.

II. MATERIALS AND METHODS

2.1. Presentation of the study area

The Ourika watershed is located in the High Atlas and is a sub-watershed of the large Tensift basin (Figure 1).

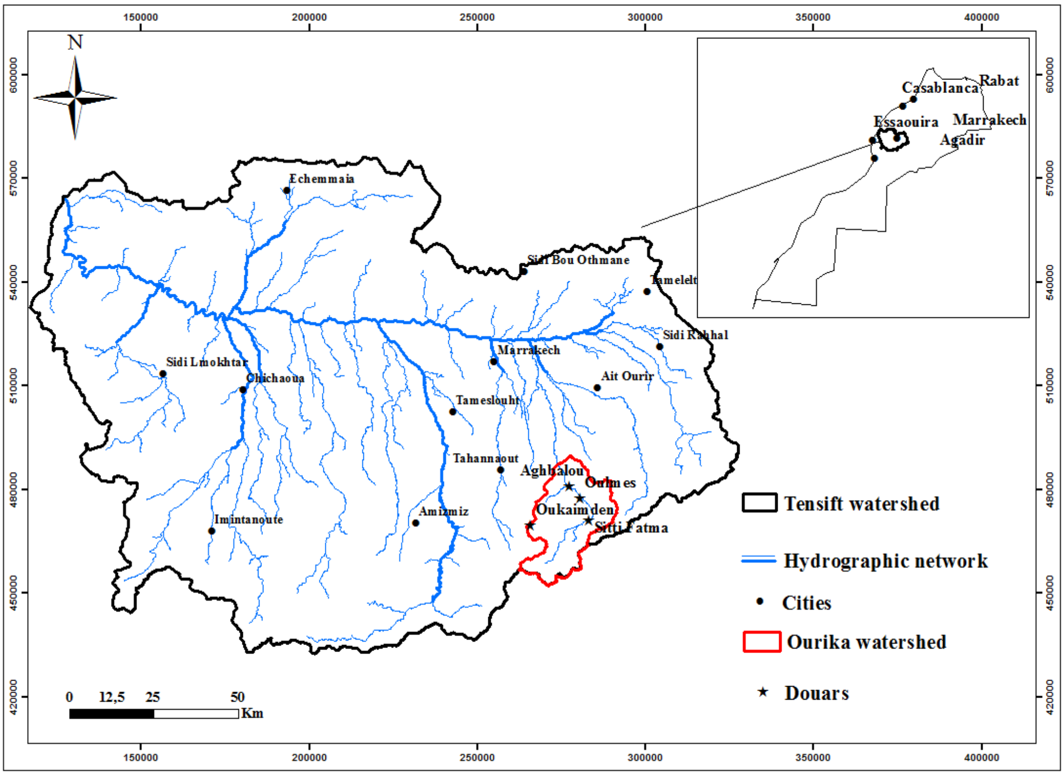

Figure 1. Location of the Ourika watershed

It covers an area of 576 km² and is located between latitudes 31°N and 31°21'N, and longitude 7°30'W and 7°60 'W. It is limited to the south by the upper Oued Souss watershed, to the north by the Haouz plain, to the east by the Zat watershed and to west by the Rheraya watershed. The slopes of the watershed are generally steep, amplifying runoff and erosion. Geologically, the watershed presents two types of facies [18]:

- A hard bedrock (igneous or metamorphic rock) located upstream, representing approximately 61% of the watershed with presence of pink granite, Toubkal andesite and migmatite.
- A soft to moderately soft substrate located at lower elevations, composed of Permo-Triassic and Quaternary deposits, representing approximately 39% of the watershed. These include friable sandstone and red marl, conglomerates and massive red sandstones, shale and sandstone flysch. Sandstone and red marl account for 31% of the watershed while shale and sandstone flysch represent only 8%.

The ravines of the upstream traverse a hard bedrock characterized mainly by low sediment yield. The waters are clear and uncharged during floods. Conversely, ravines in the central part of the watershed are very vulnerable to erosion and are characterized by sediment and fluid loads.

The climate of the watershed is characterized by high spatial and temporal variability. Annual precipitation averages 500 mm. This increases with altitude and is of the order of 400 mm in the foothills while exceeding 700 mm on the high peaks of the watershed. Average temperatures range from 21.5 to 32°C for and 4 to 5.7 ° C for maxima and minima respectively. July and August are the hottest months of the year, while December and January are the coldest. The temperature varies between 48.2°C and -7.2°C, with an average of 27.8 ° C.

Tree cover in the watershed is represented by the Mediterranean and Mesomediterranean and Thermomediterranean stages. For the most part, it is under holm oak, juniper and cedar forests [19].

2.2. Methodology

2.2.1. Mapping of land uses

The land use map was obtained following a supervised classification by maximum likelihood of a Landsat image 8 (14 June 2015)of the watershed and based on the vegetation map prepared by Ouhammou for the Ourika watershed [19]. The vegetation index, NDVI, was used to distinguish different density classes for forest vegetation. Croplands were digitized from the Google Earth images of adequate resolutions.

2.2.2. Mapping of risks of erosion

The most widely used models for quantifying soil loss are the USLE and the revised RUSLE models due to their ease of implementation and compatibility with geographic information systems [20-23]. The RUSLE model has been widely used in both agricultural and forest environments for the prediction and spatial distribution of mean annual soil loss by integrating the various erosion factors [12-13].
The equation is expressed by the equation:

$$A=R*K*LS*C*P$$

Where:
A =soil loss rate (t/ha/year)
R = rainfall erosivity (MJ.mm/ ha.h.an)
K = soil erodibility (t.h/ha. MJ.mm)
LS = topographic factor (L in m, S in %),
C = plant cover factor
P = agricultural practices factor

Rainfall erosivity was determined using Rango & Arnoldus's formula [24] applied to 5 stations in the Ourika watershed over a period of 20 years (1995-2015).

$$\text{Log } R= 1.74 * \text{Log} \sum (P_i^2/P) + 1.29$$

Where:
Pi: monthly rainfall in mm
P: annual rainfall in mm.

Experiments on different soil types has enabled the development of a statistical equation used calculate soil erodibility, K [13]:

$$K = 1/100 * [2.1 * M^{1.14} * 10^{-4} (12 - A) + 3.25 (B -2) + 2.5 (C - 3)]$$

Where:
M = (% fine sandy +% loam) * (100 -% clay)
A = percentage of organic matter
B = permeability code
C = structure code

Due to the lack of a soil map for the area, the geological substrates and land use maps were superimposed to identify homogeneous units. Soil samples were collected from these units (17 samples) and analyzed in the laboratory to determine soil erodibility factor, K.

The LS factor was calculated using LS-TOOL developed by Zhang et al. [25]. The methodology for calculating the LS factor is applied to each pixel of the digital elevation model. Calculating L is based on the equation developed by Desmet and Govers [26]. As of S, its calculation is based on the equation developed by Wischmeier and Smith [13], which was amended in the RUSLE model for better representation of the degree of slope inclination [27].

NDVI, an indicator of vegetation's health was used [28]. The formula used for determining C [29-30] is as follows:

$$C= \exp [-(\alpha NDVI/(\beta-NDVI))]$$

Where α and β are parameters without units that determine the shape of the curve connecting NDVI to C. This equation has been proven to be more accurate than a linear relation [31]. These authors attributed values 2 and 1 to α and βrespectively.

Agricultural practices such as contour in alternating strips or terraces, ridging etc., are effective in soil conservation. P values were estimated based on slope [32].

III. RESULTS AND DISCUSSION

3.1. Mapping of land cover

The mapping of land cover in the Ourika watershed revealed that 48% of the watershed was represented by non-forest empty spaces, 24% by woodland, 11% by moderately dense forests, 9% by scrubland, 7% by croplands and 1% by dense forests (Table 1 and Figure 2). Non-forest empty spaces were mainly under thorny xerophytes primarily occupying part of the watershed's upstream. The forests consisted of holm oak, cedar and juniper species which were mostly degraded and sparse (24%), with 11% representing moderately preserved forests(11%)and 1% those in healthy condition. The scrublands (9%) were represented by rangeland and very degraded forests. Croplands (7%) were located mainly along the Wadi and on terraces installed under slopes.

Table 1. Area and proportion of different land uses in the Ourika watershed

Land use	Area (ha)	Percentage
Farmlands	3751	7
Open forest	13944	24
Moderately dense forest	6604	11
Dense forest	432	1
Shrubland	5014	9
Non-forest area (empty space)	27854	48
Total	57600	100

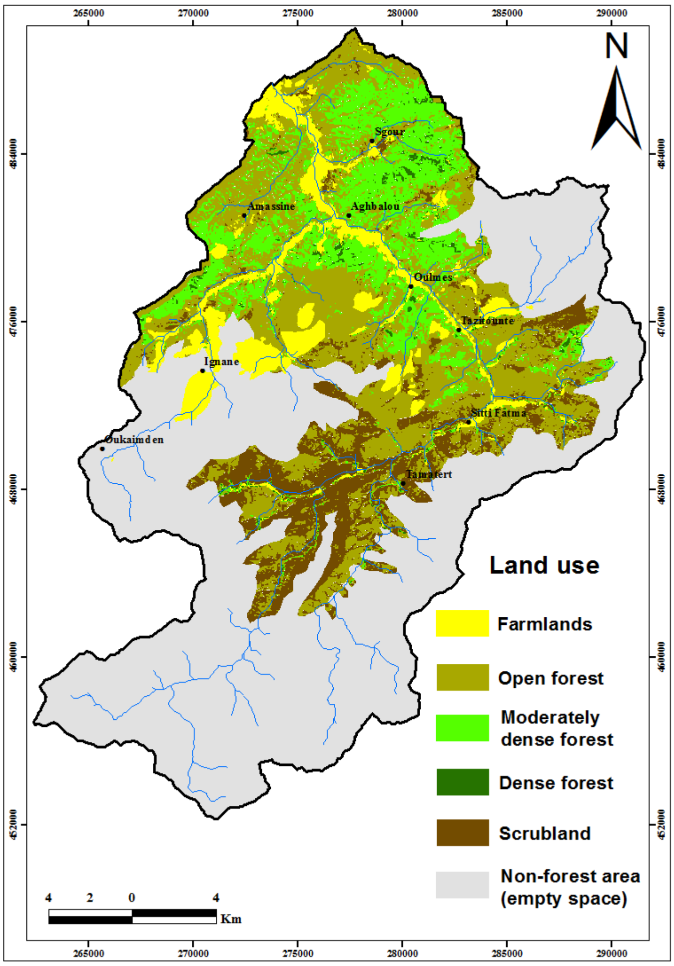

Figure 2. Land use map of the Ourika watershed

3.2. Mapping of risks of erosion

To estimate soil loss in the Ourika watershed, the RUSLE model was used. The various factors in the model were estimated and spatialized in a GIS environment, and the combination of these factors resulted in the watershed's erosion risk map.

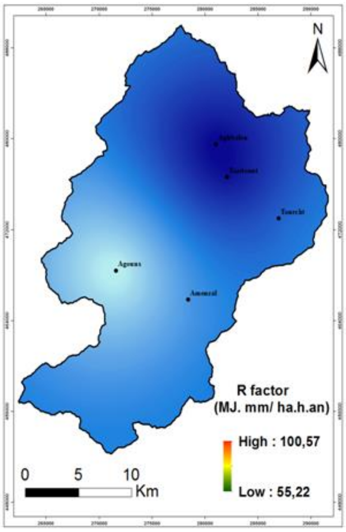

Figure 3. R factor map

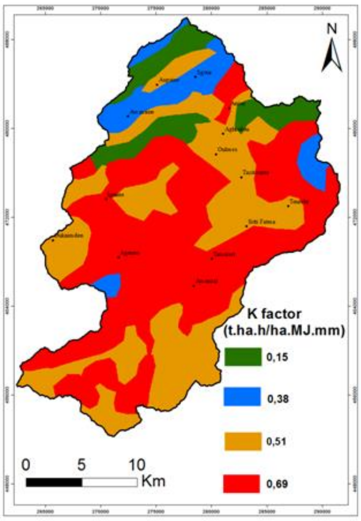

Figure 4. K factor map

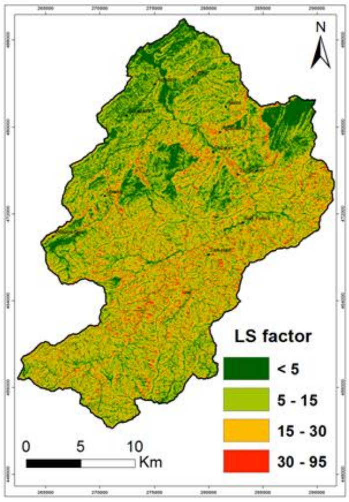

Figure 5. C factor map

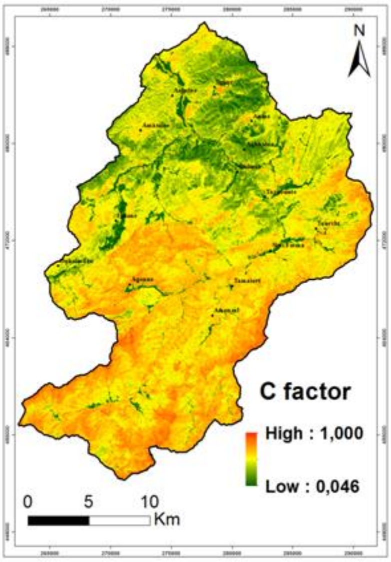

Figure 6. C factor map

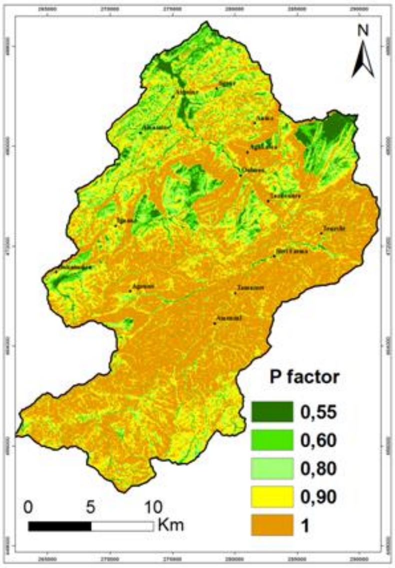

Figure 7. P factor map

Rainfall erosivity values in the Ourika watershed ranged from 55 to 100 t.ha.h/ha.MJ.mm (Figure 3). These R values exceeding 50 t.ha.h/ha.MJ.mm indicate that the entire watershed is subject to a high climatic aggressiveness. On the other hand, the K factor ranged from 0.15 t.ha.h/ha.MJ.mm for the most resistant soils (to erosion) to 0.69 t.ha.h/ha.MJ.mm for the least resistant soil (Figure 4). The watershed's soils are of high sensitivity to erosion in the sense that more than 83% of the watershed presented an erodibility index, K, greater than 0.50 t.ha.h/ha.MJ.mm. The LS index considered low (between 0 and 5) represented only 25% of the watershed area (Figure 5). The results showed that 83% of the watershed area had a very low plant cover with only 13% of the area being well protected with C < 0.5 (Figure 6). This could be explained by the predominance of non-forest empty spaces, clear forests, degraded rangelands and cultivated lands that are considered highly susceptible to erosion [10]. Farming techniques such as contour crops in alternating strips or terraces, mounding and ridging are effective soil conservation practices. Low and moderate P values correspond to areas of low to moderate slope with values ranging between 0.55 and 0.6 for low-slope areas to 0.8 to 1 for areas with higher slopes Figure7). 50% of the watershed area presented P value equal to 1.

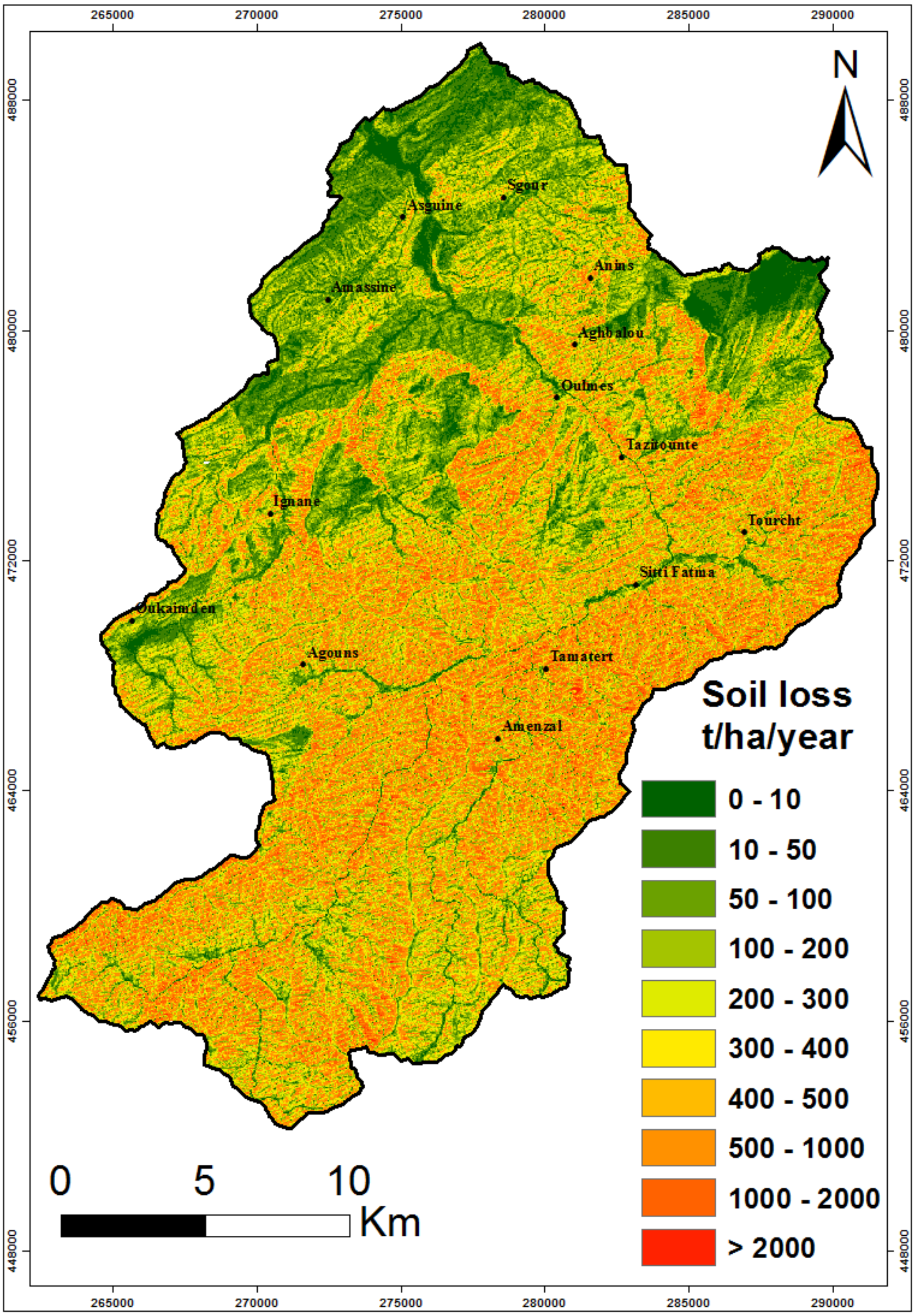

Figure 8. Soil loss map of the Ourika watershed

Soil losses result from a combination of the RUSLE model's factors including climate aggressiveness (R), soil erodibility (K), topographic factor (LS), vegetation cover (C) and erosion control practices (P). The combination of these in a GIS environment resulted in the soil loss map of the watershed (Figure 8).

The average value of soil losses in the Ourika watershed was 380 t/ha/year with a standard deviation of 362 t/ha/year; this reflects the significance and great variability of water erosion in the watershed. These results are close to those obtained under similar conditions in the Oum Er-Rbia watershed where soil losses of the 50-

400 t/ha/year class represent 54% of the watershed area ([33]; [34]). The average soil loss value of 380 t/ha/year obtained in the Ourika watershed is lower than that obtained in the Telata watershed which is 524 t/ha/year [35].

Indeed, 75% of the catchment area presented an erosion rate of over 50 t/ha/year, corresponding to high erosion rates that cannot be offset by soil formation. These include land under crops, clear forests, shrublands and non-forested empty spaces. Under arboriculture, moderately dense and dense forests, and some areas of low slope, soil losses were lower than 50 t/ha/year. Losses below the tolerance level (<7 t/ha/year) accounted for only 4% of the watershed area. This was mainly under arboriculture not mixed with cereal growing, dense forests and parts of moderately dense forests that protect the soil.

IV. CONCLUSION

The study of risks of erosion in the Ourika watershed was done using the Revised Universal Soil Loss Equation (RUSLE) integrated into a GIS. The various factors involved in the processes of erosion were identified and their combination in a GIS environment resulted in soil loss results of the watershed.

The Ourika watershed is subject to strong climatic aggressiveness with an average value of 79.23 of MJ.mm/ha.h whose standard deviation is of 9.7 MJ.mm/ha.h, indicating that the entire watershed is subject to a high climatic aggressiveness. The average value of soil erodibility, K, was 0.48 t.ha.h/ha.MJ.mm with a standard deviation of 0.28 t.ha.h/ha.MJ.mm. This confirmed the watershed's high vulnerability to water erosion. The topographic factor, LS, values ranged from 0.01 to 94.5. This was due to slopes of more than 35% representing 72% of the watershed area. As for the vegetation factor, C, it was very high with values higher than 0.5 for 73% of the watershed area.

The average soil loss value obtained in the watershed was 380 t/ha/year. The results indicated that 48% of the watershed area was subject to soil loss between 50-400 t/ha/year while 30% between 400 and 1000 t/ha/year. Soil loss below the tolerance level (<7 t/ha/year) represented only 4% of the watershed area. Dense and moderately dense forests and non-cultivated areas under arboriculture protect the soil against erosion, improve physical and chemical soil characteristics, facilitate the infiltration of water into the soil and limit runoff and consequently risks of erosion.

The universal soil loss equation, even though subject to criticism, present results that are of great interest for both land planners and managers in the orientation of the actions against erosion.

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