# Quantification of soil losses using RUSLE model in the Boumlal watershed (Central Rif, Morocco)

*Khadija* El Ouazani Ech-Chahdi[1*], *Abdelaziz* El-Bouhali[1] and *Mhamed* Amyay[1]

[1]Research Team Natural Environments, Planning, and Socio-Spatial Dynamics, Sidi Mohamed Ben Abdellah University. Fez, Morocco.

**Abstract.** This contribution estimates soil losses in the Boumlal watershed by applying the Revised Universal Soil Loss Equation (RUSLE) and using GIS and remote sensing. This model incorporates five essential factors in water erosion: rainfall erosivity (R), soil erodibility (K), slope length (LS), cover management (C), and erosion control practice (P). The overlay of these parameters makes it possible to produce the synthetic map of annual soil losses (t/ha/year) and identify the most vulnerable areas to water erosion. The results indicate that Boumlal watershed is characterized by high sediment production. Indeed, more than 40% of the watershed produces a considerable amount of sediment exceeding 50 t/ha/year, with soil losses reaching over 200 t/ha/year in some parts of the study area. However, areas with low erosion rates represent approximately 33% of the total watershed area. The extent of water erosion and the high soil loss values are linked to the study area's vulnerability and inadequate anthropogenic interventions. Water erosion in this watershed directly affects soil quality, agricultural land productivity, arable land area, and the siltation of downstream reservoirs.

**Keywords:** Water erosion, USLE, soil loss, GIS, Boumlal watershed.

## 1. Introduction

Water erosion is a global issue that significantly reduces agricultural productivity and dam storage [1]. According to some estimates, average rates of soil loss worldwide range between 12 and 15 t/ha/year [2], and nearly 10 million hectares of agricultural land are lost each year due to soil erosion [3], posing a threat to global food security. Land degradation through water erosion is widespread in Mediterranean regions due to extended periods of drought followed by aggressive rainfall and the prevalence of steep slopes with vulnerable soils [4]. Estimates indicate that water erosion affects approximately 35% of land in Greece, 45% in Tunisia, and 50% in Turkey, with soil losses ranging from 500 to 600 million t/ha/year [5]. In Morocco, a study by FAO in 1990 indicated that erosion affects nearly 40% of the land [6]. Thus, soil degradation is estimated between 5 and 10 t/ha/year in the Middle Atlas and exceeds 20 t/ha/year in the Rif [7]. Despite covering less than 6% of the total land area of the country, the Rif region produces approximately 60% of soil losses nationwide [8].

The erosion phenomenon constitutes the primary factor in soil degradation and the major challenge for watershed managers. Due to its significance, various qualitative and

* Corresponding author: khadija.elouazaniechachahdi@usmba.ac.ma

quantitative models for assessing water erosion have been developed by organizations and researchers. One of the most widely used worldwide and in Morocco is the Universal Soil Loss Equation (USLE) and its revised (RUSLE) and modified (MUSLE) versions [9]. It estimates the rate of soil loss in t/ha/year by integrating several natural and anthropogenic factors that determine water erosion. This study focuses on mapping the risk of water erosion in the Boumlal watershed using the RUSLE model. Integrating the model factors using GIS is an essential step to identify the area's most vulnerable to degradation and demonstrate the contribution of each factor to initiating erosive dynamics.

## 2. Study area

The Boumlal watershed is part of the Central Rif, located in the southwestern part of the Ouargla basin and covering an area of approximately 42 km². Administratively, it falls within the provinces of Taounate and Al-Hoceima. The watershed is characterized by rugged topography, with elevations ranging from 1780 meters at Jbel Erzinyia upstream to 521 meters downstream. It features steep slopes heavily impacted by anthropogenic activities, intensifying runoff energy. The lithology primarily consists of friable formations like marls and flysch, which exhibit low resistance to erosion. Vegetation cover is inadequate for protecting slopes over half of the watershed, with a notable trend of deforestation for cannabis cultivation in the upstream area [10, 11]. The climatic context is marked by concentrated thunderstorm precipitation in time and space, with intense showers during the summer and autumn when the soil is inadequately protected by vegetation, exacerbating the erosion risk.

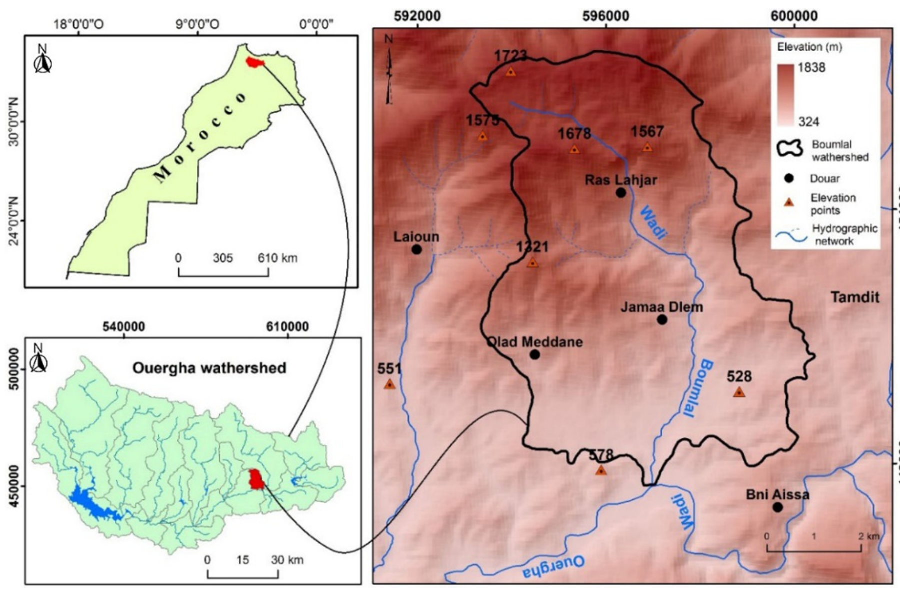


**Fig. 1.** Study area location

## 3. Methodology and data

The quantification of soil losses in the Boumlal watershed relies on data from diverse sources. All the data selected for this study are listed in Table 1. These parameters (factors) form the basis for calculating the Revised Universal Soil Loss Equation (RUSLE), widely used for predictive modeling of water erosion at the watershed scale [7, 8]. The RUSLE model quantifies the annual rate of soil erosion by combining five factors: Rainfall erosivity (R), Soil erodibility (K), Slope length (LS), Cover management (C), and Erosion control practice (P). The estimation of annual soil loss rates in the Boumlal watershed is based on the formula (Eq. 1) proposed by Wischmeier and Smith in 1978 [12].

$$A_{RUSLE} = R * K * LS * C * P \qquad (1)$$

**Table 1.** Data used to study water erosion in the Boumlal watershed

| Factors | Data | Sources |
|---|---|---|
| **R** | Rainfall data | Sebou Hydraulic Basin Agency (ABHS) |
| **K** | Soil map of the Ouergha watershed | Anti-Erosion Management Plan for the Ouergha Watershed Upstream of the Al Wahda Dam, Phase I, 1995 [13] |
| **LS** | Digital Elevation Model 30 m | https://search.earthdata.nasa.gov/search |
| **C** | Landsat 9 satellite images 2023 | https://earthexplorer.usgs.gov/ |
| **P** | Satellite images and fieldwork | Google Earth and field |

# 4. Results

## 4.1 Analysis of water erosion factors

The water erosion modeling in the Boumlal watershed is based on the RUSLE model, which integrates multiple factors (Figure 2) that trigger, regulate, and accelerate water erosion. The analysis of the R factor shows a significant difference between the upper and lower parts of the watershed. The highest values of rainfall aggressiveness are recorded in the upper part, which receives more rainfall due to higher elevations. However, lower values are observed in the lower part of the study area where altitudes are lower.

The K factor values range from 0.07 (low value) to 0.60 (high value). The spatial distribution of this factor shows that the high values correspond to more erodible soils (weakly developed soils of alluvial and colluvial origin and raw minerals), covering approximately 65% of the watershed's area, with K factor values ranging from 0.45 to 0.60. Conversely, the low erodibility soils (calcareous-dolomitic massifs of the Lias and Jurassic) represent 13% of the watershed.

The map of the LS factor reveals a relatively rugged topography in the study area. Values for this factor range from 0 to 80, with higher values presented in the midsection of the watershed, where steep slopes and high elevations are prevalent. Furthermore, lower values correspond to flat terrain.

The results for the P factor in the Boumlal watershed indicate values typically ranging from 0.1 for well-appointed areas to 1 where no management practices are observed. The most common anti-erosion measures in the study area include reforestation and bench terraces aligned along contour lines. These measures, mainly implemented in the lower part of the watershed, are primarily carried out by the government as part of projects such as DERRO and the Integrated Development Program (PDI). In the middle section of the watershed, significant peasant interventions are observed, including the construction of small walls aligned with contour lines and terraces, which promote soil stabilization and reduce runoff energy. However, these efforts remain insufficient, given the magnitude of the erosion problem.

The vegetation cover (C) factor map shows that the study area is poorly protected by vegetation cover, especially in the downstream part where crop cultivation dominates. Conversely, areas of the watershed occupied by forests and dense orchards promote high soil protection. It is worth noting that the study area has experienced a progressive decline in the forest massif of Jbel Erzinyia located upstream due to the expansion of cannabis cultivation, exposing the soil to the aggressiveness of precipitation.

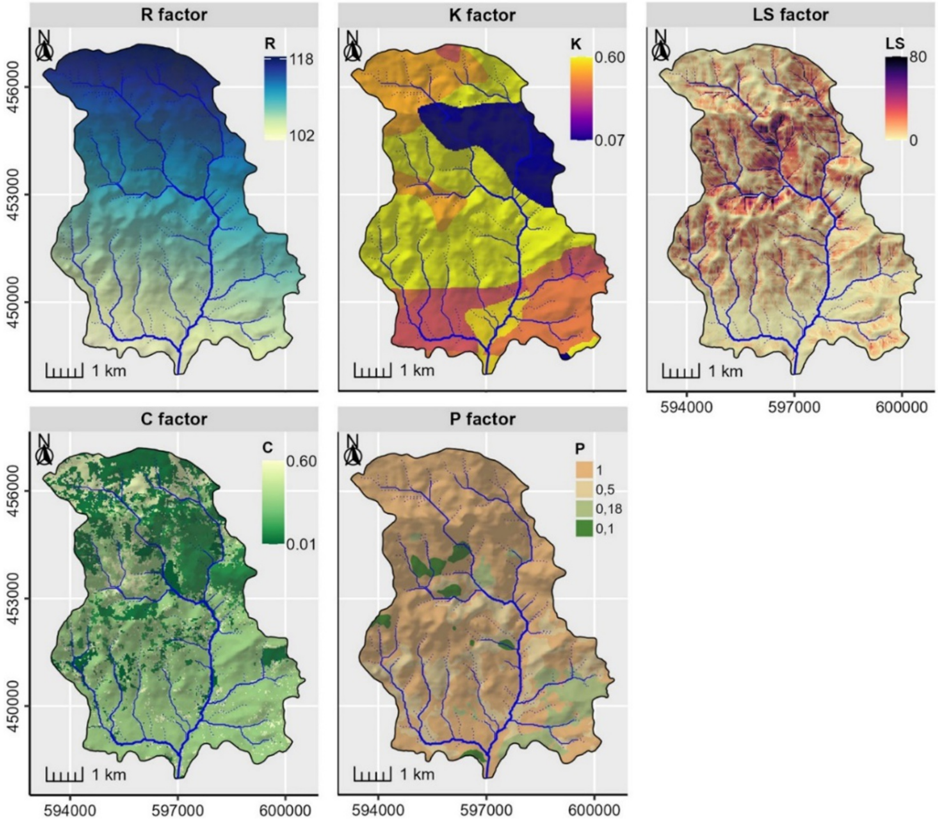


**Fig. 2.** The factors of water erosion, RUSLE model

## 4.2 Soil loss quantification

The overlay of synthetic maps of RUSLE model factors using GIS enables the creation of a soil loss map (t/ha/year), illustrating the spatial distribution of water erosion severity in the Boumlal watershed (Figure 3). The results demonstrate that soil losses vary across the watershed depending on climatic conditions, lithological formations, slope length, type and density of vegetation cover, and human activities. Soil loss values range from [0 to 10] for areas with low erosion to over 200 t/ha/year for regions producing significant sediment loads. Approximately 40% of the total basin area produces over 50 t/ha/year, notably on steep south-facing slopes characterized by high runoff energy. Additionally, cannabis cultivation areas remain uncovered for a large part of the year, directly exposing them to precipitation aggressiveness.

The areas in the basin characterized by low erosion rates [0 - 10 t/ha/year] represent 33% of the total area. They are located in the lower part of the watershed due to the prevalence of low altitudes, less steep slopes, and low precipitation aggressiveness despite the dominance of friable lithological formations (gray marl Messinian). Low soil losses are also observed in the upstream part, where soils are well protected by vegetation (Jbel Erzinyia forest) and in areas with terraces and dense arboriculture. Additionally, the calco-dolomitic rock outcrops situated in the northeastern part of the basin show high resistance to erosion. The average soil loss values [between 10 and 50 t/ha/year] predominate on moderately vegetated slopes with moderate slopes, where anti-erosion practices (such as reforestation with moderate density) are implemented.

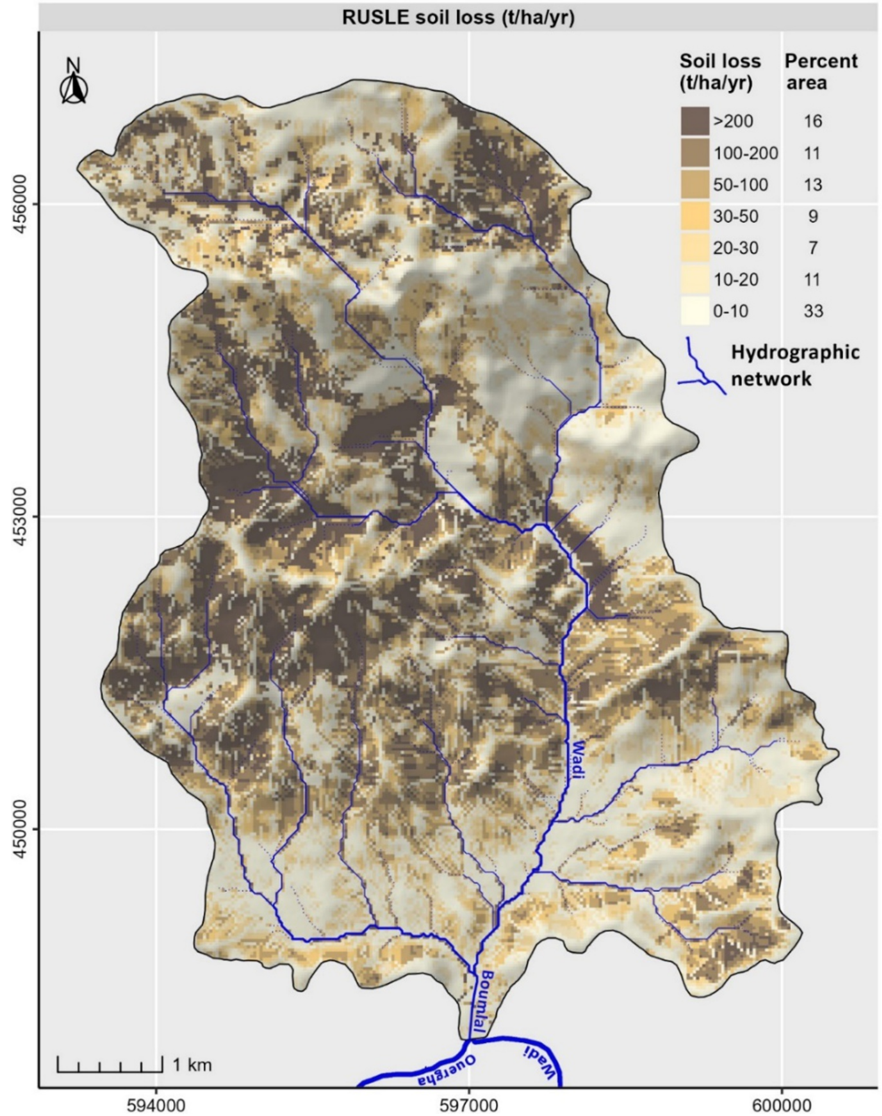


**Fig. 3.** Soil loss map (t/ha/year), RUSLE model

## 5. Conclusion

This study focused on quantifying water erosion in the Boumlal watershed by applying the Revised Universal Soil Loss Equation (RUSLE). The results indicated erosion risk in different parts of the watershed. They demonstrate a logical spatial distribution influenced by several factors (slope, soil type, vegetation type and density, and the aggressiveness of rainfall). Areas of the watershed with steep slopes, high altitudes, erosion-sensitive soils, and poor vegetation cover produce considerable amounts of material [between 50 and > 200 t/ha/year]. These zones are affected by diverse forms of erosion, such as badlands, gully erosion, and landslides. Conversely, areas of the watershed that are well-protected by vegetation and have mild slopes produce low amounts of sediment [less than 10 t/ha/year], and signs of erosion are less apparent. The water erosion in the study area leads to decreased soil fertility, reduced agricultural land, and the silting of dams. Finally, water erosion modeling is crucial for implementing anti-erosion measures at the watershed scale.

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**Author contribution**
All authors contributed to the study and approved the final manuscript. Khadija El Ouazani Ech-Chahdi: Conceptualization, Methodology, Software, Data analysis, Writing – original draft. Abdelaziz El-Bouhali: Methodology, Data analysis, Writing - Review & editing. Mhamed Amyay: Supervision, Writing – review & editing, Validation.
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