GEOMATICS AND ENVIRONMENTAL ENGINEERING • Volume 16 • Number 2 • 2022

https://doi.org/10.7494/geom.2022.16.2.95

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An Estimation of Soil Erosion Rate Hot Spots by Integrated USLE and GIS Methods: a Case Study of the Ghiss Dam and Basin in Northeastern Morocco

Abstract: Soil erosion is a major factor leading to dams' siltation and reducing their storage capacity. This study mapped the hot spots of soil erosion areas to predict the soil erosion/siltation in the Ghiss basin/dam (northeastern Morocco). In this context, various data has been prepared in the geographical information system for the estimation of soil erosion by integrating the universal soil loss equation (USLE). The result of this study revealed that soil loss rate ranges between 0 and 19 $t \cdot ha^{-1} \cdot yr^{-1}$. Therefore, the hot spots in the soil erosion area are to be found upstream, potentially leading to dam siltation over time. To avoid Ghiss dam siltation, we suggest terrace farming and reforestation in the soil erosion area hot spots.

Keywords: reforestation, Rif, risk, soil loss, terrace farming

Received: 22 September 2021; accepted: 3 February 2022

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1. Introduction

Soil erosion is a major contributing factor in dam siltation [1]. In Morocco, soil erosion rates for a basin area of 71 million hectares are 1.408 $t \cdot ha^{-1} \cdot yr^{-1}$, which has led to dam siltation and the reduction of the storage capacity of the dams by 0.56% every year [2], with negative economic (1 billion USD) (Tab. 1) and environmental consequences [2, 3]. Furthermore, it has a negative impact on hydropower and agricultural activities [4–6]. The siltation phenomenon of the dam basin in Morocco has been studied by many researchers [7–11], and it has been found that more than 65 $Mm^3 \cdot yr^{-1}$ of sediment affects the dams. Therefore, the siltation of reservoirs has resulted in serious loss of storage capacity and reductions in their lifespan [10], such as three check dams in the Msoun basin (eastern Pre Rif), were totally filled with sediment in less than seven years [9].

Table 1. Soil loss costs according to watersheds (DH – Moroccan dirham)

Dam	Area watershed [km^2]	Reservoir capacity [Mm^3]	Siltation [$Mm^3 \cdot yr^{-1}$]	Money loss [million DH]
Mohamed V	49,920	465	10.00	1,815
Ouahda	6,153	3,730	18.50	1,462
Hassan I	1,670	254	2.90	752
Moulay Youssef	1,441	175	2.60	735
O. Makhazine	1,820	772	4.60	730
Idriss I	3,680	1,173	2.20	659
Allal Fassi	5,765	81	1.20	629
El Kansera	4,540	265	1.40	586
Bine El Ouidane	6,400	1,300	5.00	549
Mansour Eddahbi	15,000	505	4.70	390
M.B.A. Khattabi	780	34	1.30	316
Lalla Takerkoust	1,707	68	0.50	293
Sidi M.B. Abdellah	9,800	477	1.70	258
Y.B. Tachfine	3,784	303	1.43	188
Aoulouz	4500	100	2.10	127
Al Massira	28,500	2,747	2.50	118
Hassan Eddakhil	4,400	343	1.17	113
Ibn Batouta	178	36	0.56	113
Nakhla	107	6	0.30	100

Table 1. cont

Abdelmoumen	1,300	213	0.23	55
Hachef	220	300	0.50	48
Mellah	1,800	8	0.15	12
Total	153,465	13,355	65.54	10,048

Source: [2]

The Mohamed Ben Abdel Karim Khattbi (MBAK) (Tab. 1) dam in Al-Hoceima Province is considered one of the dams most prone to siltation in Morocco, yet it constitutes the only source of water for the city of Al Hoceima and the surrounding urban centers [12]. To avoid drinking water shortage problems, another dam is under construction in the Ghiss basin.

Soil erosion is very high in the Rif region of Morocco, with rates sometimes reaching 30–60 $t \cdot ha^{-1} \cdot yr^{-1}$ [13, 14]. In this context, our objective in this study is the estimation of soil loss in the Ghiss basin, and its impacts on the Ghiss dam siltation by integrating the universal soil loss equation (USLE) and geographic information system (GIS). Therefore, this study can provide information on annual soil loss and hot spot areas in the watershed and its location of the Ghiss dam to take the necessary interventions [13]. In Morocco, many researchers have studied the vulnerability of watershed erosion using the USLE empirical model [11, 13, 16–18], their results of soil loss estimation varying from one basin to another. This difference is due to variations in the physical characteristics of each basin [18]. Various data have been used in this model such as rainfall erosivity (R) factor, soil erodibility (K) factor, and use land cover data, cover, and management (C) factor, conservation practice (P) factor, slope length, and steepness (LS) factor, by integrating of all these factors, we can compute annual soil loss ($t \cdot ha^{-1} \cdot yr^{-1}$) in the Ghiss basin.

2. The Study Area

The Ghiss basin located in the central Rif of Morocco (Fig. 1), its delimitation by GIS provides a total area of 84,595 ha, its altitude is between 2 and 2055 m, and it decreases gradually northeast. Also, annual precipitation (30 years) decreases gradually northeast from 953 to 270 $mm \cdot yr^{-1}$, and its slope is between 0 and 52 degrees. The study area stretches from latitude 35.19 north to 34.80 longitude 4.44 to 3.83 west. The main stream is the Oued Ghiss, which is around 80 km in length [20] and flows into the Mediterranean Sea, its water is a source of irrigation for many farmers. Recently, a dam project has been introduced (Fig. 2) in the study area in order to provide potable water to the population of Al Hoceima and the surrounding urban centers. This is especially important given the end of the validity period of the

MBAK dam because of the siltation problem. However, to avoid the siltation phenomenon due to high soil erosion, by anti-erosion works in the Ghiss watershed, as a first step it is necessary to estimate the annual soil loss of the Ghiss watershed.

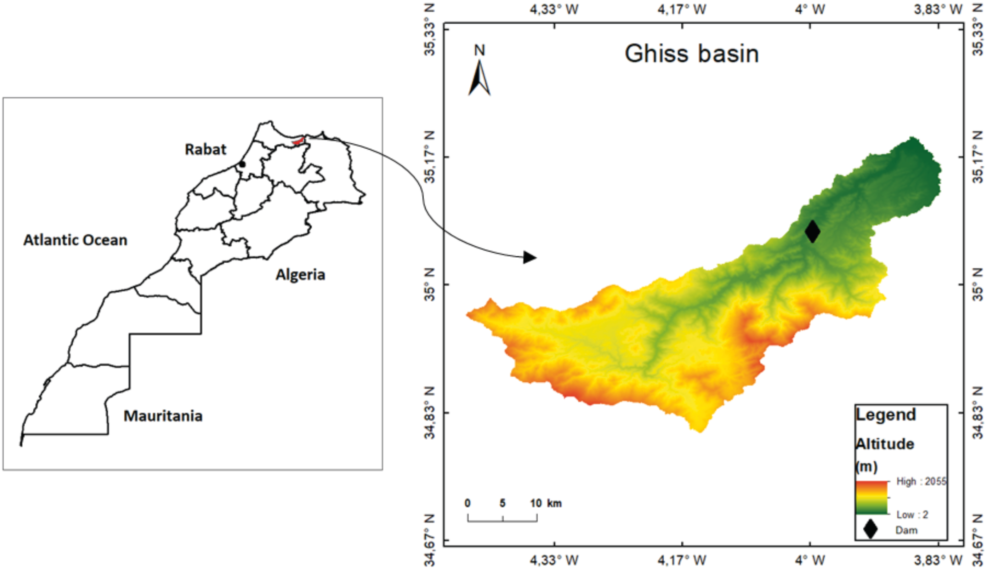

Fig. 1. Localization of study area

Fig. 2. Dam under construction in the Ghiss basin

3. Materials and Methods

The estimation of soil loss was quantified using the USLE model Equation (1) proposed by Wischmeier and Smith [16], and it is applied globally [11, 17, 21–28] by employing five parameters using several data sources and integrating GIS:

$$A = R \cdot K \cdot LS \cdot C \cdot P \tag{1}$$

where:

A – annual soil losses [$t \cdot ha^{-1} \cdot yr^{-1}$],
R – factor of rainfall erosivity [$MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot yr^{-1}$],
K – factor of soil erodibility [$t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$],
LS – factor of length and gradient of slope,
C – factor of land cover,
P – factor of conservation practices.

The methodology adopted in the study is shown in Figure 3.

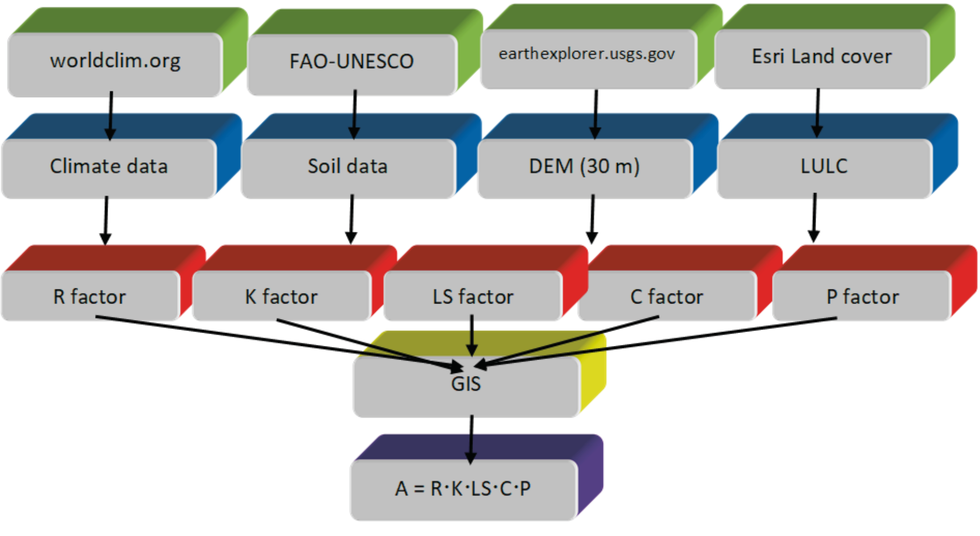

Fig. 3. Flowchart of the methodology

3.1. Rainfall Erosivity Factor (*R*)

This was defined by Wischmeier and Smith [19] as the product of the total kinetic energy multiplied by the maximum 30 min rainfall intensity, and it is considered to be a driver of soil erosion processes [17]. There are many methods to calculate the annual rainfall erosivity factor (*R*) [17, 21, 22, 25–28]. For this study, we used the Equation (2) of Nguyen [29] to measure the *R* factor based on annual precipitation (30 years), and the data was downloaded through the WorldClim site [30].

The R factor value in the study area varies from 88 to 262 (Fig. 4). A high R factor value is to be found upstream, and a low R factor downstream:

$$R = 0.548257 \cdot P - 59.9 \tag{2}$$

where P is the annual precipitation [mm].

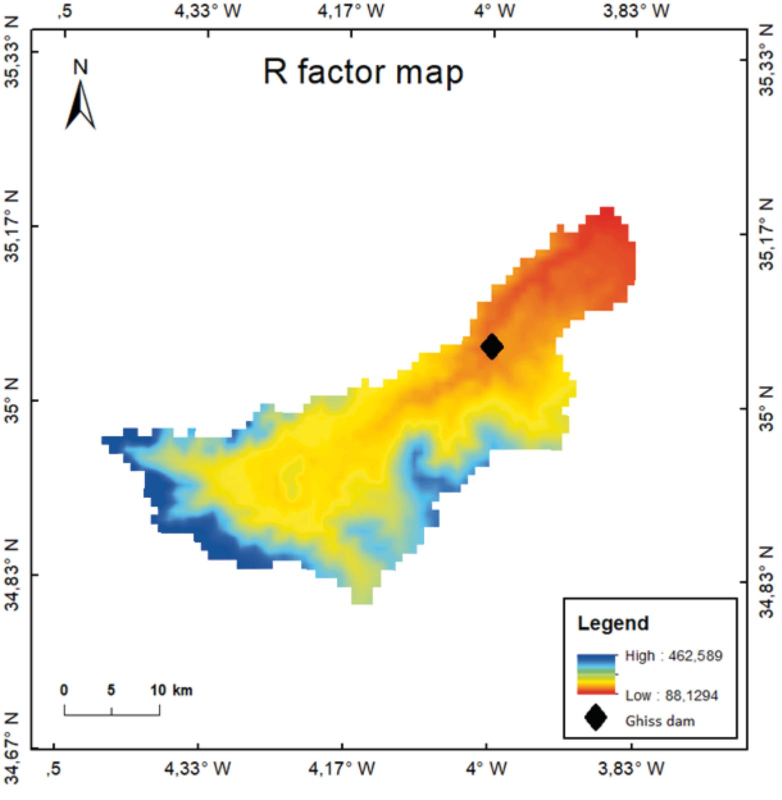

Fig. 4. R factor of the study area

3.2. Soil Erodibility Factor (K)

The soil erodibility factor (K) represents the susceptibility of soil or surface material to erosion [26], it is strongly related to the physical properties of the soil [31], such as soil organic matter, and percentage of sand, silt, and clay in the soil [32]. According to the FAO soil map of the world, two different soil types were identified in the study area: Chromic Luvisols (LC) and Calcaric Fluvisols (JC) (Tab. 2). The soil types were assigned K factor values from the FAO soil classification to obtain the K factor map (Fig. 5), which shows that the majority have a low K factor.

Table 2. Different soil type and their corresponding *K* factor (OM – organic material)

Soil symbol	Sand [%]	Silt [%]	Clay [%]	OM [%]	*K*
LC	39.6	39.9	20.6	1.118	0.34
JC	64.3	12.2	23.5	1.083	0.20

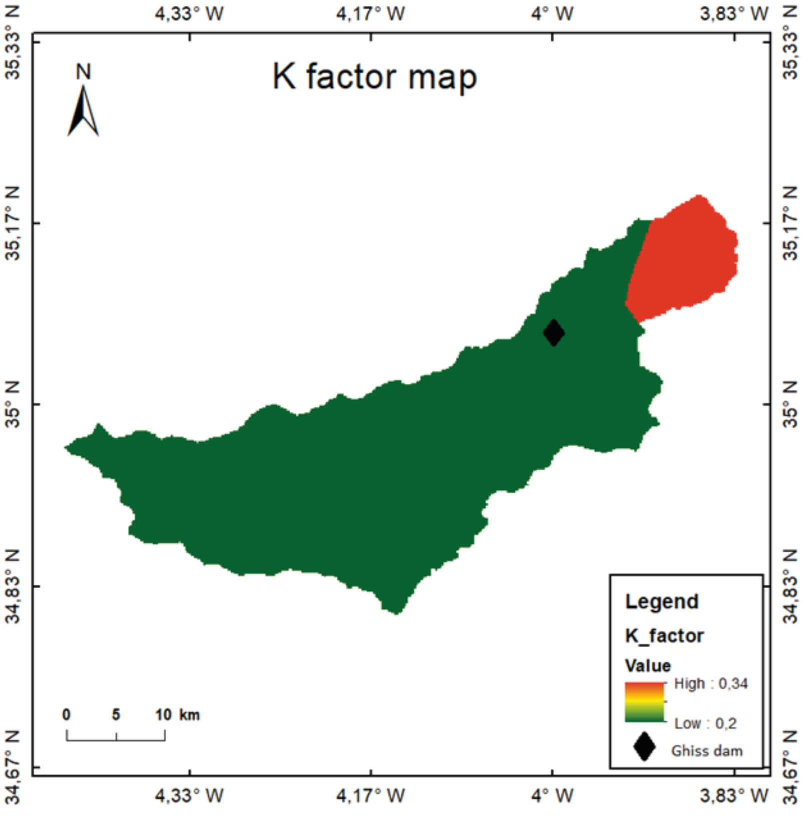

Fig. 5. *K* factor of study area

3.3. Slope Length (*L*) and Steepness (*S*) Factor (*LS* Factor)

It reflects the effect of length and steepness on erosion. The data used to calculate this factor is DEM (30 m) downloaded from Earth Explorer to extract the topo-hydrographical configuration (Fig. 6). The empirical Equation (3) adopted to calculate *LS* factor is used by many researchers and was proposed by Moore and Wilson [33]:

$$LS = \big((\text{flow accumulation} \cdot \text{cell size})0.4/22.13\big) \cdot \big((\sin \text{slope})1.3/0.0896\big) \qquad (3)$$

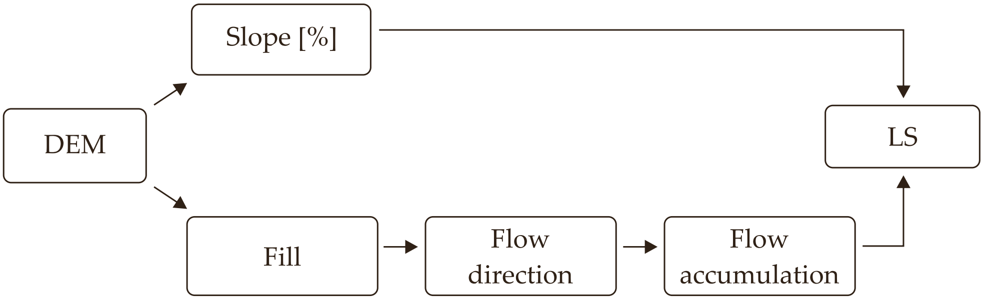

Fig. 6. Flowchart of *LS* factor

The *LS* factor value in the study area varies from 0 to 22 (Fig. 7).

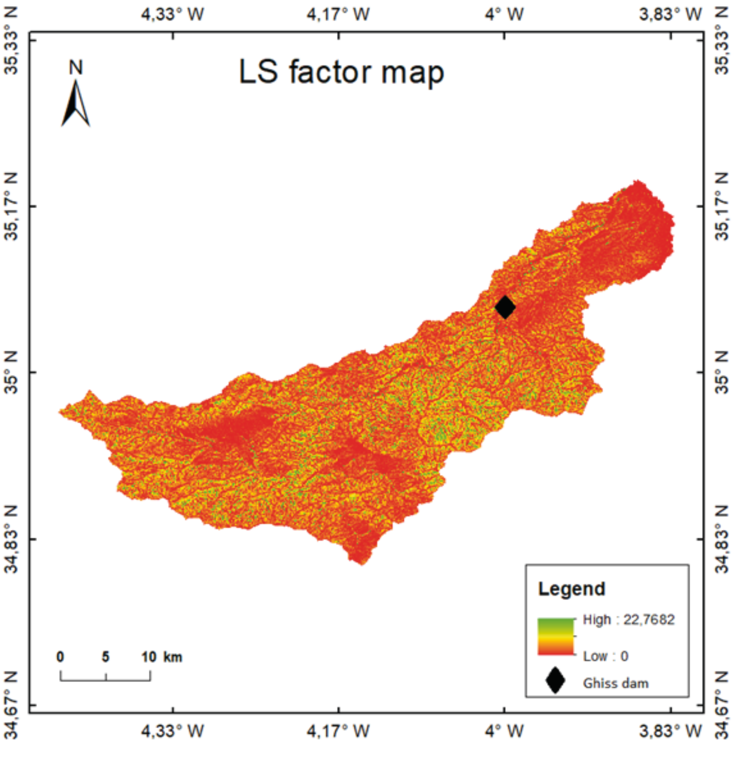

Fig. 7. *LS* factor of study area

3.4. Cover Management Factor (*C*)

This is one of the most important factors in the USLE equation that controls soil loss [34]. The principal land cover classes include scrub (71%), urban (9%), crops (11%), trees (1.4%), and bare ground (1.7%), each land cover was assigned with its corresponding *C* factor as per Hurni [35] and Reusing et al. [36]. Therefore, the analysis of the cover factor distribution (Tab. 3) shows that more than half of the watershed (71%) has moderate protection levels (0.2). The results showed that the *C* factor in the research area ranged from 0 to 0.2 (Fig. 8).

Table 3. Different land cover classes and their corresponding *C* factor

Land cover class	Area [km^2]	Area [%]	*C*
Water	0.7973	0.094249	0.00
Trees	46.3792	5.482509	0.01
Grass	0.3315	0.039187	0.05
Crops	94.5291	11.17433	0.15
Scrub	608.9033	71.97877	0.20
Urban	80.0374	9.461261	0.004
Bare ground	14.9707	1.769694	0.05

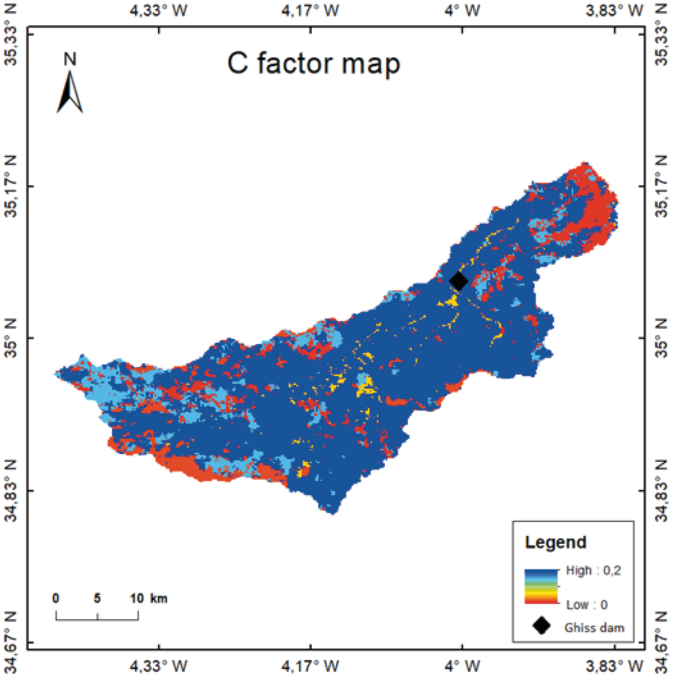

Fig. 8. *C* factor of study area

3.5. Conservation Practice Factor (*P*)

The *P* factor map was derived from the LULC [37] and support factors [17]. The resultant map was converted to a grid map of 100 m cell size. The values of the *P* factor range from 0.56 to 1 (Fig. 9), in which the high value is assigned to areas with no conservation practices; the minimum values correspond to urban land, trees, and crops.

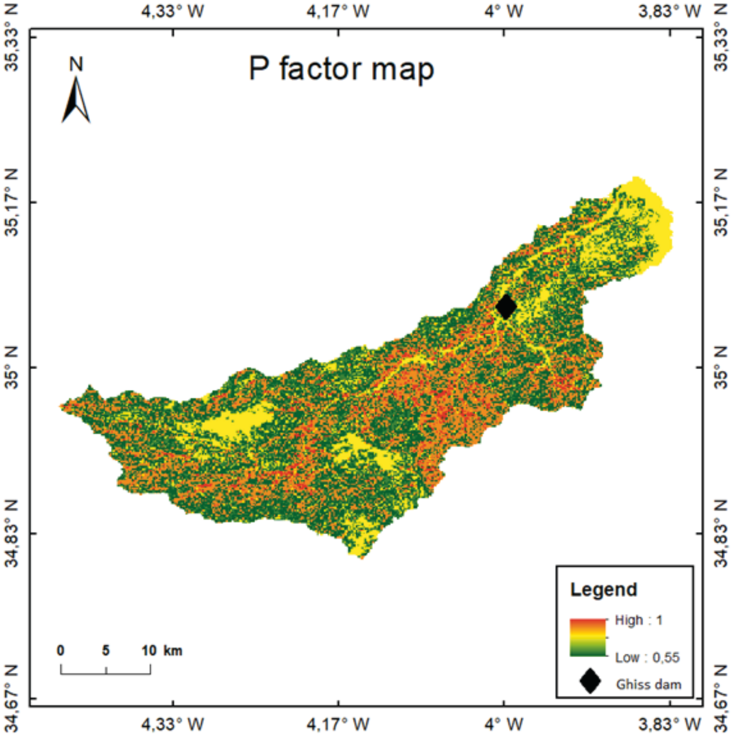

Fig. 9. *P* factor of study area

4. Results and Discussion

The average annual soil erosion potential (*A*) of the Ghiss basin is shown in Figure 10, and was obtained by integrating all raster factors data using Equation (1). The minimum and maximum losses are respectively about 0 and 19.5 $t \cdot ha^{-1} \cdot yr^{-1}$ (Fig. 10).

Previous work on the same watershed using the RUSLE method revealed that the annual soil loss is more than 30.1 $t \cdot ha^{-1} \cdot yr^{-1}$ [38]. Regarding other watersheds in the Rif region: the annual soil loss in the Nekor watershed using the RUSLE model is more than 37.2 $t \cdot ha^{-1} \cdot yr^{-1}$ [38], according to the RUSLE 3D model it is 60.77 t·ha^{-1}·yr^{-1} [11], and the USPED model puts it at 65.86 t·ha^{-1}·yr^{-1} [16]. The annual soil loss in the Makhazen watershed using the USLE model is 735 t·ha^{-1}·yr^{-1} [17]. These examples of soil loss estimation in the Rif region vary from one basin to another and even in the same watershed. This difference is due to many factors: the model used to estimate soil erosion, the physical characteristics of each basin, the chosen precipitation period (*R* factor).

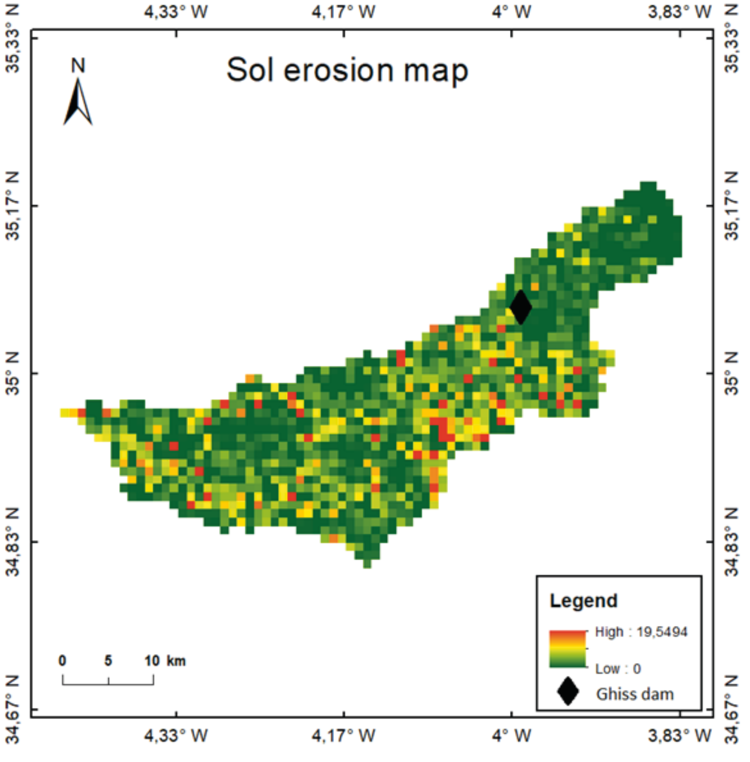

Fig. 10. The soil loss map of study area

To facilitate the selection of the anti-erosion area, the Ghiss watershed was classified into three spots according to soil erosion risk categories (low, moderate, high). Using these erosion risk classes (Fig. 11), it is observed that 98% of the area basin was classified as low erosion risk spots (Tab. 4), because of scrub, which is the dominant cover class in the study area, and protects the soil in different ways, including the interception of raindrops and the provision of organic carbon [39, 40]. Nevertheless, the low percentage (1.47%) of soil erosion hot spots (moderate and high classes), can lead to Ghiss dam siltation because of its location at the top of the dam. To prevent the dam from siltation, it is necessary to conduct anti-erosion work upstream of the Ghiss dam, such as terrace farming and reforestation.

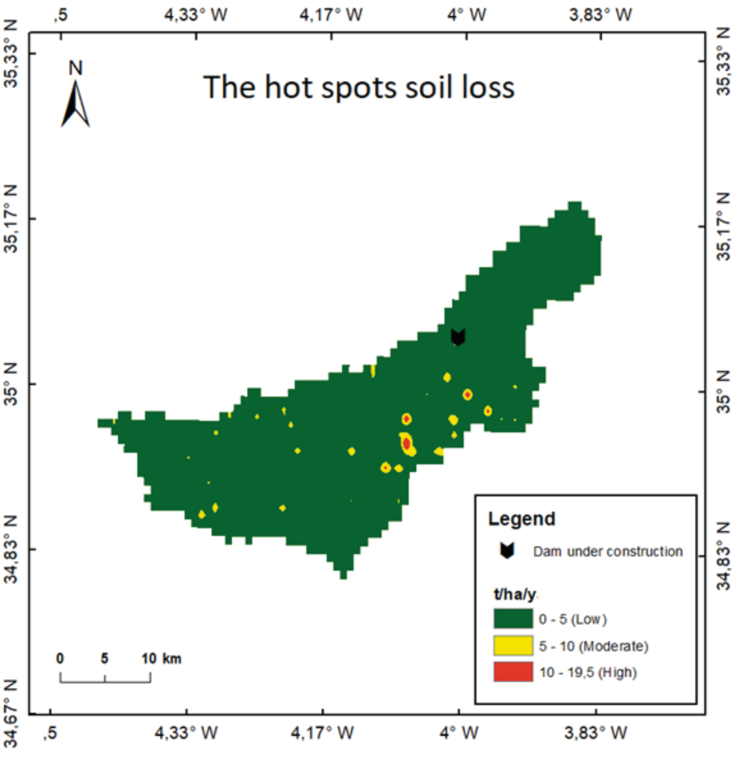

Fig. 11. The soil loss hot spot map of the study area

Table 4. The soil loss classification spots according to area and percentage

Class	Area [ha]	Area [%]
Low	83,346.16	98.52
Moderate	1,118.37	1.32
High	130.07	0.15

5. Conclusion

This study estimated annual soil loss rate ranges, using the USLE model and GIS environment, to be between 0 and 19 t·ha^{-1}·yr^{-1}. The results of this study may help guide managers in selecting erosion area hot spots to be addressed in anti-erosion management to preserve the storage capacity of the Ghiss dam and to reduce the negative economic and environmental consequences of dam siltation. However, it must be noted the uncertainties regarding soil and climate data may have impacted soil loss estimates.

Acknowledgments

We highly acknowledge the contributions of the reviewers and editors for their remarks which helped to improve the quality of this manuscript.

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