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Adaptation of the revised universal soil loss equation (RUSLE) to soil loss modeling in a semi-arid watershed: a case study from western high atlas, Morocco

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Key factor (s) triggering erosion in a semi-arid environment (Western High Atlas of Morocco)

Abstract

In the western High Atlas of Morocco (WHAM), most of the mountainous regions experience important soil loss triggered by both natural and anthropogenic factors. It forms a major geohazard that impacts negatively upon agricultural production due to decreased water availability and reductions in soil fertility, which in the absence of measured datasets, the situation of soil loss will be getting worse. Hence, the relevance of using modeling techniques such as RUSLE (Revised Universal Soil Loss Equation), in quantifying and identifying areas subject to erosion. Not only this study aims at assessing soil loss in WHAM, but it also intends to study the controlling factors in different three areas throughout the WHAM, in an attempt to find the key factor (s) that controls the most soil loss in this region. The combination of the controlling factors maps with the resulting soil loss map in a GIS environment using Pearson's correlation method, allows us to provide a matrix that computes the influence of these factors on the erosion process. Findings show that the WHAM is subject to significant amounts of erosion, this is mainly due to the topographic factor (LS), which is considered to be extremely rugged, followed by the soil conservation practices factor (P) and the vegetation cover factor (C). This study provides mandatory information for stakeholders helping in implementing proper management planning in drylands.

Introduction

In semi-arid environments, soil erosion represents a big challenge regarding natural resources management, manifesting in the field as land degradation that impacts water quality, dam storage capacity (Gayen and Saha 2017; Gayen et al. 2020; Zakerinejad and Maerker 2015) and agricultural production (Tessema et al. 2020). Furthermore, an increase has been clearly observed in terms of soil loss triggered by erosion, due to agricultural activities and deforestation in several regions of the world, especially in semi-arid environments (Nearing et al. 2017), which consequently threatened the global food security because of soil nutrients reduction of arable lands (El Mujtar et al. 2019; Pradeep et al. 2015).

Dryland areas including the WHAM, tend to intensify the erosive effect due to high-intensity rainfall events, land cover patterns, land management practices, and topography (Gayen et al. 2019, 2020). Indeed, several studies have been carried out to deal with soil erosion and mitigate its negative repercussions on humans and the environment (Elaloui et al. 2017; Gayen et al. 2020; Somasiri et al. 2022), however, there is a lack of studies that can identify the main core of this issue, preventing even the initiation of the erosive process. Therefore, this research is aiming at studying the dependency relationship between all the controlling factors and subject areas to soil loss in WHAM, to highlight the most influencing factor (s) in this region.

Over the last few centuries, several models have been adopted to quantify and identify areas at erosion risk (Lal 2001; Teshome et al. 2021), in order to reduce its harmful effects. The used models for erosion assessment are countless such as Chemical Runoff and Erosion for Agricultural Management System (CREAMS) (Knisel 1980), Areal Non-point Source Watershed Environment Response Simulation (ANSWERS) (Beasley et al. 1980), Water Erosion Prediction Project Model (WEPP) (Nearing et al. 1989), and the European Soil Erosion Model (EuroSEM) (Morgan et al. 1998). However, the most commonly used type is the empirical-based model is the Universal Soil Loss Equation (USLE) (Ketema and Dwarakish 2021; Wischmeier and Smith 1978). The USLE model has been adapted to fit the Moroccan conditions named the Revised Universal Soil Loss Equation (RUSLE) (Arnoldus 1980).

In this study, the adjusted RUSLE model has been applied using Remote sensing and GIS. The application of the RUSLE provides five thematic maps of the controlling factors in addition to the resulting map of soil loss. These maps are then integrated into a GIS environment to produce a matrix showing the level of dependency between each factor and the soil loss using Pearson's correlation (Pearson 1896), allowing to analyze the influence of the controlling factors on the erosion process. This result will serve as a decision support system for managers to mitigate the factor (s) responsible for erosion in WHAM. This method could be adopted and applied to similar environments, particularly in the absence of datasets.

Study area

The western High Atlas of Morocco (WHAM) belongs to the large mountainous chain of the High Atlas that occupies an area of 1000900 ha. It is bounded in the east by the central high atlas, in the west by the Atlantic Ocean, in the north by the Meseta domain and in the south by the anti-Atlas (Fig. 1).

The WHAM is the oldest massif, predominantly Jurassic or Cretaceous formations (with some less extensive outcrops of Triassic, Permian, and even Carboniferous2) intersected by deep valleys (Moreau et al. 2020). Its highest point is the Toubkal summit at 4,167 meters above sea level, visible from Marrakech.

The climate of the WHAM is subtropical oceanic. This region is exposed to the disturbances coming from the Atlantic, they are relatively humid with spaced but sometimes diluvian rainfalls. It falls between 600 and 1000 millimeters of water per year on average. The summer drought, interspersed with thunderstorms, is intense. Snow cover is generally persistent above 2,500 to 3,500 meters from November to April and can persist from September to June for the high peaks (with large variations depending on exposure). Some rivers never get dry, feeding fertile highland basins. These conditions allow the existence of the forest (pines, holm oaks, cedars, etc.) but it decreases because of the triplicated effect of the dry climate, the overexploitation (heating and construction) and the overgrazing of sheep and goats (Wikipedia 2022).

In this study, as the WHAM is a large area to cover in this kind of research, we choose three model areas that can represent different variations of the WHAM and also where the erosion has been clearly observed. These areas are the Argana corridor, Beni Mohand river basin and High Souss upstream watershed. A detailed description of each area has been already made in previous studies (Bou-imajjane et al. 2020; Bou-imajjane and Belfoul 2020).

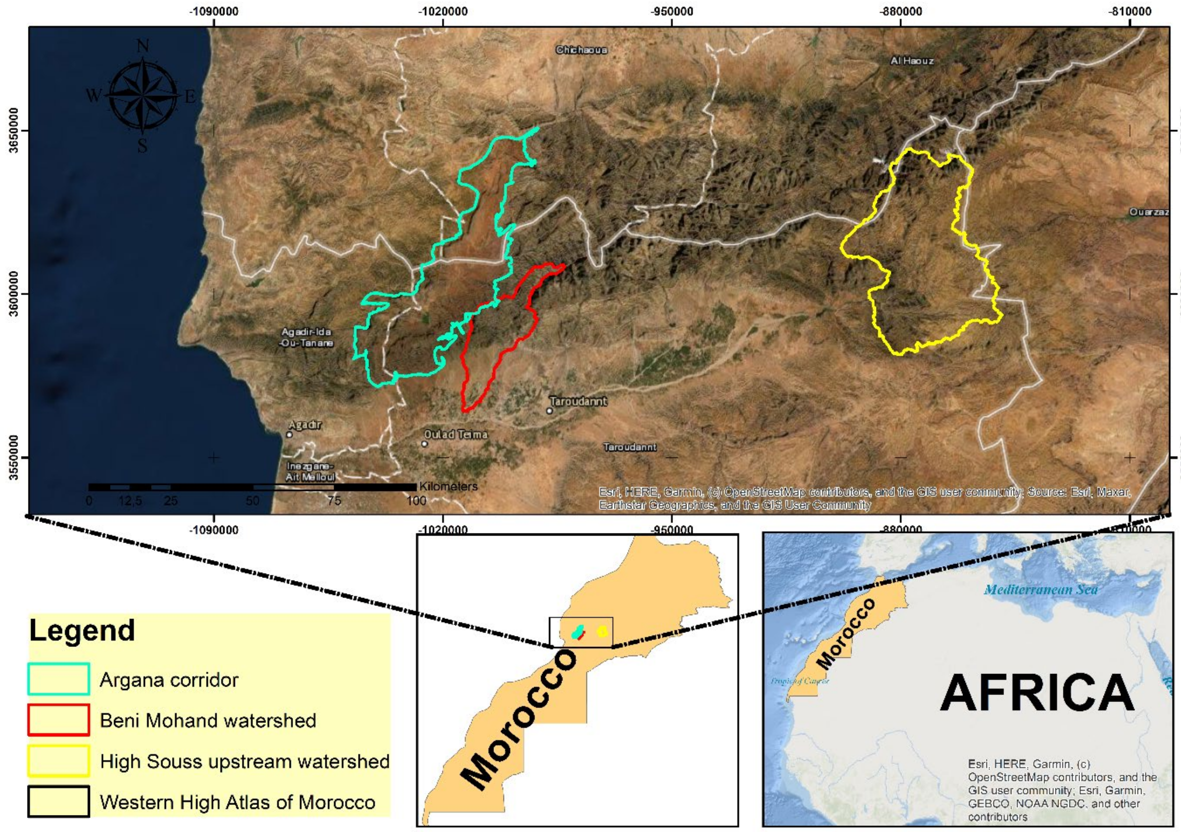


Fig. 1 Location of the studied area

Materials and methods

1. Data sources and collection approaches

The following table presents the used data in soil loss assessment in the three areas of the WHAM, as data inputs to the RUSLE. All information about their sources and characteristics are described in Table 1:

Table 1: Data availability (sources and characteristics)

Datasets	Data source	Data characteristics
DEM	Advanced Land Observing Satellite (ALOS)	12.5 m of spatial resolution, it is used to extract the slopes, their lengths and orientations, as well as to derive the hydrographic network. Data are sourced from https://search.asf.alaska.edu
Soil data	FAO Universal Soil Database	Data on soil type, organic component and texture. Data are sourced from http://www.fao.org/land-water/databases-and-software/en/
Rainfall data	Regional Office for Agricultural Development of Souss Massa (ORMVASM) and the Souss Massa Hydrographic Basin Agency (ABHSM) in Morocco	Rainfall data (1968-2014) included a time series of monthly rainfall from different climatological stations located in and around the study areas. These data include monthly average precipitation data from 33 climatic stations.
Land cover	Landsat 8 satellite imagery	This image was acquired on October 29, 2019. The LC08 imagery was captured using a multispectral imaging sensor providing 11 bands, with a UTM/WGS84 projection (Zone 29) and a resolution of 30 m; they are encoded on 16 bits and can be downloaded for free from the United States Geological Survey GloVis (USGS) website at: https://glovis.usgs.gov/app
Field truth data	Google Earth satellite imagery	Targeted field observations to validate areas at risk of erosion.

2. Revised Universal Soil Equation (RUSLE)

This study is based on the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), in its revised version, called the RUSLE (Arnoldus 1980). The RUSLE is flexible and efficient for erosion modeling, providing a quantitative map of potential erosion, even if some of the dataset inputs are lacking. The RUSLE model is a set of mathematical equations based on five controlling factors. These factors are integrated in a GIS environment and combined to compute estimates of average annual soil loss. The RUSLE is shown in Fig. 2 and expressed as (Eq 1):

$$A = R \times K \times LS \times C \times P$$

Eq 1

where *A* is the average annual soil loss rate (t/ha/year), *R* : the rainfall erosivity factor (MJ mm/ha h year), *K* : the soil erodibility factor (t *h* / MJ mm), LS : the topographic factor (L in *m*, S in %), *C* : the cover vegetation factor, and *P*: the soil conservation practices.

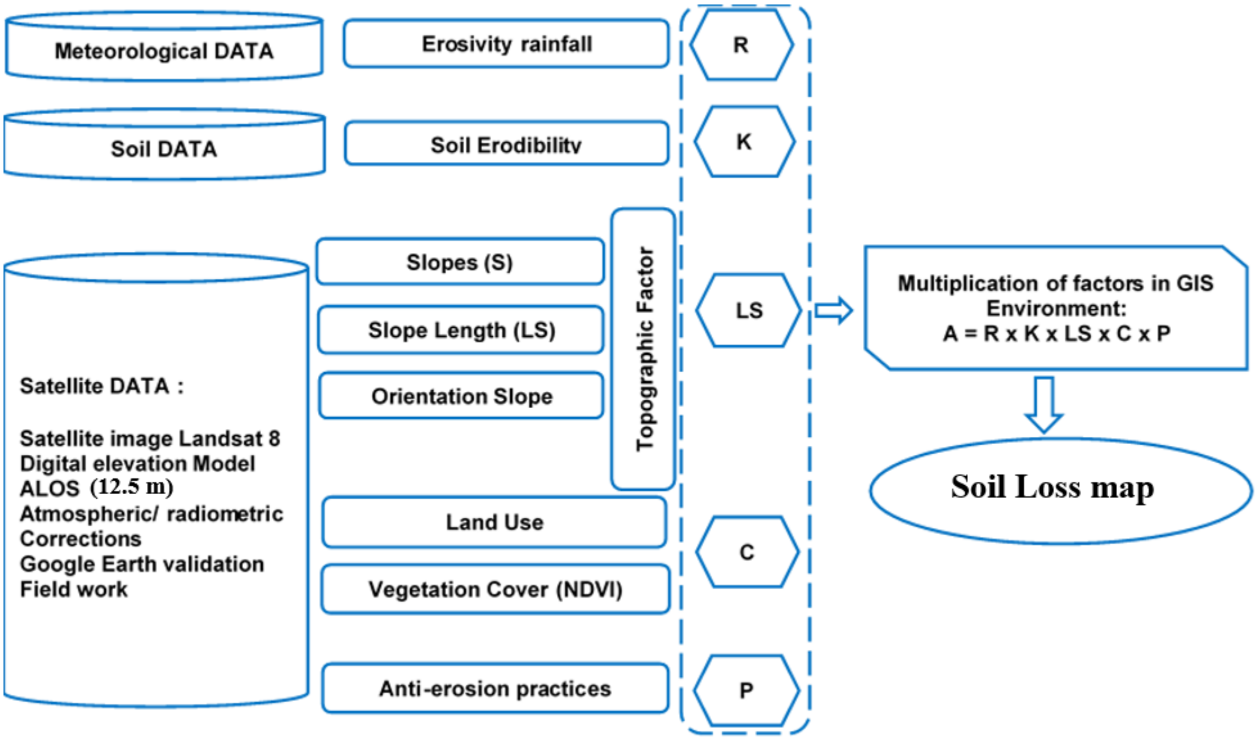


Fig. 2 The RUSLE methodology flowchart.

a. Rainfall erosivity factor (R):

The rainfall erosivity factor is the driving force of erosion by rainfall. The R factor reflects the impacts of key rainfall characteristics that cause soil erosion, explicitly rainfall duration and intensity. This factor reflects the sensitivity of an area to erosion based on rainfall forces. In the RUSLE model, the R factor uses the kinetic energy generated over 30 minutes at its maximum intensity (Issa et al. 2014; Wischmeier and Smith 1978). The rainfall datasets used here are restricted to monthly and annual rainfall records (1968–2014) collected from the regional government agricultural (ORMVASM) and water resource (ABHSM) agencies (see data source section above). Due to this dataset limitation, the alternative approach of Arnoldus (1980) (Eq 2) has been applied to 15 climatic stations located in and around the study area (Fig. 3):

$$R = \sum_{i=1}^{n=12} (MRi^2)/AR$$

Eq 2

where R represents the average rainfall erosivity (MJ.mm/ha.H.year), MRi reffers to the average monthly precipitation in millimeters, and AR represents the average annual precipitation in millimeters.

Rainfall data are interpolated using the Inverse Distance Weighted (IDW) method. It is a deterministic interpolation approach that accounts for the influence of the spatial distancing from one climate station to another enabling creation of a rainfall erosivity map (Fig. 3). This IDW method has been successfully useful to calculate the erosivity factor (Dissanayake et al. 2019). The resulting R factor quantification output represents a thematic map showing the spatial distribution of rainfall aggressivity across the WHAM (Fig. 3).

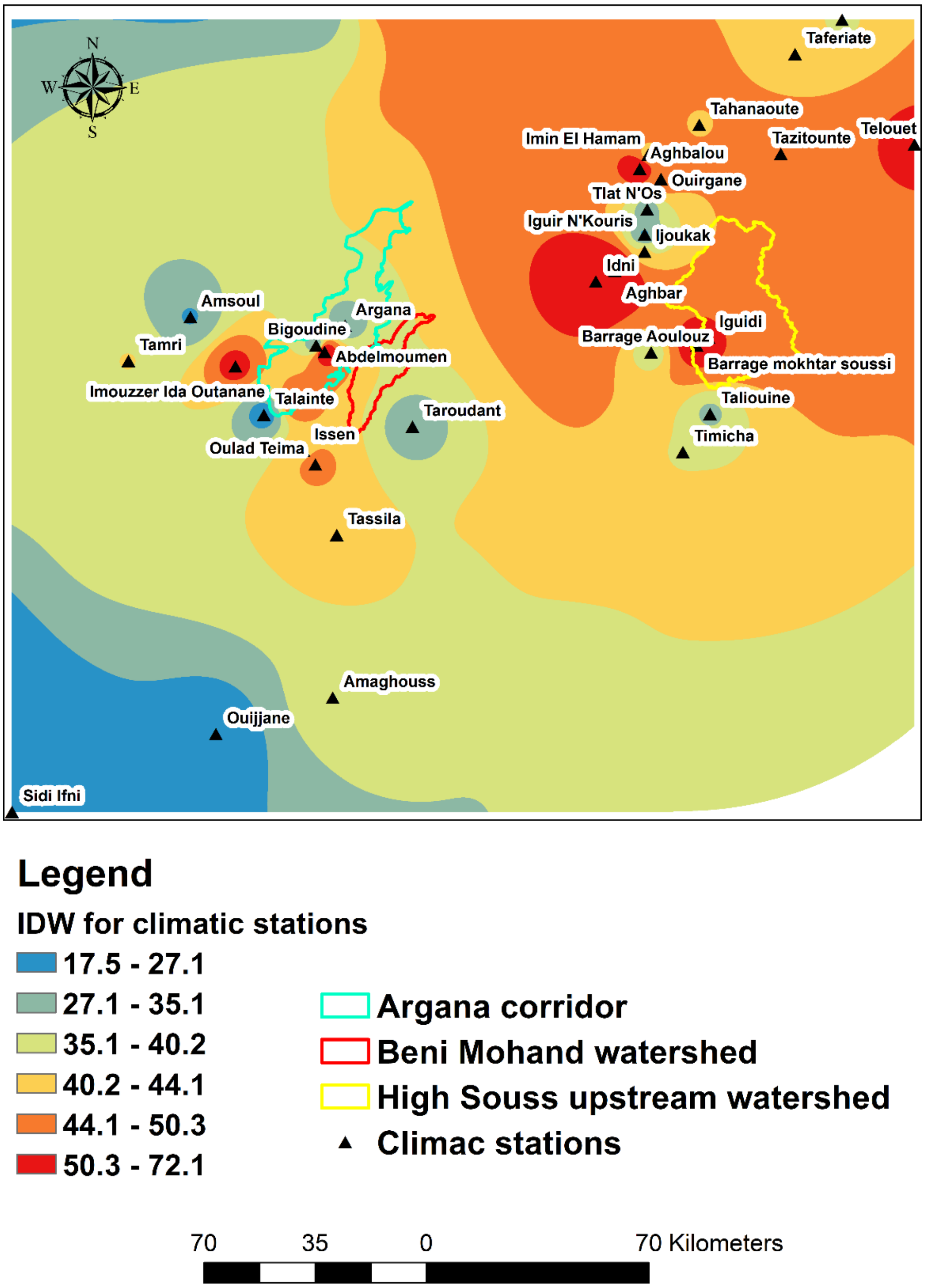


Fig. 3 Location of climatic stations

b. Soil Erodibility Factor (K):

Soil erodibility corresponds to the sensitivity of soil particles to rainfall impact and runoff detachment processes, contextualized by different soil characteristics (Pérez-Rodríguez et al. 2007). This erodibility factor quantifies the contribution of the intrinsic soil characteristics, such as its texture (sand, silt, and clay composition), structure, permeability, profile organization, and organic matter content (Parysow et al. 2003; Wischmeier and

Smith 1978). In other words, this factor indicates the soil erosion susceptibility and resistance. in this study K factor has been calculated using Eq 3 of Sharpley and Williams, (1990) which has demonstrated its effectiveness when applied in a similar environment (Gourfi and Daoudi 2019).

To create the erodibility map, the universal soil database has been used in this study because of the non-availability of this data in the study area. Hence, soil data were extracted from this database, then integrated in a GIS environment using the following formula (Eq 3):

$$K = A \text{ x } B \text{ x } C \text{ x } D \text{ x } 0.1317 \quad \text{Eq 3}$$

where:

$$\mathrm{A} = \left[0.2 + 0.3 \exp\left(-0.0256\, SAN\, \left(1 - \frac{SIL}{100}\right)\right)\right] \quad \text{Eq 4}$$

$$B = \left[\frac{SIL}{CLA + SIL}\right]^{0.3} \quad \text{Eq 5}$$

$$\mathrm{C} = \left[1.0 - \left(\frac{0.25\mathrm{C}}{\mathrm{C} + \exp[(3.72 - 2.95\mathrm{C})]}\right)\right] \quad \text{Eq 6}$$

$$D = \left[1.0 - \frac{0.70\, SN1}{SN1 + exp[(-5.41 + 22.9\, SN1)]}\right] \quad \text{Eq 7}$$

SAN, SIL, and CLA are the percentage of sand, silt, and clay, C is the organic carbon content, and SN1 is the sand minus sand content, divided by 100.

c. Topographic Factor (LS):

The LS ‘topographic factor’ demonstrates the effects of slope length (L) and slope steepness (S) on the erosion process. The LS factor considers these components of a slope to influence the production and transport of slope sediment (Roose 1994). Soil erosion increases where slope length is developed. This increase is even multiplied with steepness. Furthermore, this soil erosion relationship can be influenced by the soil particle size and the vegetation coverage.

In this study, slope steepness (S) and slope length (L) were calculated using a DEM (ALOS-12.5 m), then combined in a GIS environment to compute a topographic map using the following Eq 8 (Wischmeier and Smith 1978):

$$\mathrm{LS} = (\mathrm{L}/22.13)^{\mathrm{m}}\ (0.065 + 0.045\mathrm{S} + 0.0065\mathrm{S}^2)$$

Eq 8

L and S: are respectively the slope length (in m) and the slope steepness (in %) . L = flow accumulation × cell size (DEM spatial resolution) and values of "m" are given in Table 2.

Table 2: Variation of m depending on slope steepness value

Value of m	Slope %
0.5	> 5
0.4	3 - 5
0.3	1 - 3
0.2	< 1

d. Vegetation cover factor (C):

The vegetation or cover-management factor (C) is one of the most important factors controlling the erosion process according to the RUSLE. It represents the effect of vegetation on erosion, as the vegetation intercepts rainfall, increases infiltration and thus collectively decreases rainfall energy.

The vegetation cover factor enables to differentiate between bare and covered lands, and also between type and coverage density. The commonly used technique to generate a C factor map is the Normalized Differential Vegetation Index (NDVI) (Wang et al. 2002). The C factor map has been calculated using the NDVI extracted from Landsat 8 OLI imagery of 30 m resolution, then classified into five classes according to RUSLE Table 3. These classes have been validated using field truth data, for which values have been assigned. These values range between 0 and 0.7 in the study area, where the higher the value is, the lower the coverage (Erencin et al. 2000), meaning that erosion arises in areas with higher C factor values. The NDVI map is calculated using the following formula (Eq 9):

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{R})/(\mathrm{NIR} + \mathrm{R})$$

Eq 9

NIR: is the near-infrared band, belonging to the surface reflectance values of band 5 (Landsat8 OLI), *R :* is the red band belonging to the surface reflectance values of band 4 (Landsat8 OLI).

Table 3: C factor classification depends on the landcover type

Land cover	C factor
Bare land	0.70
Cultivated land	0.60
Land with moderate vegetation cover	0.10
Dense vegetation	0.05
Water (dam)	0

e. **Soil conservation practices factor (P):**

The soil conservation practice factor refers to the ratio of soil loss depending on each agricultural method, based upon the capacity of these various cultivation techniques to conserve soil. There are numerous conservation techniques including ridging, contour plowing, slope terracing, and alternating strip crops. These datasets are not available for the study area, that is why an alternative approach is used instead, determined based on the relationship between cultivation practices and slope (Shin 1999). This method has shown its usefulness in a similar environment. The P factor values range from 0.55 to 1 in this study (Table 4). Lower values are assigned to areas with support practices, while higher values correspond to steep slopes that lack soil conservation practices.

Table 4: Values of soil conservation practices factor (P) depending on slope intervals (Shin 1999)

Slope %	P factor
0.0 – 7.0	0.55
7.0 – 11.3	0.60
11.3 – 17.6	0.80
17.6– 26.8	0.90
>26.8	1.00

f. RUSLE Erosion Map:

The various input datasets have been computed to create the five controlling factors: erosivity (R), erodibility (K), topography (LS), vegetation cover (C), and soil conservation practices (P). The resulting maps are then combined in a GIS environment using the RUSLE formula to produce a soil loss map of the three study areas representing the WHAM, communicating soil loss values and their spatial distributions.

3. Pearson's correlation

In this study, the determination of the key factor(s) controlling erosion in the Western High Atlas is essentially based on the extrapolation of the obtained results in each of the studied regions. In an attempt to clarify the factors that most influence the erosion process in this segment of the Atlas Mountains, this study will provide a framework for management solutions. The understanding of the relationship between erosion and the controlling factors is an important step in the process of management and conservation of both soil and water resources.

To understand the relationship between soil loss and the controlling factors, Pearson correlation method is used for the good results it provides. Pearson's correlation was developed as a matrix to calculate correlation coefficients as a ratio between two layers divided by the product of their standard deviations (Pearson 1896) (Eq 10). This ratio provides a unitless number varying between -1 and +1. It expresses the degree of dependency between the variables (layers).

$$\boldsymbol{R} = \frac{\sum_{i=1}^{n}(\boldsymbol{Xi} - \overline{\boldsymbol{X}})\,(\boldsymbol{Yi} - \overline{\boldsymbol{Y}})}{\sqrt{\sum_{i=1}^{n}(\boldsymbol{Xi} - \overline{\boldsymbol{X}})^2}\,\sqrt{\sum_{i=1}^{n}\,(\boldsymbol{Yi} - \overline{\boldsymbol{Y}})^2}}$$

Eq 10

E : Correlation coefficient
$\boldsymbol{Xi}$: Values of the variable X in a sample
$\overline{\boldsymbol{X}}$: Average of the values of the variable X

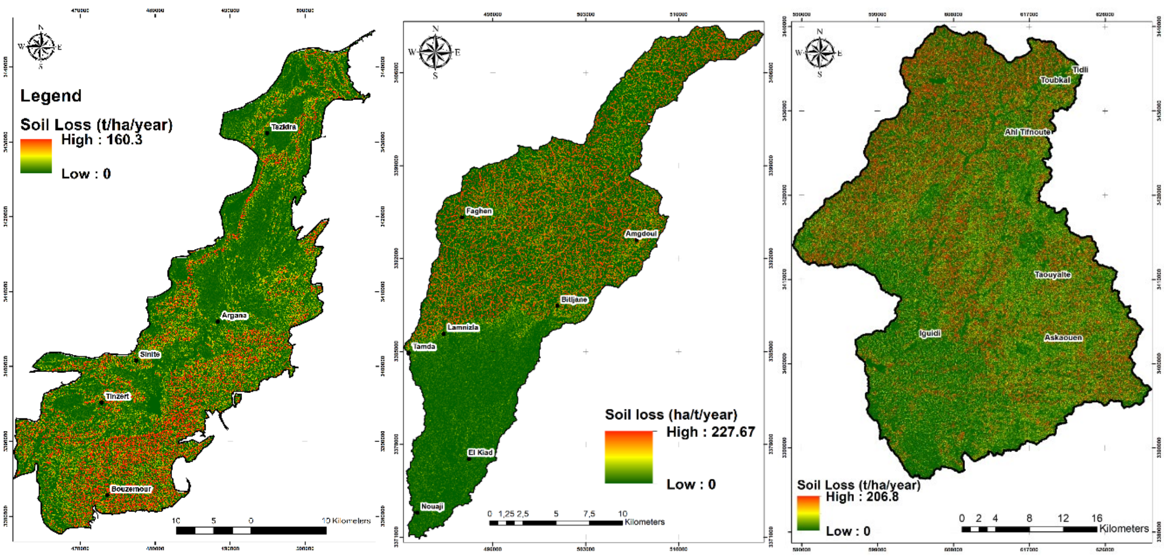
$\boldsymbol{Yi}$: Values of the variable Y in a sample
$\overline{\boldsymbol{Y}}$: Average of the values of the variable Y

Pearson's correlation is used in a GIS environment to examine the dependency between the factors and the soil loss map. The results of this statistical analysis provide a numeric coefficient that indicates the degree of contribution of each factor in the erosion process. Although the factors are measured in different units, this analysis is very useful because it reduces the number of variables to a unitless coefficient, allowing reading and analysis of the factors effectively.

Results & Discussion

1. Erosion maps calculation using RUSLE

The combination of the controlling factors provides a soil erosion map that predicts soil loss for each pixel. The estimation of this last is carried out in three regions/catchment areas in the WHAM, where pieces of evidence of erosion have been observed in the field. These areas are: a) the Argana corridor, b) the Beni Mohand River basin and c) the High Souss upstream watershed (Fig. 4). In this study, we only used the resulting maps, as the detailed process of soil loss map production has been described in previous studies, see the following references for more details (Bou-imajjane et al. 2020, 2022; Bou-imajjane and Belfoul 2020).



a) Argana corridor b) Beni Mohand basin c) High Souss upstream watershed

Fig. 4 Soil loss maps

To streamline the reading, analysis and interpretation of soil loss maps, we have used the same data sources and adopted FAO's classification (FAO 1980). This classification considers that soils can sustain up to 5 (t/ha/yr). Above this value, soils will be subject to moderate to severe degradation, which may affect both agricultural production and natural resources. The application of this classification will also help to better guide the choice of management techniques to control erosion.

Findings, in the Argana corridor, show that this area is subject to significant erosive risk with average annual losses ranging from 0 to 160.3 (t/ha/yr). This rate is equivalent to an average loss of 47.52 (t/ha/yr), with a total quantity of 5.2 million tons per year. Table 5 summarizes the outcomes of the Argana's study, all the details are meticulously described in a previous study (Bou-imajjane et al. 2020).

These soil losses cover 3.85% of the total area of the Argana corridor exceeding the tolerance threshold.

Table 5 : Overview of erosion study results in the Argana Corridor (Bou-imajjane et al. 2020)

	Low	**Moderate**	**Average**	**High**	**Very high to severe**
Soil Loss **(t/ha/an)**	**< 5**	**5 – 25**	**25 – 50**	**50 – 100**	**>100**
Area **(%)**	96.15	2.63	0.44	0.39	0.39
R factor **(MJ.mm/ha.H.an)**	**24.47 – 27.12**	**27.12 – 33.02**	**33.02 – 38.93**	**38.93 – 44.84**	**44.84 – 53.89**
Area **(%)**	0.57	41.90	25.94	21.25	10.32
K **(t.ha.H / ha.MJ.mm)**	**0.0138**	**0.0183**		**0.0227**	
Area **(%)**	73.61	26.05		0.34	
(LS) factor	**0.00 – 4.67**	**4.67 – 10.68**		**10.68 – 16.69**	**16.69 – 568.02**
Area **(%)**	90.90	4.32		2.26	2.52
C factor	**0 water bodies**	**0.05 Dense vegetation**	**0.10 Average vegetation cover**	**0.60 cultivated land**	**0.70 bare land**
Area **(%)**	0.44	6.47	13.07	0.34	79.68
P factor	**0.55**	**0.60**	**0.80**	**0.90**	**1**
Area **(%)**	16.98	13.36	14.56	15.05	40.05

In the case of the Beni Mohand river basin, the average annual loss rate is estimated to vary between 0 and 227.67 (t/ha/yr), with an average loss by water erosion calculated to 40.38 (t/ha/yr) and a quantity of soil loss that reaches 1.4 Million (tons/year). These soil losses cover 15.49% of the total area. Table 6 shows the values attributed to each of the influencing factors. These results are taken from a previous study conducted in Beni Mohand basin (Bou-imajjane and Belfoul 2020).

Table 6 : Overview of erosion study results in Beni Mohand river basin (Bou-imajjane and Belfoul 2020)

	Low	**Moderate**	**Average**	**High**	**Very high to severe**
Soil Loss **(t/ha/an)**	**< 5**	**5 – 25**	**25 – 50**	**50 – 100**	**>100**
Area **(%)**	84.51	12.91	2.31	0.14	0.13

R factor **(MJ.mm/ha.H.an)**	**35.65 – 36.21**	**36.21 – 37.69**	**37.69 – 39.18**	**39.18 – 40.67**	**40.67 – 44.56**
Area (%)	0.45	6.29	18.37	47.09	27.8
K **(t.ha.H / ha.MJ.mm)**	**0.0176**	**0.0183**		**0.0227**	
Area (%)	61.66	24.59		13.74	
(LS) factor	**0 – 4.02**	**4.02 – 9.80**		**9.80 – 15.58**	**15.58 – 664.57**
Area (%)	94.29	2.11		1.39	2.22
C factor	**0 water bodies**	**0.05 Dense vegetation**	**0.10 Average vegetation cover**	**0.60 cultivated land**	**0.70 bare land**
Area (%)	0	6.42	12.98	2.12	78.5
P factor	**0.55**	**0.60**	**0.80**	**0.90**	**1**
Area (%)	25.87	5.85	4.51	7.77	56

In the High Souss Upstream watershed (Bou-imajjane et al. 2022), the average annual loss rate varies from 0 to 206.8 (t/ha/year), with an average loss estimated at 57.27 (t/ha/year). These annual losses equivalent to 7.3 million (t/yr) cover 2.09% of the total area. Table 7 provides detailed results of this study taken from the following reference (Bou-imajjane et al. 2022).

Table 7 : Overview of erosion study results in High Souss upstream watershed (Bou-imajjane et al. 2022)

	Low	**Moderate**	**Average**	**High**	**Very high to severe**
Soil Loss **(t/ha/an)**	**< 5**	**5 – 25**	**25 – 50**	**50 – 100**	**>100**
Area (%)	97.91	1.92	0.08	0.05	0.04
R factor **(MJ.mm/ha.H.an)**	**41.5 - 46.3**	**46.3 - 48.5**	**48.5 - 50.8**	**50.8 - 53.0**	**53.0 - 57.9**
Area (%)	21.25	2.7	44.83	28.8	2.42
K **(t.ha.H / ha.MJ.mm)**	**0.0183**				
Area (%)	100				
(LS) factor	**0.00 – 2.41**	**2.41 – 8.08**	**8.08 – 13.75**	**13.75 – 19.42**	**19.42 – 528.2**
Area (%)	87.65	8.21	2.34	0.99	0.79
C factor	**0 water bodies**	**0.05 Dense vegetation**	**0.10 Average vegetation cover**	**0.60 cultivated land**	**0.70 bare land**

Area (%)	0.14	10.48	25.16	0.87	63.35
P factor	**0.55**	**0.60**	**0.80**	**0.90**	**1**
Area (%)	3.38	5.20	9.94	14.25	67.23

According to these findings, the area where soil losses occur on a considerable scale is the Beni Mohand river basin since 15.49% of the lands are exposed to significant losses, followed by the Argana corridor with 3.85% and finally the Upper Souss basin with only 2.09% of lands. Moreover, despite the large areas of damaged terrains, such as the Beni Mohand basin, erosion can be intensified in certain areas, reaching alarming levels. This was the case for the Argana Corridor with erosion rates ranging from 0 to 160.3 (t/ha/yr), where the estimated average loss of 47.52 (t/ha/yr). This difference is explained by the fact that, the interaction of factors in the same basin changes from one place to another, depending on the influence of the controlling factors (Table 8).

Table 8 : Overview of soil loss and controlling factors values in the three areas

	Argana Corridor	Beni Mohand river basin	High Souss upstream watershed
R factor **(MJ.mm/ha.H.an)**	**24.47 - 53.89**	**35.65 - 44.56**	**41.5 - 57.9**
K factor **(t.ha.H / ha.MJ.mm)**	**0.0138 - 0.0227**	**0.0176 – 0.0227**	**0.0183**
LS factor	**0 – 568.02**	**0 - 664.57**	**0 - 528.2**
C factor	**0 – 0.70**	**0.05 – 0.7**	**0 – 0.7**
P factor	**0.55 - 1**	**0.55 - 1**	**0.55 - 1**
Total Area **(ha)**	**110143**	**34894**	**127962**
Soil loss **(t/ha/an)**	**Entre 0 et 160.3**	**Entre 0 et 227.67**	**0 à 206.8**
% Area at risk	**3.85 %**	**15.49 %**	**2.09 %**
Soil loss quantity **(tonnes)**	**5.2 Million**	**1.4 Million**	**7.3 Million**

Average annual soil loss **(t/ha/an)**	**47.52**	**40.38**	**57.27**

2. Statistical analysis using Pearson's correlation

In a GIS environment, we used the thematic maps of the controlling factors and also the erosion map as an input to calculate correlation coefficient between the soil loss map and each one of the factors, in order to estimate the impact of these factors on the erosive process. This statistical analysis has been applied to the three studied areas that are: Argana corridor, Beni Mohand River Basin and High Souss upstream watershed. The outcome of this processing represents a table that contains the controlling factors (R, K, LS, C, P) and the soil loss map as variables. The numeric coefficient in each cell is a unitless number that quantifies the degree of dependency between two variables.

a. Argana Corridor

The correlation matrix (Pearson correlation) calculated for the Argana Corridor (Table 9), shows that soil losses have a significant positive correlation with the topographic factor (LS) of (R1=0.84) and a fairly moderate correlation with the soil conservation practices factor (P) (R1=0.20). It also shows a weak correlation with the vegetation cover factor (C) (R1=0.10), soil erodibility factor (K) (R1= 0.09) and rainfall erosion (R1=0.06).

Table 9 : Correlation matrix (Pearson) of the Argana Corridor

Variables	R	K	LS	C	P	Soil loss
R	1	0.00387	0.02967	-0.12350	0.10249	0.06335
K	0.00387	1	0.07121	-0.05398	0.23514	0.09842
LS	0.02967	0.07121	1	-0.04828	0.23958	**0.84343**
C	-0.12350	-0.05398	-0.04828	1	-0.16420	**0.10229**
P	0.10249	0.23514	0.23958	-0.16420	1	**0.20749**
Soil loss	0.06335	0.09842	**0.84343**	**0.10229**	**0.20749**	1

b. Beni Mohand River Basin

For Beni Mohand River basin, the calculated correlation matrix also shows that soil loss has a positive and significant correlation with the topographic factor (LS) (R2=0.43). An almost average correlation was calculated for the soil conservation practices (P) of (R2=0.13) and a weak correlation for the vegetation cover factor (C) with a coefficient of (R2=0.07). However, the rainfall erosivity (R) and soil erodibility (K) factors showed almost no dependency on the soil loss layer (Table 10).

Table 10 : Correlation matrix (Pearson) of Beni Mohand river basin

Variables	R	K	LS	C	P	Soil loss
R	1	0.46338	-0.06919	0.08011	-0.44977	-0.04869
K	0.46338	1	-0.06922	0.03695	-0.52307	-0.06766
LS	-0.06919	-0.06922	1	-0.03600	0.14395	**0.43512**
C	0.08011	0.03695	-0.03600	1	-0.23656	**0.07809**
P	-0.44977	-0.52307	0.14395	-0.23656	1	**0.13628**
Soil loss	-0.04869	-0.06766	**0.43512**	**0.07809**	**0.13628**	1

c. The High Souss upstream watershed

For the High Souss upstream watershed, the correlation demonstrated a significant dependency of soil losses on the topographic factor with a value of (R3=0,81), a positive correlation fairly moderate with the vegetation cover factor (R3=0,16) and a weak correlation was recorded for the anti-erosion practices factor (R3=0,11). On the other hand, there is evidence of independence from the soil erodibility factor (K) with (R3=0) and a negative but weak correlation for the rainfall erosivity factor (R) (R3= -0.08) (Table 11).

Table 11 : Correlation matrix (Pearson) of High Souss upstream watershed

Variables	R	K	LS	C	P	Soil loss
R	1	0.000004	-0.02939	-0.29937	-0.01487	-0.08568
K	0.000004	1	23.17370	0.0000001	-0.0000007	0.00000001
LS	-0.02939	23.17370	1	-0.01994	0.12923	**0.81678**
C	-0.29937	0.0000001	-0.01994	1	-0.11391	**0.16929**
P	-0.01487	-0.0000007	0.12923	0.81678	1	**0.11102**
Soil loss	-0.08568	0.00000001	**0.81678**	**0.16929**	**0.11102**	1

3. Key factor (s) triggering erosion in WHAM

Pearson's correlation was applied to identify the factors having an impact on the erosion process. Findings obtained from this statistical analysis show a significant and positive correlation in the Argana corridor, the Beni Mohand basin and the High Souss upstream watershed with the topographic factor (LS), with a high correlation coefficient. This analysis showed as well a medium correlation for the soil conservation practices factor (P), followed by the vegetation cover factor (C) with a low correlation. On the opposite side, the soil erodibility factor (K) and the rainfall erosivity factor (R) demonstrated almost no correlation in this area (Table 12).

Table 12 : Independence calculation of factors to soil loss in the three locations as interpreted by (Cohen 1988)

	Argana Corridor	Beni Mohand river basin	High Souss upstream watershed
R factor **(MJ.mm/ha.H.an)**	Low correlation (R1=0.06)	No correlation	Very low and negative correlation (R3= -0.08)
K factor **(t.ha.H / ha.MJ.mm)**	Low correlation (R1= 0.09)	No correlation	No correlation
LS factor	High correlation (R1=0.84)	Average correlation (R2=0.43)	High correlation (R3=0.81)
C factor	Low correlation (R1=0.10)	Low correlation (R2=0.07)	Moderate to low correlation (R3=0.16)
P factor	Moderate to low correlation (R1=0.20)	Moderate to low correlation (R2=0.13)	Low correlation (R3=0.11)

The correlation outcomes have been very effective in revealing the key factor controlling erosion in a typical semi-arid climate environment such as the Western High Atlas. The determining parameter is undoubtedly the topographic factor (LS), since it is strongly correlated with soil losses. This has been clearly expressed by the high values of the topographic factor (LS), which reach 664.57, and thus leads to a high level of soil loss ranging from 40.38 (t/ha/yr) to 57.27 (t/ha/yr).

Although some conservation practices existed in the region (referring to the method of (Shin 1999) based on the estimation of the P-factor from slope data), the (P)-factor of erosion control practices remains moderately correlated with soil losses. On the other hand, there is a moderate to low correlation for the vegetation cover factor, even though the region has a large area occupied by bare soils and therefore highly vulnerable to erosion. The studied areas present a significant rainfall erosivity, nevertheless, there is a weak correlation. The same case for the factor of soil erodibility presents a dependency almost equal to zero. This can be explained by the lack of data and the scarcity of the WHAM, which ended up getting a generalized study, where the more detailed the datasets, the more effective the study.

Conclusions

Findings show that, based on the quantitative model of the revised universal soil loss equation (RUSLE), the investigated areas have a significant erosive potential reaching alarming rates. For the Argana corridor, the rate of soil loss varies from 0 to 160.3 (t/ha/yr), a rate of 0 to 206.8 (t/ha/yr) for the High Souss upstream basin and 0 to 227.67 (t/ha/yr) for the Beni Mohand basin. These regions have respectively an average annual rate of soil loss of 47.52, 57.27 and 40.38 (t/ha/year). This is equivalent to an annual amount of soil loss estimated at 5.2 million (t/year) for the corridor of Argana, for the basin of Beni Mohand the amount of loss is 1.4 million (t/year) and 7.3 million tons for High Souss upstream basin.

In addition, Pearson's correlation combined with the RUSLE model have been very useful in determining the key factor that triggers soil loss in WHAM. Indeed, the used methodology has shown high positive values for the topographic factor, demonstrating a high dependency of the erosion to the topographic factor, followed by the soil conservation practices factor (P) with moderate positive values and the vegetation cover factor (C) with slightly low values. This means that erosion is more likely to occur on steep slopes of significant length slope, where lands are less protected and land use is sensitive to erosion.

Therefore, these three factors require significant attention when planning, by adopting conservation measures to reduce runoff by breaking up the slope length. From a soil conservation practice point of view, it is essential to encourage farmers to adopt agricultural approaches that can improve surface conditions. It is also recommended to implement these techniques in areas of high vulnerability first, particularly in areas where the LS factor is high and where conservation practices are scarce. This is mainly the case in the areas around rivers with high losses and also near dams to minimize the siltation rate.

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