Potential Soil Erosion Modeled with RUSLE Approach and Geospatial Techniques (GIS Tools and Remote Sensing) in Oued Joumouaa Watershed (Western Prerif-Morocco)

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Abstract

Water erosion is a complicated phenomenon that contributes to soil degradation and is linked to natural and anthropogenic causes that are difficult to manage in time and space. It has a significant impact on our country and necessitates a number of studies and efforts to prevent and manage it. Geospatial approaches (GIS tools and remote sensing (RS) data) were used to test the RUSLE strategy in the Joumouaa watershed, where it was found to be accurate. The latter is a mountainous range with a 60 km² area that is part of the Western Prérif and in the Teroual region (northern Morocco). The proposed technique integrates the RUSLE for calculating erosion with geospatial techniques for detecting variables that cause water erosion and soil loss. The erosivity factor R had a range of values, with an average of 1832.76 to 1968.87. It was shown that soils had an erodibility factor k of 0.016 to 0.0245, which indicates that they are the most vulnerable. With the upstream being rougher and more sensitive, the LS factor ranged from O and more than 43%. According to the nature of the land, there are different C factors. Water erosion affects all regions of the basin to varying degrees, depending on the processes that cause erosion. The results show that the soils in the Joumouaa watershed are medium to highly erodible, with maximum erodibility ranging from 50 to 280 t/h/year, a sparse plant covers with little protection, and moderate to high climatic aggressiveness. An understanding of the danger of soil erosion may be gained from this study, as well as a guide for land management techniques and land planning that can be used to construct a decision support tool in terms of natural resource management.

Keywords: Soil erosion; RUSLE model; Geospatial techniques; Joumouaa watershed; Erodibility

1. Introduction

Water erosion is a damaging phenomenon to the ecosystem in general. On several scales, it has detrimental effects on the socio-economic framework (national, regional, local). It has a negative impact on natural resources, agricultural production, water quality, and infrastructure, among other things (Benzougagh, 2020; 2022). According to research conducted by the United Nations Food Organization (FAO), deteriorated soils cover 12.6 million hectares of cropland and rangeland in Morocco (Zouagui

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et al., 1977). According to a recent FAO assessment from 1990, water erosion destroyed 40% of the land in the entire region (Lufafa et al., 2003).

Water erosion is a significant environmental concern in Morocco. It is the primary source of soil degradation. As a result of this, the ecological system's long-term health and socially responsible development are directly affected, and the quality of the environment is improved (Forootan Danesh et al., 2020; Meshram et al., 2017; Ren et al., 2018). Many researches have been conducted on the issue of water El garouani, 2008; Sadiki et al., 2004; Al karkouri, 2003). Water erosion mapping is a critical technique for understanding the phenomenon's distribution and geographic scope, as well as determining its quality. The empirical equation established in the US to estimate soil erosion loss in agricultural fields has been widely used around the world in its original or modified form, including in the Maghreb and Morocco. The six elements that regulate water erosion include soil slope, climatic aggressiveness, soil erodibility, and anti-erosion techniques, and RUSLE is a multiplicative function of them (Renard et al., 1997).

Due to the ease with which spatial data can be accessed, interpreted, and classified using GIS, the RUSLE model has been successfully applied to the prediction of soil erosion via the use of geospatial approaches (Lufafa et al., 2003). Precipitation pattern (R variable), topography (LS indicator), plant cover (C indicator), soil type (K factor), and management strategies are all factors that can affect soil erosion in the Joumouaa watershed. This study will look at how these factors affect the risk of soil erosion (P factor). As a bonus, it could also be used to encourage land management practices that keep soil from being eroded and improve culture and governance. The method and results of this study are important for figuring out how likely it is that soil will be eroded, as well as for planning land management strategies and making decisions about how to protect natural resources.

2. Study Area

The watershed of Oued Joumouaa is part of the large watershed of Oued Ouergha, with an impluvium of nearly 60 Km² and perimeter of 59 km. Its northern and southern borders are with Zoumi, while its eastern and western borders are with Oued Ouergha, Oued Drader, and Tafrant Ouergha. It is located in the southern Rift Valley between the longitudes 5° 18.985'O and 5° 15.723'O east and the latitudes 34° 43.916'N and 34° 35.176'N north. (Fig.1).

![Map of localization of Joumouaa Watershed](image-url)

Fig.1. Map of localization of Joumouaa Watershed
On the USGS website, you can find a Digital Elevation Model (DEM) of the basin region with a resolution of 30 meters, which shows how high the basin surface is and how it looks like. This model is called a Digital Elevation Model (DEM). With altitudes ranging from 92 meters to 756 meters, the Joumouaa basin has a somewhat rugged nature (Fig.2). Table 1 summarizes this distribution of altitude ranges. Soil erosion is exacerbated by higher runoff owing to the presence of steeper slopes and less permeable surfaces in the Oued Joumouaa basin. (Table 2 shows info on slope variations and proportions of slope) (Fig.2b).

**Table 1. Summary of altitude range distribution in the oued Joumouaa.**

| Altitude | Area in km² | Cumulative area in km² | Area in % | Cumulative in% |
|----------|-------------|------------------------|-----------|----------------|
| 760-600  | 17,52       | 17,52                  | 29.2      | 29.2           |
| 600-500  | 14,19       | 31,71                  | 23.65     | 52.85          |
| 500-400  | 11,37       | 43,08                  | 18.95     | 71.8           |
| 400-300  | 9,94        | 53,02                  | 16.56     | 88.36          |
| 300-200  | 3,77        | 56,79                  | 6.28      | 94.64          |
| 200-92   | 3,12        | 60                     | 5.2       | 100            |

**Fig.2. A.** Elevation map of o.Joumouaa basin; B) Slope map of the o.Joumouaa basin.
Table 2. The Oued Joumouaa basin’s slope classes.

| Class | Slope in % | Area in km² | Area in % |
|-------|------------|-------------|-----------|
| 1     | <5         | 21.27       | 37.074    |
| 2     | 5-10       | 14.90       | 25.96     |
| 3     | 10-15      | 14.74       | 25.68     |
| 4     | 15-42      | 3.86        | 6.73      |
| 5     | >42        | 2.60        | 4.53      |

2.1. Precipitation

The hydrologic component of its rivers requires knowledge of its climatic parameters (Remondi et al., 2016). When the soil isn't covered by vegetation at certain times of the year, precipitation may have a significant influence on the physical environment, contributing to active soil degradation procedures (Abdellah et al., 2018). Data from 1974 to 2004 was evaluated in our research region to determine how precipitation in the area changed over time. Basin-wide precipitation varies greatly from year to year, with significant seasonal and interannual variability. At the Teroual station, the average yearly rainfall readings reveal a modulus of 428.74 mm based on 30 years of data (1974-2004). By examining yearly rainfall, we observed that 1986 was the wettest year of the 30 years, with precipitation totaling 875.3 mm, indicating an excess of rainfall (Fig. 3). 1981 was the driest year, with 115.6 mm. It should be noted that no recordings were made in 200.

Fig.3. Annual Precipitation at Teroual station (1974-2004).

2.2. Land use/land cover

The rate at which land is used affects the rate at which erosion occurs, which in turn affects the rate at which it occurs. Land usage determines the level of soil protection. As a result, vegetation cover has
a significant impact on linear erosion. In addition to absorbing rainfall mechanical energy, it presents a broad area of soil, limits drainage, and maintains high porosity at the soil surface. Its effect is increased. In the year of our Lord (Maqsoom and al, 2020). Plant cover, on the other hand, improves soil permeability and reduces runoff volume in the event of rainfall. Meso-fauna may flourish when runoff energy is absorbed by rubbish, which limits the pace at which it infiltrates (Roose and Sarraillh, 1990). Land use patterns in the Oued Joumouaa basin are shown in Figs. 4 and 5. The Oued Joumouaa basin's geographical position and configuration result in a land use that is dominated by natural habitats and agricultural operations. The following are some of the things we're looking into: The north and west mountain ranges were covered in woodland and shrubland, while the valley bottoms held most of the agricultural land. The catchment region is represented in Table 3 by the areas of various land uses. We discovered that natural environment vegetation (Arboriculture 24.95%) prevails, followed by intensive culture 6.4%.

![Fig.4. Land use and land cover in the O. Joumouaa watershed](image-url)
3. Material and Methodology

We used an approach based on Renard et al. (1991) universal soil loss equation (RUSLE) to identify soil susceptibility to water erosion risk in the Joumouaa watershed. Many researchers throughout the world have adopted this method. Water erosion risk assessment and mapping particularly in Morocco (El Garouani et al., 2008; Benzougagh et al., 2020). A model for estimating erosion that takes six significant parameters into consideration is represented by the RUSLE equation (Fig. 6). It is written as follows:

\[
A = R \times K \times LS \times C \times P
\]  

Where:
A: The average soil erosion per surface unit (t/ha/year);
R: The rainfall and runoff erosivity factor (Mjmm/ha-H-year);
K : Soil erodibility (t-ha-ha-MJ-mm);
LS: Slope length (L) and steepness (S);
C: Vegetation cover, management, and cultural methods;
P: Conservation practice.

The application of this equation necessitated a thorough examination of the universal equation's many components across the whole catchment area, as well as their representation in the form of thematic maps. The QGIS Geographic Information System, version 2.18.2, uses digitization to incorporate these maps (open source software). Each pixel's several polygons are linked to their respective databases. The "Modeller" module connected the Renard et al. (1991) model's mathematical equations to the GIS "Overlay" module, allowing the rate of erosion to be determined at all sites in the basin. Additionally, using the technique outlined below, create the soil loss map. Fig. 6 depicts the proposed methodology for the erosion model.
3.1. Rainfall Erosivity (R-factor)

Water erosion is primarily caused by rain. Its erosivity is primarily determined by its quantity and intensity (over 30 minutes), as well as the kinetic energy generated immediately by it. Rainfall accelerates soil erosion in the watershed, according to numerous studies. Rainfall on a daily basis provides a more realistic picture of seasonal sediment output distribution and soil erosion rate (Srinivasan et al. 2019). The erosive danger increases as the intensity of the rain increases; this factor was calculated using Renard and Freimund’s (1994) method as following equation (2):

There are a number of rain gauges located across the Joumouaa watershed that provide data for the R factor (Table 3).

\[
R = 0.4830P^{1.610} \quad \text{If} \quad P < 850 \text{ mm} \quad (2)
\]

\[
R = 587.8 - 1.219P + 0.004105P^2 \quad \text{If} \quad P > 850
\]

**Table 3.** Precipitation stations in oued Joumouaa Watershed

| Station   | Latitude    | Longitude   | Elevation (m) |
|-----------|-------------|-------------|---------------|
| Teroual   | 34° 40.538’N| 5° 16.185’O | 454           |
| Zoumi     | 34° 48.196’N| 5° 20.655’O | 368           |
| Tafrant   | 34° 37.528’N| 5° 7.186’O  | 234           |
| Ouazzane  | 34° 47.722’N| 5° 34.054’O | 285           |
| Lamjaara  | 34° 35.400’N| 5° 15.000’O | 95            |

This method was used to construct the climatic aggression index for 6 sites within or adjacent to the watershed. These data show not only how crucial precipitation is in erosive processes, but also that it is a significant influence in the erosion process. Qgis has been used to interpolate precipitation data employing inverse distance weighting (IDW) interpolation, which is a sort of interpolation.
3.2. Soil Map Erodibility (K-factor)

The K-factor quantifies the cumulative effects of soil factors on the texture of the soil. However, it demonstrates that a certain soil type is resistant to erosion in general. It’s a measurement for how quickly rain and runoff may separate and transport soil particles. Because of the dearth of information on soil quality in the Oued Joumouaa basin, K values were derived using FAO data (Digital Soil Map of the World, 2019). (Toubal et al., 2018). An erosion vulnerability and rate can be determined by the k-factor, which is also known as the erodibility factor. The William et al. approach was used to compute the K-factor:

\[
K = \left[ 0.2 + 0.3 \exp \left( 0.0256 \times SAN \left( 1 - \frac{SIL}{100} \right) \right) \right]
\]

\[
\left( \frac{SIL}{CLA + SIL} \right)^{0.8} \times \left[ 1 - \frac{0.25C}{\exp \left( 3.72 - 2.95C \right)} \right] \times \left[ 1 - \frac{0.75N1}{SN1 + \exp \left( -5.51 + 2.95N1 \right)} \right]
\]

SAN, SIL, and CLA are the abbreviations for the soil sand fraction, silt fraction, and clay fraction (percent). The symbol C stands for the carbon content of the topsoil (percent). SN1=1-SAN/100. Texture, roughness, structure, organic matter content, and moisture content all have an effect on the soil’s ability to withstand erosion. Soil's erodibility and erosion susceptibility are reduced by its organic content. The split has resulted in an increase of infiltration.

3.3. Slope length and steepness (LS-factor)

For example, the slope length and angle have an impact on sheet and rill erosion. Runoff source to site of deposition or concentration is referred to as slope length, which is the distance between these two points. It’s also critical to consider the slope length and steepness, which represent the flow's capacity to transport material (Moore and Wilson, 1992). As part of this experiment, the formula for calculating the LS factor (4) was as follows (4):

\[
LS = \left( FA \times \frac{\text{CellSize}}{25.13} \right)^{0.4} \times \left( \frac{\text{sin(steepness)}}{0.0896} \right)^{1.5}
\]

Where:
- LS: slope length and slope steepness factor; FA: flow accumulation
- An "accumulation of flow" is a raster-based calculation that takes into account all of the cells that flow into a downslope cell. It is based on the DEM grid cells' sizes that the cell size is calculated (30 m resolution).

3.4. Management of the Land’s Vegetation (C-Factor)

The C-factor assesses the cumulative impacts of trees on land degradation, according to Benzougagh et al. (2020), crop sequences, and other land cover areas, distributed between the intervals (0,01,1). Plant cover is second only to topography in terms of importance in reducing soil erosion. (Panagos and al 2020). In terms of soil loss, For agricultural land, the ratio of soil loss to soil loss from plowed and continuously tilled bare ground is known as "Factor C." With adequate cover, the risk of soil erosion is reduced. The NDVI (Normalized Difference Vegetation Index) and other vegetation indices are quantitative metrics based on the spectral features of vegetation that try to measure vegetative biomass. The Normalized Difference Vegetation Index (NDVI) of the study region was calculated using Landsat 8 images with a 30-meter resolution. (5).
PIR and R stand for near infrared and red, respectively, on the color wheel. The Landsat 8 image shows bands 5 and 4 of the near-infrared spectrum. Higher values indicate more vegetation, whereas lower values indicate no vegetation, depending on whether the NDVI is applied to bare terrestrial or aquatic sources (Karaburun 2010). The formula (De Jong, 1994) for calculating the C-value is as follows:

$$C = e^{-\alpha \left( \frac{NDVI}{\beta - NDVI} \right)}$$

(6)

where $\alpha = 2$ and a value of 1 appear to produce appropriate outcomes

3.5. Conservation Practice (P-factor)

In order to gauge soil loss, the P-factor might be used. Fields with and without a specific conservation strategy are compared here. P-factor values may be found between 0.10 and 1.00. A rating of one is assigned to an area that does not engage in any of the aforementioned practices. P values vary depending on the practice used as well as the slope. These protections are not present in the study area. As a result, P is assumed to be constant ($P = 1$) (Toubal et al., 2018; Benzouga, 2020).

4. Results and Discussions

This basin's soil erosion was simulated using the RUSLE model, and its amplitude and geographic variation were quantified using geospatial approach. (GIS tools and remote sensing). Erosion risk factors included slope length, slope steepness, land cover (the C-factor), and soil protection/conservation strategies (P-factor).

4.1. Erosivity of Rainfall (R-factor)

Using an inverse distance formula, the R-factor map was generated weighting approach unknown cells on a map may be predicted using IDW by measuring the distance between them and nearby known cells. In this method, the power option is used to lessen the impact of things that are far away. IDW has also been used to produce the R-factor map in many research, and the IDW technique is incorporated in QGis. Use this approach to map out the Joumoua watershed's rainfall erosivity (Fig. 8). Many studies have shown that soil erosion rates in watersheds are influenced most by the rainfall erosivity R factor. This study relied on the amount of rain that falls on an annual basis. The availability of the R-factor, convenience of calculation, and increased regional coherence were all benefits. (Shinde et al. 2010). The calculated R-factor using the average annual precipitation, it is ranged from 1832.76 to 1968.87 MJ mm/ha/yr/ha. As seen by the statistics, rainfall is high in the south of the research area, namely in the Ain dori region. (Fig. 7a).

4.2. Soil Erodibility (K-factor)

The soil erodibility K-factor represents the effect of soil properties and soil profile characteristics on soil loss. Therefore, it indicates that a certain soil type is resistant to erosion in general. However, the K element's value, on the other hand, is controlled by the soil's penetration potential. Soils with higher K values were more sensitive to soil erosion, based on the K-geographical factor's distribution in the research area (Fig. 7b). Accordingly, lower K values (0.01612 to 0.0254 T/H/HA/MJ/mm), which indicated low to moderate soil erodibility, were found.
4.3. Slope Length and Steepness (LS-factor)

The LS-factor is a measure of the topographic component's impact on soil erosion. It takes into account the topography of a certain location in order to prevent soil erosion. The topographic aspect here refers to the research area's susceptibility to topograhic erosion. Erosion is influenced by the length and steepness of the slope. LS-factors varied from 0 (lowest) to more than 43% (upper part). As illustrated on the map (Fig.9.b), the majority of the Oued Joumouaa watershed has low LS values.

4.4. Land Cover Management (C-factor)

The C-factor numerically expresses the outcomes of available vegetation cover for all land areas in the RUSLE model, whether in agriculture or soil erosion mitigation techniques. The Normalized Difference Plant Index (NDVI) is the remote sensing industry's go-to measure of vegetation growth (NDVI). Equation 5 is used to construct this index using satellite images within QGis software. The type of vegetation and its cover determine the C-factor's values. Green vegetation has higher NDVI values than typical surface materials like asphalt, concrete, and asphalt. NDVI values of green vegetation are greater than those of conventional surface materials such as asphalt, concrete, and asphalt. The NDVI scale runs from -1.0 to 1. NDVI values that are negative show that there is water on the ground, and positive NDVI values show that there is no water on the ground. While the RUSLE C-factor and NDVI are shown in (Fig.ure 8), the Oued Joumouaa watershed's NDVI values are shown in (Fig.ure 9.a).

![Fig.7.a. Map of rainfall erosivity in o. Joumouaa. b) Map of soil erodibility in o.Joumouaa.](image)
Fig. 8. Relationship between the NDVI and C-Factor

Fig. 9. a) Map of NDVI index of o.Joumouaa basin; b) Map of topographic of the o. Joumouaa watershed
The calculated RUSLE vegetation cover management factor $C$ is shown in Fig. 10, as a worldwide distribution. There was a wide range of $C$-factors in the study area, from 0.006 to 0.395. It was 0.20 on this map for the Oued Joumoua basin, with higher $C$-factors representing more plant cover and lower $C$-factors suggesting dryland areas. The resulting map reveals that the whole basin has minimal vegetation cover, with only a few small pockets of decent cover to the north and left. Fig. 4 shows the most common forms of land use in the research region. Because of the increased rainfall brought on by global warming, vegetation-covered soils are better able to withstand erosion.

5. Estimation of Potential Soil Erosion

This research confirms the efficiency of geospatial techniques (GIS Tools, and Remote Sensing) in evaluating erosion potential soil loss and dispersion in space. Soil erodibility, slope length and steepness, land cover management, and soil conservation have all been identified as potential erosion factors. Incorporating GIS data with the RUSLE model provides more accurate findings. A soil erosion rate map for the Oued Joumouaa watershed was created in this study. To generate the RUSLE model input factors, a variety of data sources were accessed and saved in QGIS as raster GIS layers (2.18.2. version). Figure 10.b illustrates the annual erosion map of the research Oued Joumouaa watershed as a consequence of the potential soil loss model, which helps to identify the areas prone to soil erosion. We used the classification most commonly used in different erosion studies using the RUSLE model to improve the readability of this map. Soils may withstand yearly losses of up to 10 t/ha, while losses of more than 50 t/ha are worrying, according to this categorization. The average losses for homogeneous units at the study site are in the range of 25.77 t/ha/year, with minimum and highest losses of 0.21 t/ha/year and 280 t/ha/ha, respectively. The soil loss map shows that 86.87% of the basin's area has relatively losses (class 0.21 to 10 t/ha/year), 12.71% has significant losses (class 10 to 50 t/ha/year), and the rest of the watershed has alarming losses (above 50 t/ha/yr) that occupy 0.49% of the basin's area (Fig. 10.b). The maximum values of soil losses in the classes 10-50 t/ha/yr and 50-280 t/ha/yr are mostly found in the watershed's central and upstream areas. This result is consistent with that of the application of the PAP/RAC approach in the same watershed (Najia et al. 2021), which states that the very high risk of water erosion is largely confined to the central part of the watershed and to the extreme north of the watershed on sites with badlands. These correspond to marly of friable nature, not covered by vegetation and which present high altitudes.

The relative validity of the model used is demonstrated by a comparison of the results obtained with studies conducted in other western Rif watersheds. Indeed, average soil losses in fragile areas in the Rif domain approach 17 tons per hectare per year. According to Ait Brahim et al., the Nakhla watershed loses 38.7 t/ha per year (2003). The Oued Khmiss watershed was found to lose 37t/ha/yr by Khali Issa et al. (2014), while the Tlata watershed lost 32.5t/ha/yr. At elevations ranging from 25 to 690 meters, Tahiri et al. (2014), an annual loss average of 47.18 t/ha/yr for the Oued Sania sub-basin is computed. In the Oued Sahla watershed (in the Central Rif), Sadiki et al (2009). used the RUSLE model to calculate an average annual flux of 22 t/ha. In 2004, the same author discovered a loss of roughly 55 t/ha/year in the Oued Boussouab watershed (Eastern Rif). Other models produced findings that were similar to those obtained by using RUSLE, proving the validity of this technique.
6. Conclusions

The use of RUSLE in GIS made it easy to quickly look at different ways to reduce soil degradation in the Joumouaa watershed. GIS and the RUSLE model were used to quantitatively estimate soil losses: 86.87% of the basin area is subject to water erosion risks with average annual losses varying between 0-10 t/ha/year. 12.71% of the basin reveals losses that vary between 10-50 t/ha/yr and are predominantly concentrated in the middle of the research region on low slopes, low erodibility soils, and minimal rainfall values. The maximum losses between 50-280 t/ha/yr are in the middle of the watershed, present except 0.41% of the watershed area and coincide with the high erosion risk bad lands found by the qualitative erosion study in this watershed. Soil loss is well correlated with the elements in the updated universal equation (topography, erodibility, climatology, and vegetation cover). Although the RUSLE method continues to spark debate over its limitations and conditions of use, particularly because it ignores other types of erosion such as linear erosion, bank undermining, and re-sedimentation, it remains a decision-making tool for watershed management by erosion control administrations. These findings can be supplemented with those obtained through other methods of water erosion assessment. Other methods, including as radio-isotopic methods, the SWAT (Soils Water Assessment Tools) model, the study of erosion claws, and bathymetric measurements, are of interest for greater precision.

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