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Spatial Analysis Of Water Erosion Risk In Khenchela Province Using RUSLE And GIS Techniques

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Abstract
Water erosion represents one of the major environmental processes leading to soil degradation, particularly in mountainous and semi-arid regions characterized by steep slopes and fragile landscapes. This study aims to evaluate the spatial distribution of water erosion risk in Khenchela Province (Algeria) by integrating the RUSLE model (Revised Universal Soil Loss Equation) with Geographic Information System (GIS) techniques.
The analysis relied on multi-source datasets, including a Digital Elevation Model (DEM), rainfall records, soil maps, vegetation indices (NDVI), and land use patterns. Each RUSLE factor (R, K, LS, C, and P) was computed and spatially analyzed to produce an erosion risk map. Results revealed that the northern and eastern parts of Khenchela, especially in the Shashar, Tamza, and Bouhmama districts, are the most vulnerable to erosion due to steep slopes and high rainfall intensity. Conversely, the southern plains exhibit low erosion potential. The study demonstrates the efficiency of combining RUSLE modeling and GIS-based spatial analysis in assessing soil loss, providing valuable insights for sustainable land management and erosion control planning.
Keywords: *Water erosion, RUSLE, GIS, Khenchela, spatial analysis, soil*

1-INTRODUCTION

Water erosion is a major factor in soil degradation and agricultural productivity decline, especially in mountainous and semi-arid regions with rugged terrain and increasing environmental fragility. The stability of ecosystems and the sustainability of natural resources are negatively impacted by this phenomenon, which is one of the major environmental issues facing the world today. It leads to the loss of the topsoil layer rich in organic materials, contributes to the blockage of water channels, decreases the fertility of agricultural lands, and increases desertification rates.

In this context, the analysis of water erosion risks gains strategic importance within applied geography and earth sciences, as it constitutes a fundamental step in developing environmental protection plans and sustainable land management.

Algeria, like other Mediterranean basin countries, faces increasing challenges due to climatic variability and human pressure, making water erosion a concerning phenomenon in many of its regions, especially in the eastern mountain slopes. Khenchela Province is a distinguished example of this situation, where steep terrains, intermittent and heavy seasonal rains, and intensive human activities such as overgrazing and traditional plowing on slopes converge. All of this makes it an ideal environment for studying erosion dynamics and understanding their spatial variability.

The tools for studying erosion have significantly evolved over the past few decades, as reliance on spatial modeling and digital geographic analysis has become a fundamental approach for estimating soil loss quantities and mapping hazard zones. Among the most widely used quantitative models globally is the RUSLE (Revised Universal Soil Loss Equation), developed by Renard and colleagues (1997), which allows for the estimation of annual soil loss based on a set of environmental and climatic factors, including rainfall intensity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and conservation practices (P)

Many international and regional studies, such as the work of Farhan et al. (2013) in Jordan and Bensekhria & Bouhata (2022) in Algeria, show the effectiveness of this model when integrated with Geographic Information Systems (GIS) in accurately identifying the most erosion-prone areas with high spatial precision.

An integrative approach between quantitative modeling (RUSLE) and digital spatial analysis (GIS) is used in this study to evaluate water erosion risks in Khenchela province. To represent the intensity and geographical distribution of erosion, a spatial database was created using data from multiple sources (digital, climatic, and topographic), and analyzed in a Geographic Information System (GIS) environment.

This research's main concern commences with the inquiry that follows:

The research is centered around the following question:

What is the role of natural and human factors in determining the spatial variation of water erosion in Khenchela Province? And how can the RUSLE model and geographic information systems be used to assess hazardous areas?

Based on this problem, the study seeks to achieve a set of goals, the most important of which are:

1-Analysis of environmental factors affecting water erosion (rain, soil, slope, vegetation).

2-Apply the RUSLE model to estimate annual soil loss rates across a state's geographic area.

3-Produce spatial maps of erosion risks and identify the most environmentally fragile areas.

4-Providing practical proposals to contribute to soil protection and the sustainability of agricultural activity.

The importance of this study lies in the fact that it contributes to bridging a knowledge gap at the regional level, as Khenchela Province lacks accurate quantitative studies on the phenomenon of water erosion, despite its topographical and climatic sensitivity. Its results also represent a decision-making support tool for local authorities concerned with territorial planning, rural development, and combating land degradation.

Thus, this work is not limited to the descriptive aspect, but rather aims to establish an integrated scientific approach that employs remote sensing techniques and geographic information systems to analyze a geomorphological phenomenon with extremely important environmental, economic, and developmental dimensions.

2-The theoretical and methodological context.

An analytical approach based on the RUSLE model was followed within the ArcGIS 10.8 environment according to the following steps:

2-1-Data collection:

- ✓ Digital Altitude Model (DEM - 30 m
- ✓ Rainfall data from local weather stations (1980-2020).
- ✓ Soil maps from FAO.
- ✓ Sentinel-2 images for NDVI calculation.
- ✓ Land Use Maps from CORINE Land Cover.

2-RUSLE model

The RUSLE model is based on the following quantitative relationship (Renard et al., 1997):

A=R×K×LS×C×PA = R \times K \times LS \times C \times PA=R×K×LS×C×P

- R from the Renard equation (1997) using rain data.
- K of soil physical properties (based on Bensekhria & Bouhata, 2022)
- LSL from regression analysis in DEM (Khanchoul et al., 2022).
- C of NDVI extracted from Sentinel-2.
- P according to agricultural protection practices (Chaieb et al., 2025)

2-Combine layers to create a total liter loss map (A) Identify risk area

2.2 Employing geographic information systems (GIS)

GIS is considered the optimal environment for implementing the RUSLE model, as it allows processing the five factors in the form of digital spatial layers (Raster Layers).

Through it, risk areas can be identified with high accuracy, as confirmed by the studies of Melalih & Mazour (2021) in Ain Sefra and Chaieb et al. (2025) In Wadi Al-Sulay, northern Algeria.

This approach relies on integrating climate, surface and cover data to produce a quantitative map of soil loss.

3. Study area: Khenchela Province

The province of Khenchela is located in the eastern part of Algeria, between the latitudes of 35.5° and 36.5° North, and the longitudes of 6° and 7.3° East, within the Aurès mountain region. It is bordered to the north by the province of Oum El Bouaghi, to the east by the province of Tebessa, to the south by the province of Biskra, and to the west by the province of Batna. Its terrain is characterized by a mountainous nature interspersed with plateaus and valleys such as the Ouled Arab Valley and the Khenchela Valley, with an average elevation between 800 and 1500 meters above sea level.

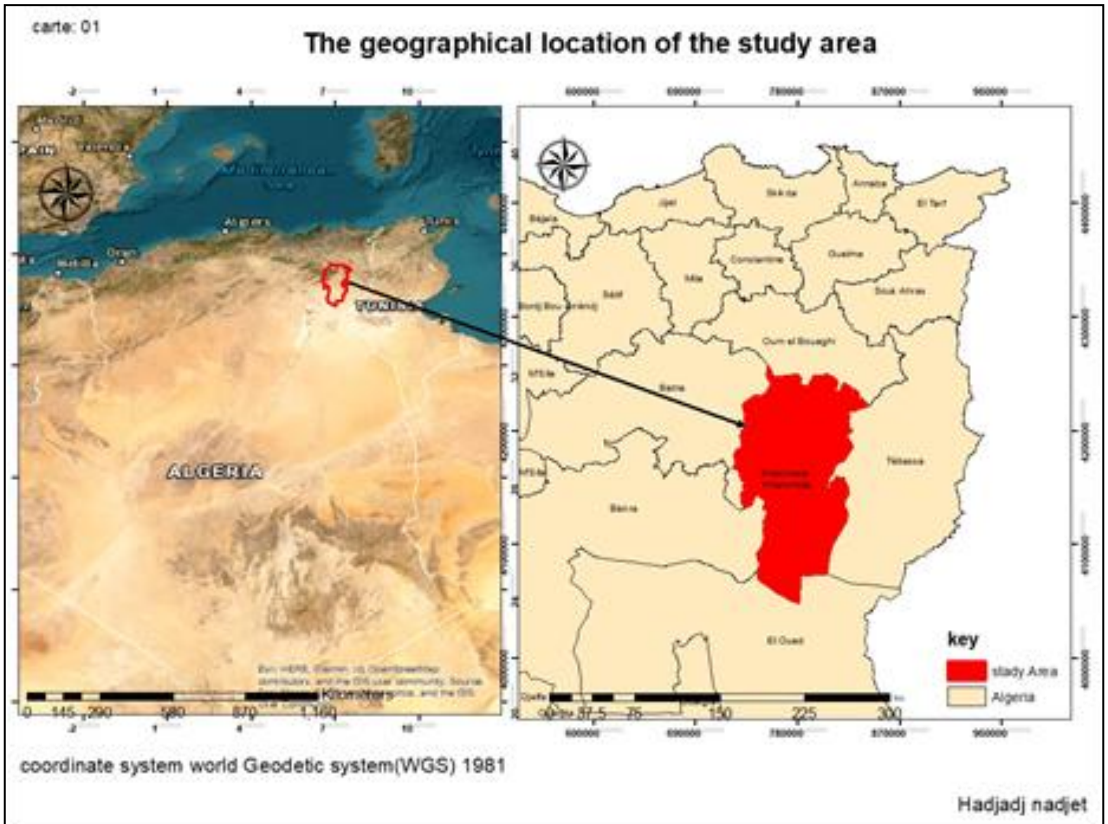

Figure (1):THE geographical location of the study area

3-1-Rain susceptibility factor to erosion (R)

The rainfall erosivity factor (R) is considered one of the most important components of the RUSLE model for estimating soil loss rates, as it represents the destructive energy of rainfall resulting from its intensity, duration, and ability to dislodge and transport soil particles thru surface runoff. The value of this factor increases whenever the rains are heavy and intense over a short period, as this leads to an increase in the kinetic energy of raindrops and a higher risk of erosion. (Wischmeier & Smith, 1978; Yin, 2017). It is calculated based on annual or monthly rainfall data using empirical equations that correspond to the nature of the local climate.

In semi-arid regions such as Khenchela Province, one of the most commonly used equations to estimate factor (R) based on annual rainfall is the following empirical equation:

R=0.7397×P1.847R = 0.7397 \times P^{1.847}R=0.7397×P1.847

Which:

- **R** Rain susceptibility factor to erosion ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot year^{-1}$)
- P Annual rainfall rate (mm)

In practice, analyzing this factor spatially using Geographic Information System (GIS) techniques allows the creation of a digital map of erosion potential, which helps identify areas most at environmental risk and develop effective plans to combat erosion and conserve soil.

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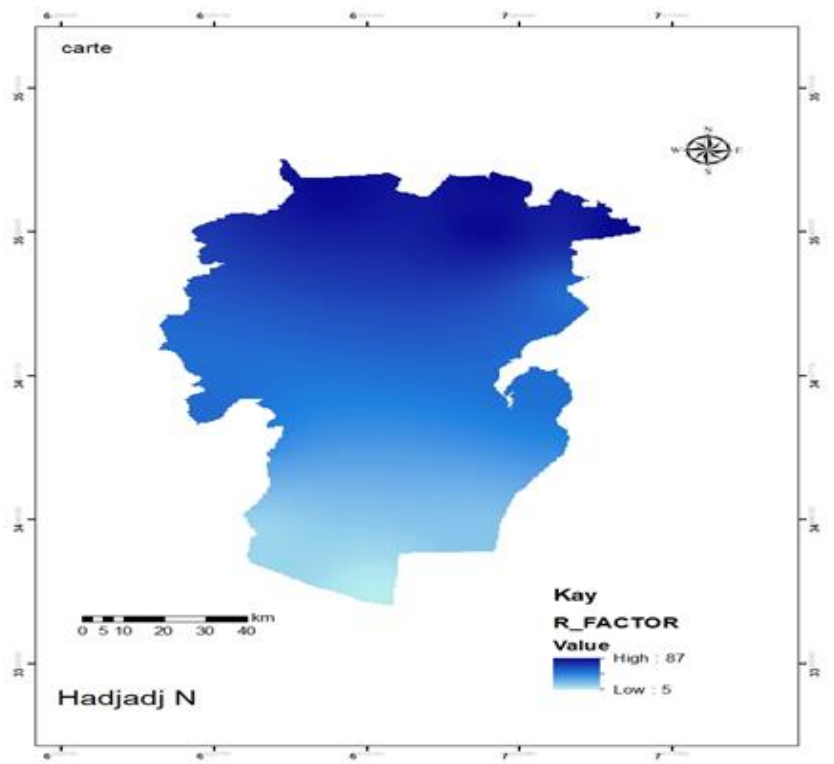


Figure (2): Rain susceptibility factor to erosion (R)

3-2-Soil Erodibility Factor (K)

The Soil Erodibility Factor (K) is considered one of the essential components in the RUSLE equation, as it expresses the soil's resistance to water erosion processes caused by the impact of raindrops or surface runoff. It reflects the physical susceptibility of the soil to disintegration and transport under the influence of climatic and hydrological factors. (Wischmeier & Smith, 1978; Melalih & Mazour, 2021). This factor is influenced by several physical and chemical properties of the soil, the most important of which are texture (the ratio of sand, silt, and clay), structure, permeability, and organic matter content. (Organic Matter). Studies indicate that coarse sandy soils are often less prone to erosion than loose silty and clayey soils, which are easily disintegrated and transported. (Othmani et al., 2023)

By factor (K) usually using the empirical equation developed under the USLE / RUSLE model, which takes into account the morphological and organic properties of the soil, and is given by the following relationship:

K=[2.1×10−4(12−OM) M1.14+3.25(s−2)+2.5(p−3)]100K = \frac{[2.1 \times 10^{-4} (12 - OM) \, M^{1.14} + 3.25 (s - 2) + 2.5 (p 3)]}{100}K=100[2.1×10−4(12−OM)M1.14+3.25(s−2)+2.5(p−3)]

Which:

- **K**: Soil erodibility factor (t·ha·h / MJ·mm·ha)
- **OM**: Organic matter percentage (%)
- **M**: Output (%green+%clay)×(100−%clay)(\%\text{green} + \%\text{clay})\times (100 - \%\text{clay})(%green+%clay)×(100−%clay)
- **S**: Structure class (1 to 4)
- **p**: Permeability class (1 to 6)

Locally identifying this factor using Geographic Information Systems (GIS) helps prepare accurate maps that show soil sensitivity to erosion, which contributes to the development of effective programs to protect soil and plants in environmentally fragile areas such as Khenchela Governorate with its mountainous sedimentary formations. (Othmani et al., 2023; Sahli et al., 2019).

3-3-Topographic factor (LS)

The topographic factor (LS) is one of the main components of the RUSLE model for estimating water erosion rates, as it combines the effects of slope length (L) and slope severity (S) on the movement of surface waters and their ability to break up and transport soil particles.

The factor (LS) is calculated based on the digital elevation model (DEM) using topographic analysis tools in Geographic Information Systems (GIS). Flow direction (Flow Direction) and flow accumulation (Flow Accumulation) are calculated from the DEM, and a regression map (Slope) is extracted in degrees or radians. These layers are then combined into a computational equation to generate a map representing the spatial change of factor values (LS), which is as follows (Desmet & Govers, 1996; Mitasova et al., 1996):

LS=(Flow Accumulation×Cell Size22.13)0.4×(sin(Slope (radians))0.0896)1.3LS = \left(\frac{\text{Flow Accumulation} \times \text{Cell Size}}{22.13} \right)^{0.4} \times \left(\frac{\sin(\text{Slope (radians)})}{0.0896} \right)^{1.3}LS=(22.13Flow Accumulation×Cell Size)0.4×(0.0896sin(Slope (radians)))1.3

The resulting map (LS) shows the areas most vulnerable to erosion, with values being low on flat lands and plateaus, while rising on long, steep slopes.

Figure (3): Soil Erodibility Factor (K)

3-4-Support Practice Factor (P)

The Agricultural Protection Practices Factor (Support Practice Factor - P) is a key component of the RUSLE model, and expresses how effective human actions and practices are in reducing water erosion compared to the natural state of the Earth's surface without any human intervention (Renard et al., 1997).

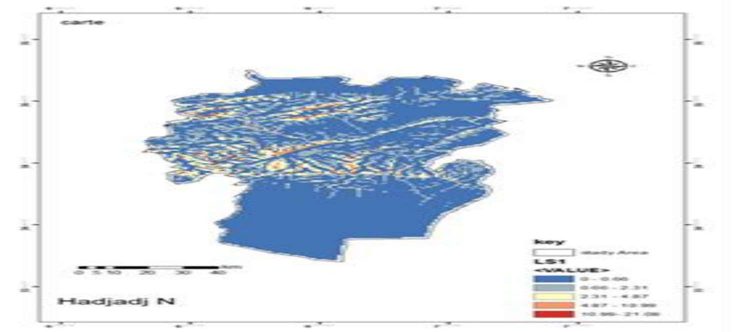


Figure (4): Topographic factor (LS)

This factor represents the ratio of soil loss under certain practice conditions to loss in the absence of preventive practices (Wischmeier & Mith, 1978). The value of factor P ranges between 0 and 1, where a value of 1 indicates the absence of any protective practices, while lower values (0.1-0.5) indicate the effectiveness of practices in reducing erosion. These values depend on the type of land use, slope intensity, and the quality of practices applied, such as terracing, contour tillage, and windbreaks or shelterbelts, all of which are methods that reduce surface runoff speed and increase soil stability. (Morgan, 2005)

In the mountainous regions of Khenchela Province, the slopes range from moderate to steep. Reforestation practices and the creation of agricultural terraces play a pivotal role in reducing the P factor values to between 0.2 and 0.4, as demonstrated by applied studies in Algeria. (Bensekhria & Bouhata, 2022). Spatial analysis using Geographic Information Systems (GIS) demonstrates the importance of integrating this factor into digital models for estimating erosion, as its map is built based on satellite images, land use maps, and field verification. (Renard et al., 1997).

3-5-Cover Management Factor (C)

The cover management factor - **C** is one of the most influential components of the RUSLE equation in estimating water erosion rates, as it expresses the ratio between soil loss in the presence of some vegetation cover and loss in the absence of cover (Renard et al., 1997). This factor represents the protective role of plants against the forces of stormwater erosion and surface runoff, as vegetation helps to reduce the energy of falling raindrops, to increase water infiltration into the soil and reduce the speed of surface runoff. (Morgan, 2005).

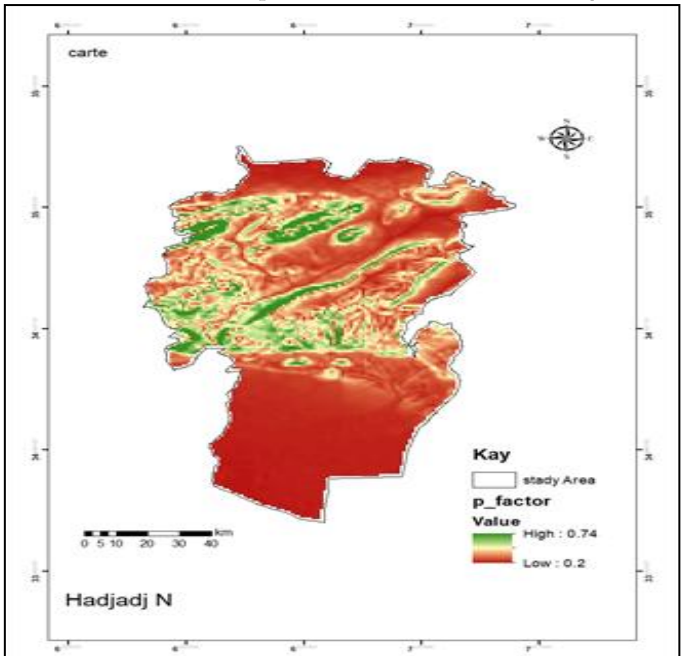


Figure (5): Support Practice Factor (P)

Factor C values range from 0 to 1, with 1 indicating a completely bare surface, while values close to 0 indicate dense vegetation that severely limits erosion. The value of C depends on the type of vegetation, its density, and its seasonal condition. For example, the C value for crop-covered agricultural areas is estimated to be between 0.1 and 0.3, while it reaches 0.001–0.01 in dense forests, and approaches 1 in barren or degraded areas (Wischmeier & Smith, 1978; Panagos et al., 2015).

In the mountainous environment of Khenchela Province, where land uses range from forests, agricultural lands, to barren areas, factor C is considered an accurate indicator for assessing the ecosystem's vulnerability to erosion. The map of this factor is usually extracted from satellite images (Landsat or Sentinel) by calculating vegetation cover indices such as NDVI, and then converting them into C values according to empirical equations. (Van der Knijff et al., 2000). For example, the equation is used:

C=exp[−α(NDVI/(β−NDVI))]C = \exp[-\alpha (NDVI / (β - NDVI))]C=exp[−α(NDVI/(β−NDVI))]

Where α and β represent experimental coefficients that vary according to the type of vegetation cover. The results of these maps show that the forested mountainous areas north of Khenchela record the lowest erosion values ($C < 0.1$), while the values increase in the semi-arid south where the vegetation density decreases. (Bensekhria & Bouhata, 2022).

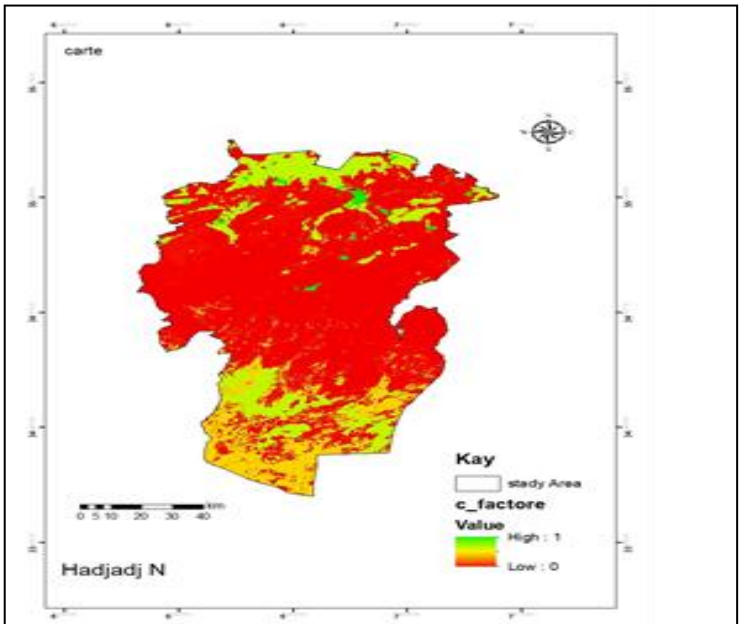


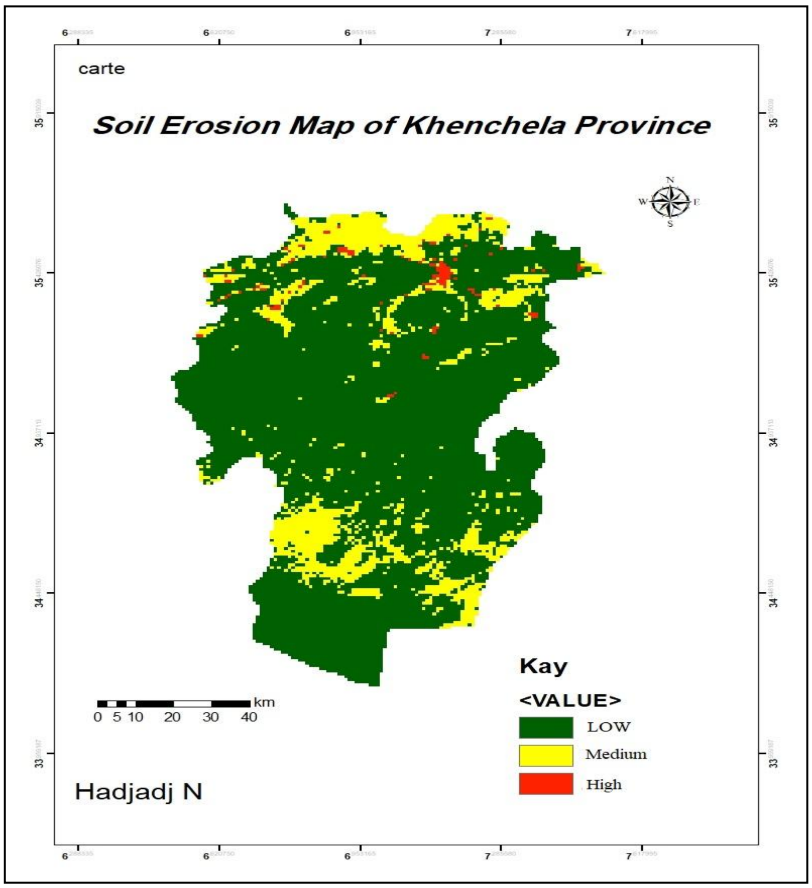
Figure (6): Cover Management Factor (C)

The integration of factor C in spatial analysis thru Geographic Information Systems (GIS) allows for the evaluation of the effectiveness of vegetation cover in reducing water erosion, contributing to the development of strategies for preserving green cover and combating desertification in environmentally fragile areas.

4- RESULTS AND DISCUSSION

The results of the study based on the RUSLE model and Geographic Information Systems (GIS) techniques to assess the risk of water erosion in Khenchela State showed clear variation in the severity of erosion across the geographical area of the state. The most important findings are that the state's largest areas fall into the low-erosion category, accounting for more than 65% of the total area. These areas are characterized by relatively weak slopes and medium to dense vegetation cover, which contributes to reducing the impact of surface runoff and protecting the soil from erosion.

In contrast, medium erosion areas represent about 25% of the area, and are mainly concentrated in the central and southern parts of the state, where the soil is affected by agricultural activities, overgrazing and low plant density. Areas with high erosion, which represent approximately 10% of the area, are concentrated in the northeast and west of the state, especially in the mountainous Aures region, which is characterized by steep slopes and deteriorating vegetation cover, in addition to the effect of seasonal heavy rains that increase surface runoff energy (R-factor).
The final erosion map shows that topographic factor (LS) and vegetation factor (C) are the most influential in determining the intensity of erosion in an area, with long, steep slopes showing the highest erosion values. Open agricultural areas without soil conservation practices also recorded high drift rates compared to areas covered by forests or natural weeds.



These results are consistent with previous studies conducted in northeastern Algeria, such as the study conducted by Ben Salama et al. (2020), which confirmed that the mountainous areas of Ouris are among the areas most affected by erosion due to the interaction between morphological and climatic factors, as well as the study conducted by Zeroual et al. (2022), which highlighted the role of vegetation in reducing the risk of water erosion.
Accordingly, the study recommends the need to adopt integrated soil management strategies that include stabilizing vegetation cover, establishing agricultural terraces in sloping areas, applying contour farming practices to reduce surface runoff, in addition to periodically monitoring erosion changes using remote sensing and satellite data.

5-CONCLUSION

This study concluded that the use of the RUSLE model supported by Geographic Information Systems (GIS) and remote sensing techniques is an effective tool for assessing water erosion and identifying risk areas in Khenchela Province. The results showed a clear variation in erosion intensity, with low levels prevailing in plains and areas with dense vegetation, while high levels are concentrated in the northern and eastern mountainous parts, characterized by sharp slopes and weak vegetation.

The importance of this assessment lies in supporting environmental planning and soil protection efforts, as the resulting maps can be relied upon to guide reforestation, surface runoff management, and land use regulation, ensuring the sustainability of natural resources. The study also emphasizes the need to continuously update erosion models by integrating long-term data on rainfall, vegetation cover, and land use, which contributes to a more accurate understanding of the phenomenon's dynamics. Water erosion in the province of Khenchela represents an increasing environmental and developmental challenge, necessitating the activation of soil protection and stabilization programs with the participation of various local stakeholders, and linking scientific research with field practices to achieve a balance between agricultural development and environmental protection in vulnerable areas.

BIBLIOGRAPHY

- Arnoldus, H. M. J. (1980). *An approximation of the rainfall factor in the Universal Soil Loss Equation*. In *Assessment of Erosion* (Vol. 98, pp. 127–132). FAO Land and Water Development Division.
- Desmet, P. J. J., & Govers, G. (1996). A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *Journal of Soil and Water Conservation, 51*(5), 427–433.
- Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). *Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)*. U.S. Department of Agriculture, Agriculture Handbook No. 703.
- Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E., & Montanarella, L. (2015). Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy, 48*, 38–50. https://doi.org/10.1016/j.landusepol.2015.05.021
- Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: A guide to conservation planning*. U.S. Department of Agriculture, Agriculture Handbook No. 537.
- Kouidri, S., & Benslimane, S. (2020). Assessment of soil erosion risk using RUSLE and GIS techniques in the northeastern part of Algeria. *Arabian Journal of Geosciences, 13*(19), 1–15. https://doi.org/10.1007/s12517-020-05901-7
- Bouhata, R., & Djemai, N. (2018). Modeling soil erosion risk using RUSLE model and GIS techniques: Case study of Soummam watershed, Algeria. *Geology, Ecology, and Landscapes, 2*(1), 45–55. https://doi.org/10.1080/24749508.2018.1432445