International Journal of Innovative Research in Sciences and Engineering Studies (IJIRSES)

www.ijirses.com ISSN: 2583-1658 | Volume: 2 Issue: 10 | 2022

Estimation of soil erosion rate applying the RUSLE model within the El Abid river basin, Central High Atlas, Morocco

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Abstract: *In Morocco, water erosion is the main cause of degradation of the soil and the environment. In the Central High Atlas Mountains (Morocco), land has been the subject of serious soil erosion problems. This study aims to assess the soil erosion susceptibility in this mountainous area, especially at the upstream part of Bin El Ouidane dam, using the Revised Universal Soil Loss Equation (RUSLE model) and spectral indices integrated with the Geographic Information System (GIS) environment. The upstream part of the lake receives the waters and sediment yield from the El Abid riverbasin. The result of the calculation for the studied catchment, El Abid, showed that the production of soil erosion is 3.960.115 m^3/ yr^{-1}. The Coefficient of deposit retention, calculated using the IntErO model, was 0.6 and as a consequence, real soil losses were calculated on 2.210.067 m^3/yr. Our findings, based on Gavrilovic classification, pointed out that the studied area has a medium potential for soil erosion risk due to the steep land slope and low vegetation cover in the watershed. The model outcome is validated using field measurements.*

Keywords: *Soil erosion yield, Modelling, IntErO, Revised Universel Soil Loss Equation (Rusle), Bin El Ouidane dam*

1. Introduction

Soil erosion is a naturally occurring process, and it is a normal geological phenomenon associated with the hydrologic cycle. It is a gradual process that occurs when the impact of water detaches and removes soil particles, causing the soil to deteriorate (El Jazouli et al., 2017)(El Jazouli et al., 2017). Erosion is a key driver of land degradation, heavily affecting sustainable land management in various environments worldwide (Spalevic et al., 2020; Verheijen et al., 2009). This phenomenon is a particularly important issue, especially in the temperate and semi-arid Mediterranean area(Tadrist et al., 2016; Ouakhir et al., 2020). Historically, intensive land use has greatly transformed the ecosystems of the Mediterranean basin, with the clearing of fields for agriculture (Grove, 1996) being the major factor affecting erosion processes (Douglas, 1993; Estrany et al., 2010). In Morocco, land degradation is mainly caused by soil erosion, which is one of the most serious agro-environmental threats encountered (Benmansour et al., 2013). Besides, more than 15 million hectares of the Moroccan agricultural land is under serious threat; due to the intensification of agricultural practices leading to unsustainable farming practices (e.g. inappropriate tillage practices, straw exportation, overgrazing) and specific bio- climatic conditions (e.g. recurring and severe droughts),(Namr & Mrabet, 2004). Regarding the results of FAO (1990), about 40% of the lands in Morocco are affected with varied intensities by soil erosion. The annual soil loss exceeds 20 t h−1 yr−1 especially in the Mountainous parts of northern Morocco and varies between 10 and 20 t h−1 yr−1 in the pre- Rif regions and 5 and 10 t h−1 yr−1 in Middle and High Atlas regions (MAEF 2001; El Jazouli et al., 2017). Being located in the Central High Atlas, the El Abid river is the most important tributary of the Oum-Er-Rbia basin, which drains a large proportion of the land from the High Atlas watershed in the South to the middle Atlas watershed in the North (Cherifi and Loudiki 2002). In the downstream of El abid river, Bin El Ouidan dam is situated and receiving the waters and sediments from the two mean river El Abid and Assif Ahansal(El Ghachi et al., 2019).Some results of soil erosion obtained by applying the IntErO model in this basin showed a production of 3.960.115 m^3yr(El Mouatassime et al., 2019). Besides, sustainable soil conservation measures can only be achieved by an in-depth understanding of the extent, risk, and spatial distribution of soil erosion (Fernández et al., 2007; Demirci & Karaburun, 2012). Multiple models have been used and applied to assess soil erosion. According to Bhattarai & Dutta, (2007) the developed models for estimating soil erosion can be classified into two groups: (i) physically based models, and (ii) empirical models (Demirci & Karaburun, (2012). Physically based models such as WEPP, ANSWERS, and EUROSEM investigate erosion processes by synthesizing individual components (Bhattarai & Dutta, 2007). Although these models can provide enough understanding of spatial and temporal situations of soil erosion, lack of data is one of the main obstacles to simulating physically based models (Bhattarai & Dutta, 2007). Empirical models such as the Universal Soil Loss Equation (USLE), the Modified Universal Soil Loss Equation (MUSLE), and the Revised Universal Soil Loss Equation (RUSLE) are the most commonly used methods to predict soil erosion, especially in catchment areas, due to their minimal data requirements and ease of application them (Lal, 2001; Bhattarai & Dutta, 2007; Zhang et al. 2009; Demirci & Karaburun, 2012). In this study, RUSLE was the model applyied in a GIS framework to estimate the soil erosion rate in the El Abid basin. Although a different study used USLE and RUSLE models with GIS to predict soil loss in other parts of Morocco (El Mouatassime et al., 2019; Toumi et *al*., 2013; El Jazouli et *al*., 2017; Chen et *al*., 2008; Meliho et al., 2018; Ouallali et al., 2016).

2. Study Area and Data

El Abid basin is the study area located in the upstream part of the Bin El Ouidane dam(fig.1). With approximately 3119 km2 surface area, the study watershed is an important tributary of the Oum Rbia bassin. It extends over the limestone of the Central High Atlas, bounded to the East and South by a line of high mountain peaks above 3000 m; the highest point in the entire basin is Azourki mountain (Jbel) (3690 m) (El Ghachi et al., 2019; Ouakhir et al.,2020). This basin extends over a large mountainous area with a significant potential of water resources, which ensures the supply of the Bin El Ouidane dam and the recharge of the aquifers of the Tadla plain downstream(fig.b1). Geologically, the basin is a part of the Central High Atlas limestone where the relief is marked by a series of anticlines and synclines, cut by narrow and deep valleys like the Ouaouizerth and Tagleft valleys (Ouakhir et al.,2020). The hydrological regime is of the snow-rainfall type and can be divided into two periods. The wet winter–spring season lasts from December to May, when average monthly precipitation can reach 800 mmand average monthly temperatures vary between 10 C° and 17C°.The dry season runs from June to October with an average monthly precipitation not exceeding 5 mm and average monthly temperatures between 17 C° and 28 C°(Cherifi & Loudiki, 1999). The land use in the study area has undergone significant changes over the past few decades due to a rapid increase in population (Simonneaux et al., 2015). Long-term hydrological records for the El Abid (1970–2019) at Ait Ouchene and Ouaouirtnh gauging stations demonstrate the annual and seasonal variability in discharge,with the winter and spring periods typically representing 87% of the flow (ABOHER 2020).

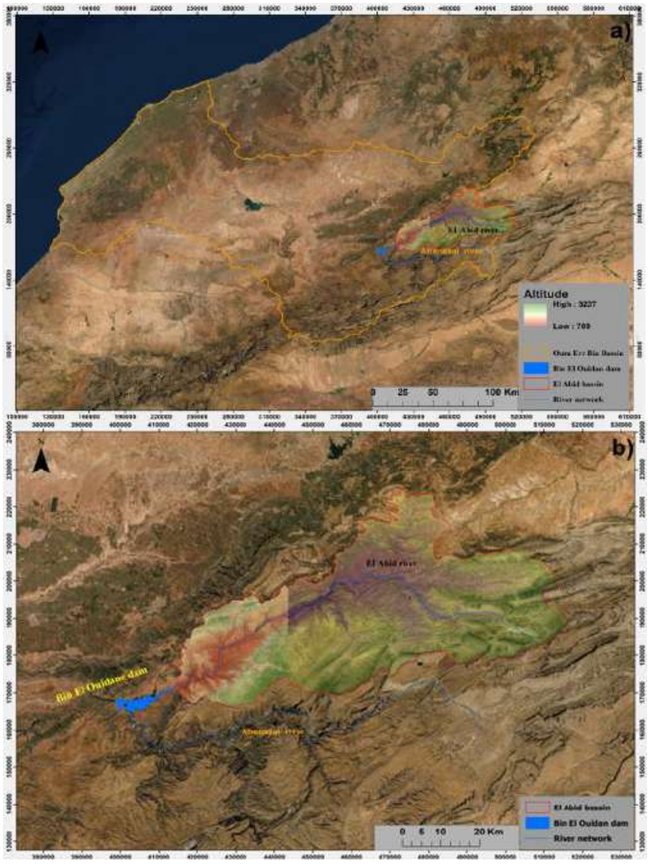

Fig.1:a) Location El Abid basin in Oum Err Bia watershed and b) the map of El Abid study area

3. Materials and Methods

In this study, the RUSLE model was applied based onthe GIS software so as to estimate the soil erosion rate in the El Abid basin. RUSLE is an erosion method that measures soil loss on the hillslopes. The estimated factors of RUSLE represent the effects of topography, soil, precipitation, land cover, and support practices on soil erosion (Demirci & Karaburun, 2012). The factors used in RUSLE were produced or obtained based on the gauging stations data from the field, soil surveys, topographic maps, and satellite images. Besides, a GIS file was built for each factor used in the RUSLE model, and all the files were explained and multiplied in the model to produce a final soil loss map of the studied watershed. RUSLE calculates using the following equation given by Renard et al (1997):

$E = R \times K \times LS \times C \times P;$

where A is the average annual soil loss in tons per hectare per year (t/ha/year), R is the rainfall and runoff erosivity, K is the soil erodibility, LS is the hillslope length and steepness, and C is the cover management (dimensionless), and P is the support practice. The R coefficient computes the impact of rainfall factor on soil erosion (Xu et al., 2008). The average annual rainfall data collected from 8 meteorological gauging stations around the study area were interpolated using the interpolation tool in GIS framwork to prepare rainfall and R factor map using this equation; R = 38.5 + 0.35r (Panday et al., 2018, 2019), where r is annual rainfall in mm. The K factor is the soil susceptibility to detachment and erosion caused by the rainfall and runoff intensity (Batista et al., 2017). K values were assigned to soil textural classes as described by Ligonja and K values were assigned to soil textural classes as described by Ligonja & Shrestha, (2015).

The slope length (L) and steepness (S) topographic factors, present the influence of slope length and steepness on soil erosion, respectively. The following equations were applied to measure the L factor (Wischmeier et al 1978)and S factor (Šurda et al., 2007); L = (Cell size/22.13).

4. Results and Discussion

4.1 Climate characteristics of study area

Located in the High Central Atlas (Morocco), the El Abid river is one of the most important Moroccan tributaries. The frequency and intensity of floods in recent decades have grown in an exceptional way, especially in the El Abid riverdue to heavy rain intensity, land use variation, and rugged topography characterized by high slope (Vicente et al 2005). Figure 3 shows the annual mean values of rainfall and discharge at the Ait Ouchene gauging station, which is located about 38 km from the upperpart of the Bin El Ouidane dam. At annual scale, the long hydrological years recorded for the El Abid river (1970— 2017) at the representative gauging station demonstrate that the El Abid river shows a strong annual and seasonal variability in rainfall (p mm) discharge (Qm3/s), with winter and spring periods typically representing about 87% of flow (fig. 2).The annual rainfall varies between 711 mm as Max and 199 mm as Min. with a mean of 415 mm. The snow-rainfall hydrological regime can be divided into two periods. The wet winter-spring season lasts from December to May, when average monthly precipitation can reach 80 mm and average monthly temperatures vary between 10°C and 17°C. The dry season lasts from June to October with an average monthly precipitation not exceeding 5 mm and average monthly temperatures between 17°C and 28°C (figure 3, Cherifi and Loudiki 2002; Latron et al 2009).

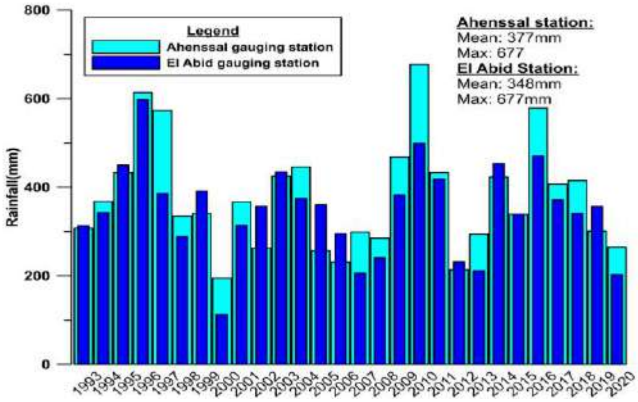

Fig.2. Distibution of rainfall at Ahenssal and El Abid gauging stations between 1993/2020 (ABHOER 2020)

4.2 Results of RUSLE model application

RUSLE is a straightforward and empirically based model that has the ability to predict the long-term average annual rate of soil erosion on slopes using data on rainfall pattern, soil type, topography, crop system, and management practices. In the present research, an annual soil erosion rate map was generated for the Pamba sub-watershed, a mountainous area that represents most of the terrain characteristics of the Western Ghats. Several data sources were used for the generation of RUSLE model input factors and are stored as raster GIS layers in the ArcInfo ArcGIS software(Prasannakumar et al., 2012). The following figures indicate the different parameters of RUSLE results within the El Abid basin.

The spatial distribution of the average soil erosion in the El Abid river basin from 2000 to 2022 was characteristically high for the annual average soil erosion, being more than 25 t ha^{-1} yr^{-1} and accounting for 62.6% of the total area (Fig. 3-e). According to these results, the spatial distribution of different land use types was detected as a good factor explaining the contrast in soil erosion results. This distribution is shown in fig.3. c. The highest values of erosion loss were observed in slope cropland areas, which had a similar loss to that of bare land, and the lowest loss was for cropland with flat topography. However, slope land uses and bare land had higher variations than flat land uses. Assuming cover from opento dense vegetation was mostly on slope land, forest, shrubs, and dense grassland reduced soil loss from slope land more than woods and moderate to sparse grass compared with

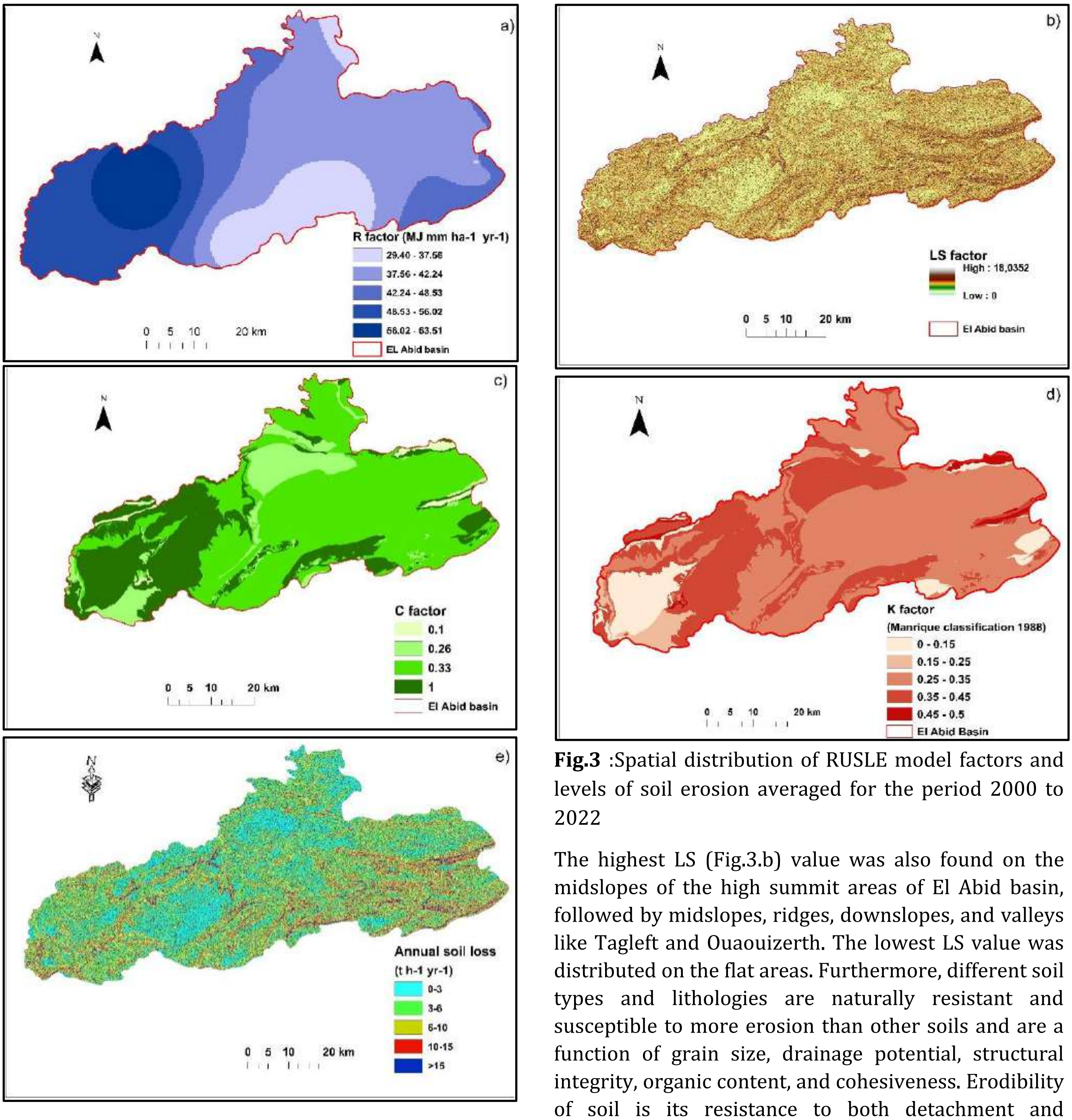

Fig.3 :Spatial distribution of RUSLE model factors and levels of soil erosion averaged for the period 2000 to 2022

the soil loss from slope land that was cropped(Sun et al., 2014).Also, one of the main effective factors on soil erosion is rainfall erosivity (R-factor)(Fig.3.a and b). The climatological data of the studied stations clearly reveal the decreasing trend of precipitation, and the main consequence of the reduction in precipitation was the decreasing in C-factor.

The soil erosion ratewas averaged for each land use type in the El Abid basin from2000 to 2022. The topography and lithology were also affected this variation.

The highest LS (Fig.3.b) value was also found on the midslopes of the high summit areas of El Abid basin, followed by midslopes, ridges, downslopes, and valleys like Tagleft and Ouaouizerth. The lowest LS value was distributed on the flat areas. Furthermore, different soil types and lithologies are naturally resistant and susceptible to more erosion than other soils and are a function of grain size, drainage potential, structural integrity, organic content, and cohesiveness. Erodibility of soil is its resistance to both detachment and transport (Khademalrasoul & Amerikhah, 2021).

5. Conclusions

Potential annual soil loss is estimated from the product offactors (R, K, LS, C and P) which represents the geo-environmental scenario of the studied area in the spatial analyst extension of Arc GIS software. A quantitative assessment of average annual soil loss for El Abid basin is made with a GIS-based version of the well-known RUSLE equation, considering rainfall, soil, land use, and topographic datasets. The land use pattern in areas prone to soil erosion indicates that areas with natural forest cover in the headwater regions have the lowest rate of soil erosion, while areas with human intervention in the downstream have the highest rate of soil erosion.

Consequently, the present analytical model helps map of vulnerability areas, and micro-scale data on rainfall intensity, soil texture, and field measurements can augment the prediction capability and accuracy of remote sensing and GIS based analysis.

Acknowledgement

The authors would like to thank the anonymous reviewers for constructive comments and suggestions.

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