# Spatial-temporal assessment of soil erosion using the RUSLE model in the upstream Inaouène watershed, Northern Morocco.

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## Abstract:

This study was conducted in the upstream Inaouène watershed, one of the largest tributaries of the Sebou River in Morocco. The aim of the study is to assess the risk of rain-induced erosion at two different periods (1984 and 2022) to better understand the trend of this phenomenon in the study area. The Revised Universal Soil Loss Equation (RUSLE) was employed to evaluate the soil loss rate, specifically concerning sheet erosion. To carry out this work, various factors of the equation (Rainfall erosivity "R," Soil erodibility "K," Vegetative cover "C," Topography "LS," and Anti-erosion practices "P") were incorporated into a Geographic Information System (GIS) and spatial remote sensing. By overlaying these factors, a quantitative map of soil losses in our watershed was obtained. The results of this study show that the upstream Inaouène experienced a significant erosion dynamic during both 1985 (T1) and 2022 (T2), with a notable decrease in the amount of soil loss over the last year. Soil degradation at T1 averaged about 68 (T/ha/year), with maximum and minimum losses between 2162 and 0.067 T/ha/year. In contrast, losses at T2 recorded an average of 52.4 (T/ha/year), with a maximum of 1850 (T/ha/year). The study area thus represents very high soil loss quantities in both periods compared to several studies conducted on this issue. This is attributed to the fact that the study area is located in a region characterized by very favorable natural and human conditions and factors for recording significant soil losses. These include concentrated and intense thunderstorms, the predominance of fragile rocks, steep slopes, low vegetative cover, and irrational human interference in the area.… .

**Keywords: Upstream Inaouène watershed, water erosion, RUSLE, Geographic Information System (GIS), remote sensing.**

## 1. Introduction:

The phenomenon of erosion and its extent today contributes to soil degradation, exerting a direct impact on the dynamics of natural environments in general and anthropogenic activities in particular (Mazouzi et al., 2021). Water erosion represents a major environmental concern in Morocco, being the primary cause of soil degradation. Consequently, it directly affects the long-term health of the ecological system as well as socially responsible development, contributing to the improvement of environmental quality (Forootan Danesh et al., 2020; Meshram et al., 2017; Ren et al., 2018). Numerous studies have been conducted on the subject of water erosion (Sadiki et al., 2004; Laouina et al., 2010; El Hadraoui, 2013; Mahé et al., 2013; Moussebih et al.; El Assaoui, 2003). Mapping water erosion proves to be a crucial method for understanding the distribution and geographical extent of this phenomenon while assessing its severity.

In fact, several local studies have been conducted to assess and quantify the risk of erosion, particularly in the Rif and Pre-Rif regions, showing erosion rates sometimes exceeding 80 tons per hectare per year (Lahlaoi Ait Fora, 1995; Landis et al., 1995; Dhman et al., 1997; Rahhou, 1999; Sadiki et al., 2004; Faleh, 2007; Abahrour, 2009; Chaaouan, 2015; Karkouri, 2019; Amhani, 2021). On the other hand, in the Middle and High Atlas, annual averages do not exceed 20 tons per hectare.

The quantification and mapping of soil loss risks can be carried out using two types of measures: direct and indirect. Measuring erosion through direct methods is a complex and demanding process for assessing soil loss (Duarte et al., 2021). The indirect method relies essentially on equations and mathematical prediction models that have been extensively developed over the past decades following technological advancements. Several models have been adopted, including some empirical models that take into account various parameters such as precipitation, lithology, topography, and vegetative cover.

The empirical equation RUSLE, developed by Renard et al. (1997) in the United States to estimate soil erosion losses in agricultural fields, is widely used worldwide, whether in its original form or modified. In Morocco, it represents a multiplicative function of six elements interpreted and classified using Geographic Information Systems (GIS). The RUSLE model has been successfully applied to predict soil erosion through the use of geospatial approaches (Lufafa et al., 2003). Rainfall erosivity (R), topographic factor (LS), vegetative cover (C), soil erodibility (K), and anti-erosion practices (P) are all factors that can influence soil erosion in the upstream Inaouène watershed.

This study will examine how these factors affect the risk of soil erosion. Moreover, it could also be utilized to promote land management practices aimed at preventing soil erosion while enhancing agriculture and governance. The method and results of this study are of crucial importance in determining the likelihood of soil erosion and planning land management strategies, making decisions to protect natural resources.

## 2. Study Area

Covering an area of 168 km², the upstream Inaouène watershed is a transitional region between the intra-Rif Mountain ranges and the hills of the eastern periphery, situated northwest of the city of Taza. This watershed belongs to the Sebou basin, considered one of the major rivers in northern Morocco. It is bordered to the east by the Msoun watershed, to the north by the Ouergha basin, to the northwest by the Lebène basin, and to the south by the Melloulou watershed. The Inaouène River is a major tributary of the Sebou River (Fig...).

Geographically, it is located between longitudes 4°51' and 3°49' west of Greenwich and latitudes 34°35' and 34°51' north of the equator. Administratively, the territory of the studied watershed belongs to the Fès-Meknès region. Five rural municipalities almost entirely belong to the territory of our watershed but in a partial manner, namely the municipalities of Tainast, Kahf el Ghar, Had Msila, Beni Ftah, and El Gouzat.

Morphologically, the watershed is characterized by mountain peaks with altitudes exceeding 1700 meters (Jbal Tainast), and the lowest point corresponds to the outlet of the watershed at an altitude of 630 meters (illustration 1). The slopes are steep and very steep, exceeding 25%.

The climate of the area is characterized by temperature contrasts and irregularities in precipitation according to the seasons. However, rainfall is generally sudden and concentrated in a few days during the wet season (Amhani et al., 2021). A statistical study of temperature and precipitation conducted on the stations of Tainast, Had Msila, and Taza between 1970 and 2018 shows irregularity in the monthly and annual precipitation quantities in this region, with the majority of precipitation being concentrated storms in time and space. The statistical study by category of daily precipitation recorded at the Taza station over the period 1979-2018 shows that this region is sometimes subjected to maximum daily heights, sometimes exceeding the threshold of 80 mm, often causing hydrological dynamics with particular erosive power (Tribak, 2000; Tribak et al., 2017).

Geology is a crucial element in studies of environmental change because it influences the distribution and dynamics of natural phenomena, especially regarding forest types and slope dynamics. Geologically, the study area is characterized by strongly altered and locally crushed morpho-structural units. The Mesozoic-Cenozoic substrate is often covered by the intra-Rifain nappe units of Senhaja, Bouhaddoud, and Aknoul (lower and middle nappes), or by autochthonous deposits of post-nappe Miocene in intra-mountain basins, such as Ouargha (Suter 1965, Andrieux 1971, Leblanc 1977).

The lithology of the basin is dominated by fragile materials, especially marl-limestone and schisto-sandstone. These formations promote runoff and prevent the formation of aquifers with rapid slope evolution.

In terms of human characteristics, the rural municipalities in the upstream Inaouène watershed in general experienced a population decrease between 1994 and 2014 (General Population and Housing Census). The analysis of figures at the level of municipalities belonging to the upstream Inaouène watershed clearly shows a significant decrease in population, with an overall negative growth rate between the two periods studied.

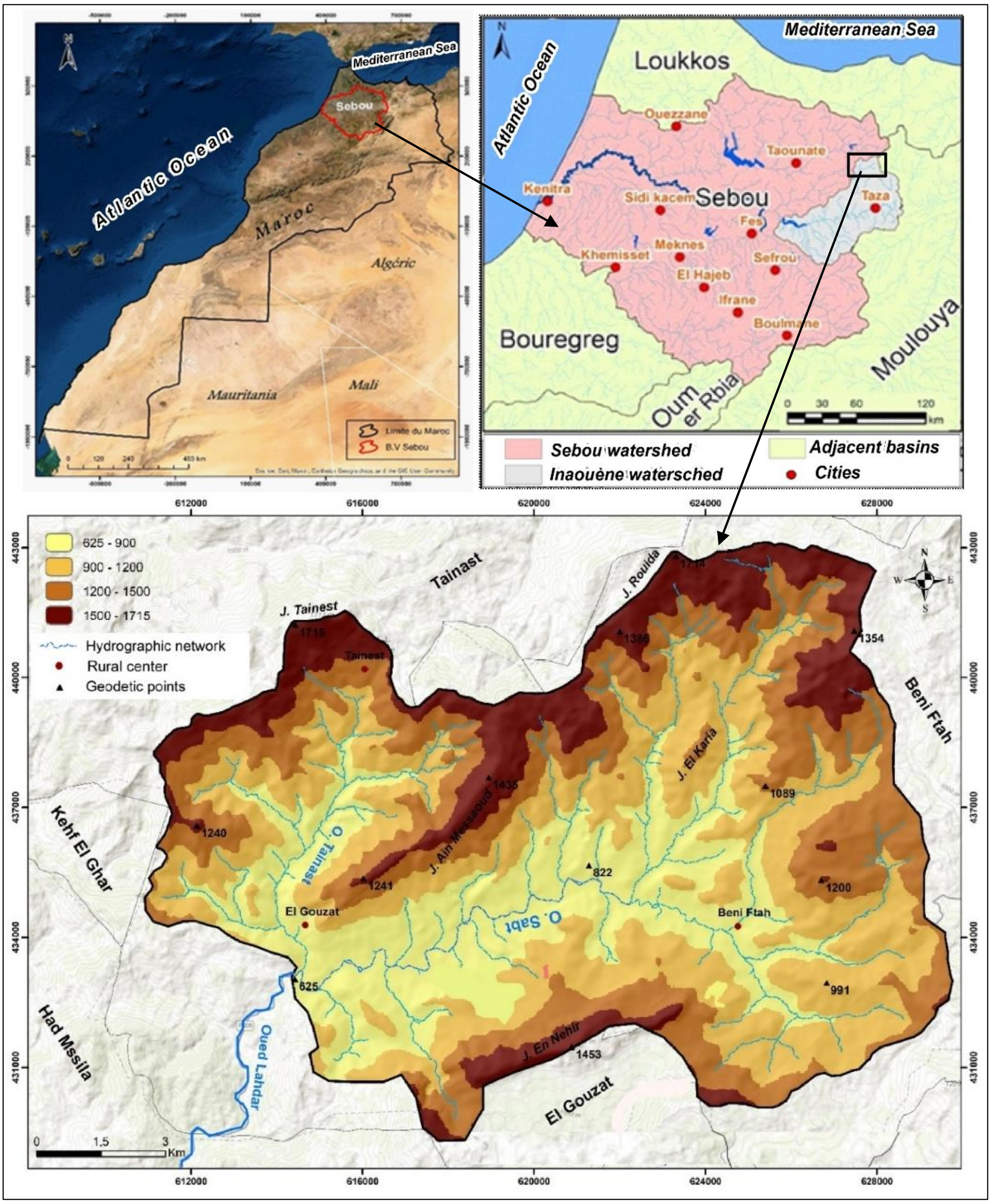



**Fig. 1. Geographical location and hypsometry of the study area**

## 3. Materials and Methods

The modeling of water erosion risk according to the RUSLE method relies on various natural and anthropogenic elements and parameters that influence the runoff process in the upstream Inaouène basin. (Figure.2)

These elements allow the calculation of the soil loss rate (A) in tons per hectare per year using the five factors as follows:

$$\mathbf{A = R * K * LS * C * P} \tag{1}$$

Where:

A = annual average soil loss rate in t/ha/year,

R = rainfall erosivity factor in MJ.mm/ha.H.an,

K = soil erodibility factor in t. ha. H/ha.MJ.mm,

LS = dimensionless topographic factor combining slope (SS in %) and slope length (L in m),

C = dimensionless vegetation cover factor,

P = dimensionless factor for anti-erosion cultivation practices.

The application of the RUSLE approach in the upstream Inaouène region required a comprehensive evaluation of each element of the universal equation across the entire watershed area. These elements were then represented in the form of thematic maps using Geographic Information Systems (GIS) and remote sensing.

The organizational diagram illustrated in (Figure 2) outlines the approach adopted to assess and map erosion potential. The objective is to create a map of soil losses at the scale of the upstream Hassan II Dam watershed. This map takes into account most of the factors described in Renard's equation (1997), which were themselves represented as thematic maps. By intersecting these digital maps using a Geographic Information System (GIS), we were able to estimate the soil loss rate at the watershed scale.

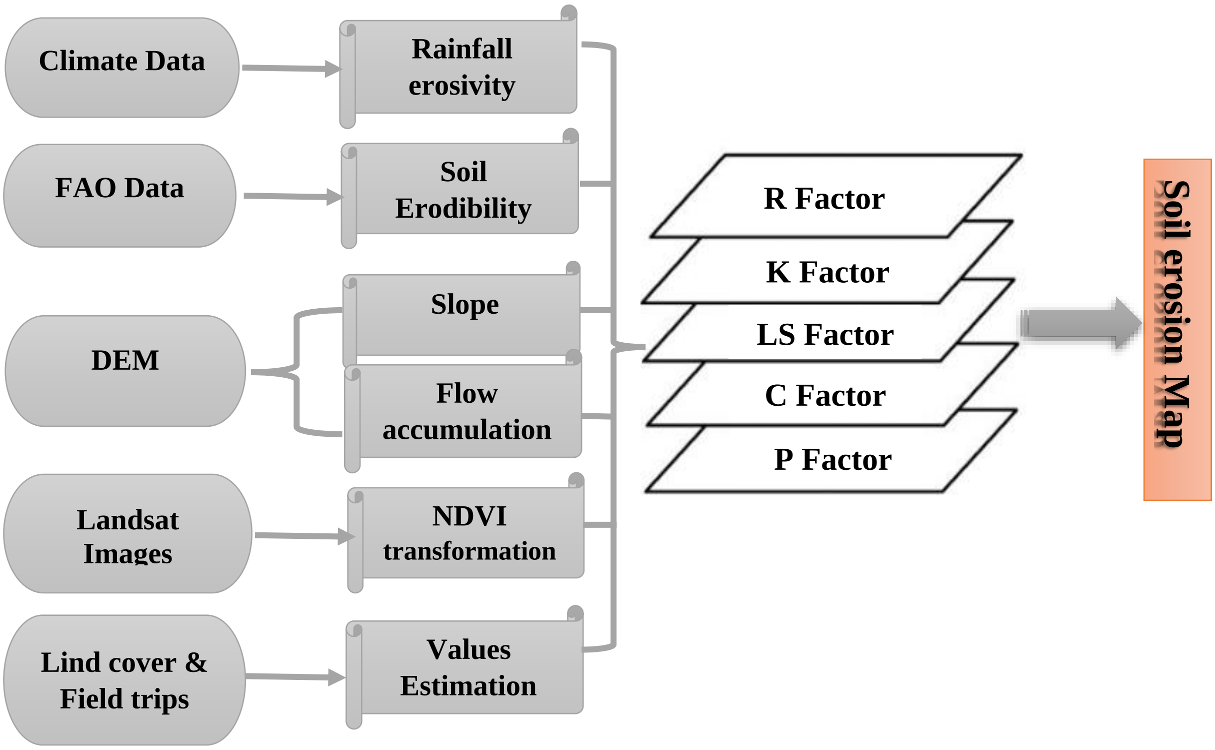



**Fig. 2. methodological diagram of the RUSLE model**

### 3.1. Soil Erodibility (K):

Mediterranean soils tend to degrade once exposed, especially in the absence of a continuous litter supply (Roose et al., 2012). Several parameters are essential in determining soil vulnerability to erosion. These include infiltration capacity, retention texture, and susceptibility to detachment. High infiltration and cohesion of materials increase the soil's resistance to detachment and rilling. Low clay content promotes erodibility. The high content of silt and fine sand destabilizes the soil structure, making it susceptible to climatic aggressiveness. Similarly, organic matter, which enhances the physical and chemical properties (cohesion, structural stability, porosity) of the soil, increases water retention capacity and strengthens erosion resistance (El Hage Hassan, 2011).

The formula used to determine the erodibility factor according to the equation of (William et al., 1990) is as follows:

$$k = \left[0.2 + 0.3\exp\left(0.0256SAN\left(1 - \frac{SIL}{100}\right)\right)\right] \left(\frac{SIL}{CLA} + SIL\right)^{0.3} \times \left[1 - \frac{0.25C}{c + \exp(3.72 - 2.95C)}\right] \times \left[1 - \frac{0.7SN1}{SN1 + \exp(-5.51 + 2.9SN1)}\right] \quad (2)$$

Where SAN, SIL, CLA are, respectively, the sand fraction of the soil, the silt fraction, and the clay fraction (%). C is the carbon content of the topsoil (%). SN1 = 1 - SAN/100.

### 3.2. The Rainfall Erosivity Factor (R):

Climatic aggressiveness promotes erosion, attributing a devastating effect to the climate (Bou Kheir, 2001). Precipitation action amplifies the driving forces needed for soil particle detachment. The index (R) expresses the ability of rainfall to cause erosion. Rainfall, through its intensity and energy, is the primary determining factor for soil loss. Wischmeier and Smith (1978) determined the rainfall erosivity for a rain event by the following equation:The application of the Wischmeier formula requires the availability of data for kinetic energy "Ec" and the average intensity of rainfall in 30 minutes "I30" according to the equation:

$$\mathbf{R = K\ Ec.I30} \quad (3)$$

In the absence of availability of these data, we adopt the relationship from Rango and Arnolds (1987), which allows for the integration of monthly and annual precipitation data as follows:

$$\text{Log } R = 1.74 \times \log \sum (12\ 1\ Pi^2/P) + 1.29 \quad (4)$$

With: **R** = Rainfall aggressiveness;

**Pi** = Monthly precipitation average (mm);

**P** = Annual precipitation average (mm)

This equation is applied based on the data (annual and monthly precipitation) processed using the WORDCLIM v2 database. Then, interpolation is performed across the entire study area.

### 3.3. Topographic Factor (LS):

Topography significantly influences the mechanism of water erosion. Several elements need to be considered to assess the role of the topographic factor, including the length and angle of the slope, surface condition, topographic position, and slope shape. The steepness of the slope enhances the erosive force of runoff water. The slope length favors runoff over infiltration and causes significant incisions (Neboit, 1991). However, the impacts of slope length are uncertain (De Noni, 2001; Roose, 1994), and soil behavior regarding infiltration depends on texture and surface condition (Casenave and Valentin, 1989). On a gentle slope, changes in land practices can lead to soil loss.

$$\boldsymbol{LS} = \mathbf{1.\ 4} * (\boldsymbol{AS}\ \mathbf{22}.\mathrm{y}\mathbf{1})\ \mathbf{0{,}4} * \mathbf{sin}\ (\boldsymbol{\theta} * \mathbf{0{,}01745})\ \mathbf{1{,}4\ 0{,}09} \quad (5)$$

**θ :** The slope angle in degrees.
**AS:** Flow Accumulation * Cell Size. The surface area (AS) map is determined by multiplying the runoff accumulation map (Flow Accumulation) by the pixel size (resolution).

### 3.4. Vegetative Cover (C):

The vegetation cover factor C was assessed throughout the watershed using the Normalized Difference Vegetation Index (NDVI) from satellite images. The satellite images were acquired in October or November, a period when the soil is considered prone to erosion as it becomes dry after a long summer period and becomes sensitive to the first autumn rains, especially when farmers plow their fields during this period. NDVI indices are quantitative measures based on the spectral properties of vegetation that attempt to measure biomass or vegetative vigor (Agapiou and Hadjimitsis, 2011). As an indirect estimation of vegetation density, NDVI, which approximates density and chlorophyll, was calculated for the study area. It was generated from Landsat OLI/TIR images with a spatial resolution of 30 meters, acquired during the wet season, and is well-suited for this application since erosion is most active, and vegetation is at its peak during this season.
Le facteur a été élaborée a par la formule suivante (Van der knijff et al., 2000) à l’aide de l'indice NDVI (Normalized Différence Vegetation Index).

$$NDVI = \frac{\text{PIR} - \text{R}}{\text{PIR} + \text{R}} \tag{6}$$

Where NIR is the intensity of light in near-infrared, and R is the intensity of light in the red channel. This index is an indicator of the energy reflected by the earth, related to different conditions of land cover types. When the measured spectral response of the earth's surface is very similar in both bands, NDVI values approach zero. A large difference between the two bands results in NDVI values at the ends of the data range. The following formula is proposed by (Van et al., 2000).

$$\text{C=exp (-exp } (-\alpha \times \frac{NDVI}{\beta - NDVI}) \tag{7}$$

With: $\alpha$=2 and $\beta$=1

### 3.5. Anti-Erosion Practices (P):

The anti-erosion practices factor (P) reflects practices that reduce the quantity and speed of runoff water, thus minimizing the effects of water erosion. Contour farming, strip cropping, terracing, afforestation with berms, ridging, and furrowing are the most effective soil conservation practices. The P values are less than or equal to 1. A value of 1 is assigned to areas where none of the mentioned practices is used. P values vary depending on the adopted practice and also on the slope. Throughout the study area, there are no anti-erosion measures, and farmers do not use anti-erosion cultivation practices. Crops are mainly cereals, and plowing is rarely parallel to contour lines. There are some attempts to rehabilitate forests through afforestation but not with berms. In this context, the value P = 1 has been assigned to the entire study area.

## 4. Results and Discussion:

### 4.1. Factor R

The spatialization of rainfall data recorded in the study area over a period of 37 years, using the Inverse Distance Weighting (IDW) interpolation method, has led to an overall assessment of the (R) factor.The synthesized erosivity maps show that the value of the R factor varies from 65 to 81 for the year 2022 (Figure 3), while for the year 1985, the values range from 71 to 89.

The high values are recorded in the center of the basin, while the lowest values are recorded downstream and upstream. Indeed, the R values undergo a dual gradient from the center towards the upstream and from the center towards the downstream. Thus, there is a decrease in climatic aggressiveness over the years.

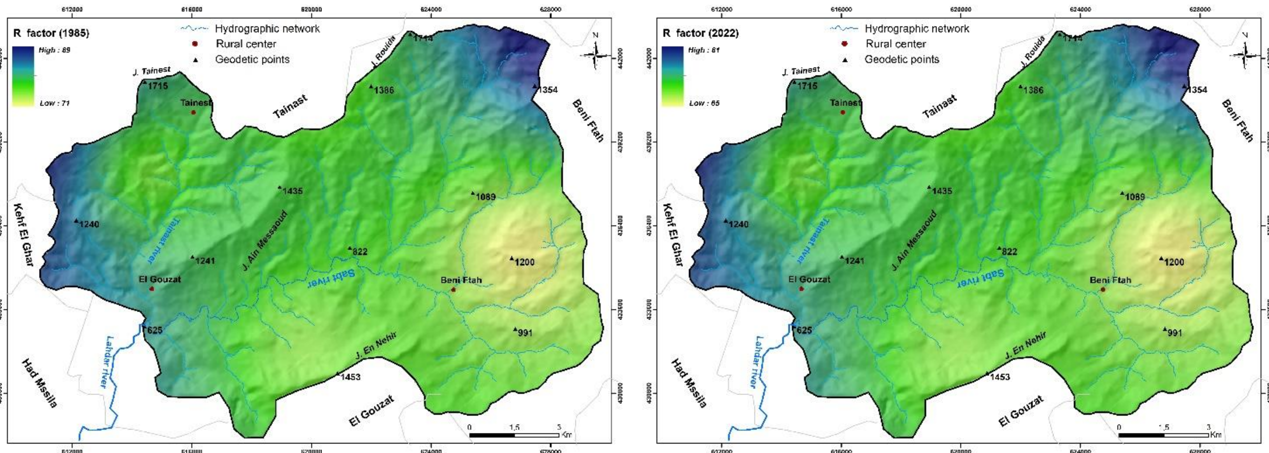



**Fig. 3 : Rainful erosivity maps for the years 1985 and 2022 in the watershed of the upstraem inaouène**

### 4.2. Factor K

From this information and the database downloaded from the FAO website, and analyzing the geological map, it is then possible to obtain the factor K for a soil using the table establishing the correspondence between standard textures and the K factor (Stone and Hillborn, 2002). The table synthesizes the K factor values for each soil type, with a value of zero assigned to water zones.

The analysis of the database and the map of the K factor show that the erodibility values differ according to the soil type. At the watershed scale, the K factor varies from 0.3 t.ha.h/ha.MJ.mm for the most resistant soils to 0.85 t.ha.h/ha.MJ.mm for the most erodible soils (Figure 4). The following figure presents the distribution of the total watershed area according to soil erodibility and the corresponding percentages.

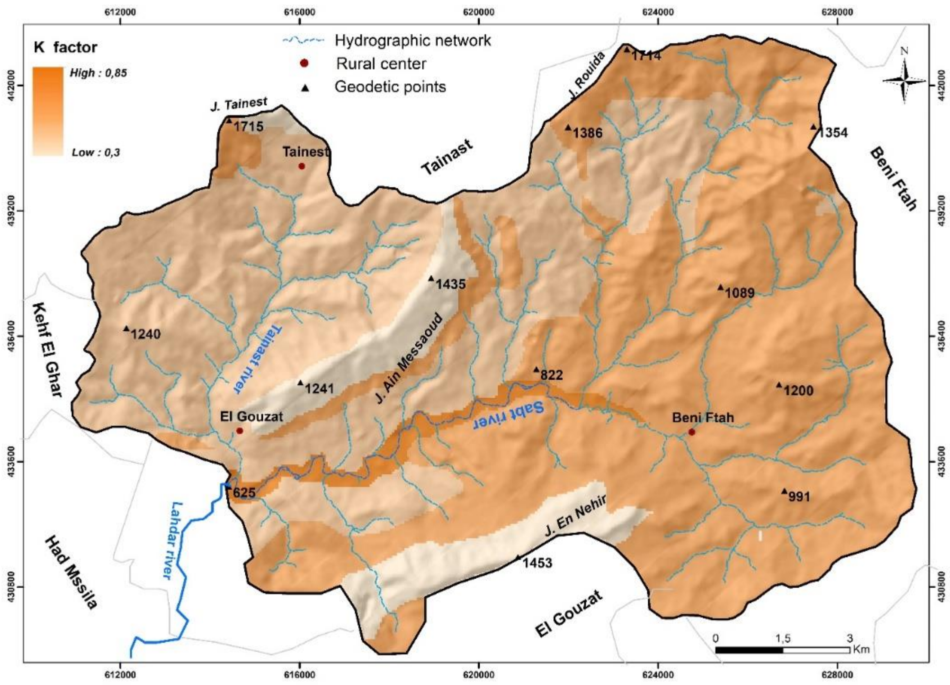



**Fig.4. Map representing the (K) factor variation**

According to the classification of soil erosion resistance by Bollinne and Rosseau (1978) based on the K factor (Table 1), the soils in the study area are considered sensitive and highly sensitive to erosion, with a value greater than 0.4 t. ha.h/ha.MJ.mm. The less evolved soils have a moderate erodibility ranging from (0.1-0.3), while soils with strong and very strong resistance are absent in our watershed.

**Table 1. Classification of soil erosion resistance according to Bollinne and Rosseau (1978)**

| SOIL TYPE | K FACTOR (T. HA.H/HA.MJ.MM) | AREA PERCENTAGE |
|---|---|---|
| **HIGHLY EROSION-RESISTANT SOILS** | K < 0.1 | - |
| **FAIRLY EROSION-RESISTANT SOILS** | 0.1 – 0.3 | - |
| **MODERATELY EROSION-SENSITIVE SOILS** | 0.3 – 0.4 | 10% |
| **FAIRLY EROSION-SENSITIVE SOILS** | 0.04 – 0.5 | 38% |
| **HIGHLY EROSION-SENSITIVE SOILS** | K > 0.5 | 52% |

### 4.3. Factor C

The obtained map (Figure 5) illustrates the distribution of vegetation cover impact values for the years 1985 and 2022. Values of C < 0.2 and C < 0.3 indicate well-developed vegetation cover and thus well-protected soil. Conversely, values of C ≥ 0.3 confirm poor soil protection. In 2022, the vegetation cover is more significant than in 1985, as the area has been reforested by the state under the Morocco Green Plan, along with developments by the High Commissioner for Water and Forests. We observe that the percentage of well-protected areas increases over a large surface. However, there are areas that have become less protected. This change is explained by the transition from cultivated land to bare land in the central and northeast parts of the study area. This trend is influenced by the impact of the summer season, well represented by the satellite image used.

The banks of the basin also show a very high vegetation rate, corresponding to agricultural land and the impact of reforestation on soil loss. Thus, it is concluded that potential erosion in this watershed is significantly accelerated. In the same vein, have shown that the risk of water erosion is higher when soils are occupied by less-covering hoe crops or degraded pastoral plants, followed by more-covering non-hoe crops, then meadows and dense forests where the risk is minimal. It should also be noted that soil tillage practices influence soil sensitivity to erosion. Generally, crops require refinement of the soil's surface layer, which can lead to the formation of a crust that, in the case of heavy rain, reduces infiltration and consequently accelerates runoff.

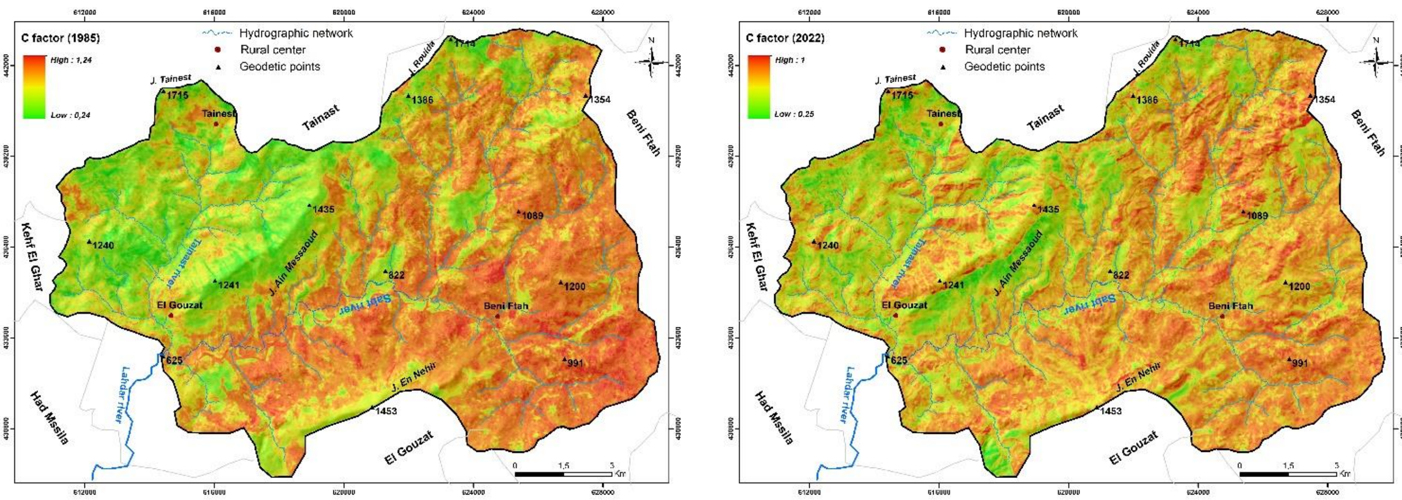



**Fig. 5: Map of the C factor in 1985 and 2022 in the upstream Inaouène watershed**

### 4.4. Factor Ls

The calculation of the slope and slope length factor in the watershed (Figure 6) shows values ranging from 0.002 to 65.33, with a maximum concentration towards the north of the basin on the slopes of the Intra-Rif, covering a significant area. Conversely, in almost half of the northern part of the basin, there is a rugged morphology with LS values exceeding 30. Low values are less sensitive to erosion, while high values upstream indicate a higher sensitivity to erosion.

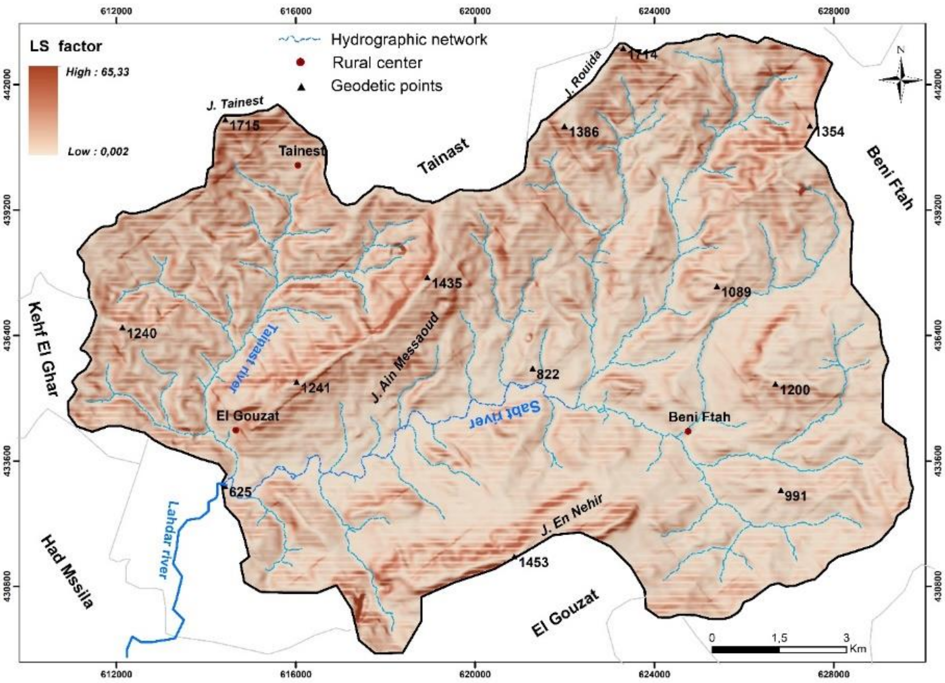


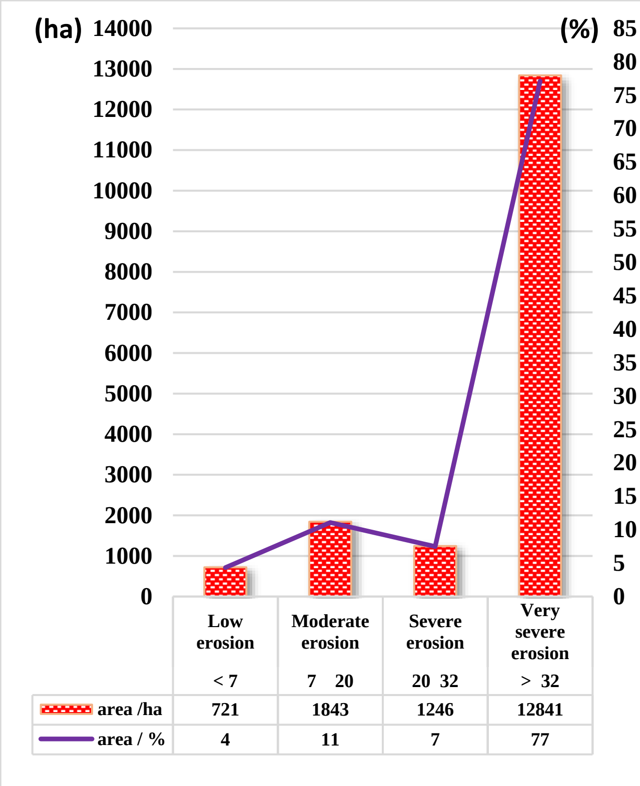
**Fig6: Map representing variation topographic factor (LS)**

### 4.5. Soil loss rates (t/ha/year): (A)

Synthetic maps of soil losses were generated using a geographic information system and spatial remote sensing. They result from the multiplicative combination of various factors (R, K, LS, C, and P) of the revised Revised Universal Soil Loss Equation (RUSLE). These maps highlight the extent of soil losses across the entire study area, as well as areas with a high risk of erosion (Figure 9).

In terms of spatial distribution, the state of erosion in the upstream Inaouène basin in both study periods clearly shows that the average soil losses are consistently above 55 t/ha/year. In 1985, areas with very high losses (<32 t/ha/year) were predominant, occupying 77% of the total watershed area, and for the year 2022, this category of loss recorded a notable decrease but still occupies a significant area of the study area (59%). This severe scenario is likely associated with the significant spread of bare lands and badlands on steep unprotected slopes where enormous amounts of sediment are discharged into main collectors every year. On the other hand, losses below 7 t/ha/year occupy only 4% of the total area in 1985 and 8% in 2022, due to the reduced area of uncultivated lands and badlands and the considerable expansion of forests and reforested areas gaining ground on most slopes, especially in the northern and northwestern parts of the basin (Figure.9). The map of classes of average annual soil losses testifies to the great fragility of the eastern and northeastern part of the basin carved into marl formations, mainly in marl-limestone and blue marls of the Miocene, where values exceeding 32 t/ha/year are dominant. Furthermore, low losses mainly dominate upstream of the basin, especially in the northern, northwestern, and central parts where a scrubland with holm oaks reinforced by reforestation with resinous trees covers these sectors.

Comparing the quantity of soil losses over time, the results obtained using the RUSLE model clearly show that the amount of soil loss in the study area has experienced a notable reduction between 1985 and 2022 (figure 7 and 8). In the category of very high losses, on the other hand, other categories have experienced a significant increase in losses. This is due to several influencing factors, where it is noteworthy that the study area has undergone a significant change in land use, with a positive evolution of forested areas between these two periods, especially concerning reforestation operations carried out by the High Commissioner for Water and Forests as part of the "Green Morocco plan". This intervention is directed towards mountainous areas with steep slopes, where losses are becoming increasingly pronounced. Additionally, by comparing climatic data, especially precipitation from meteorological stations located in the study area, it is evident that there has been a significant reduction in precipitation amounts in recent years, especially autumnal precipitation, which has a more significant impact on soil erosion.



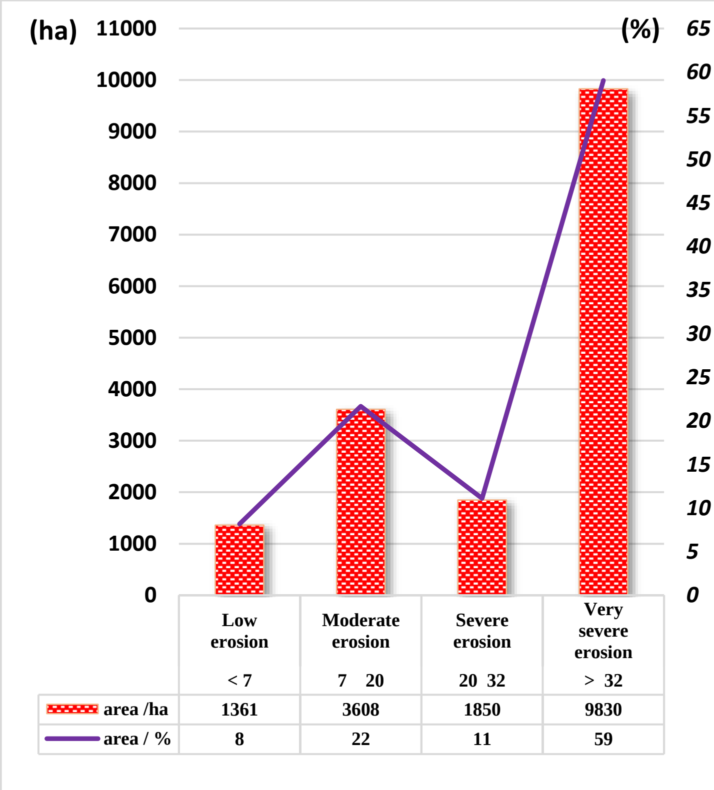




**Fig.7. Soil loss areas in 1985**

**Fig.8. Soil loss areas in 2022**

To put these results into perspective, one can compare the average losses in other basins, such as the Oued Tleta basin in the Eastern Prerif, where they are estimated at 61 tonnes per hectare per year (Tribak et al., 2009; Amahani et al., 2021). The same authors found average values of around 78 tonnes per hectare per year for the Oued Tarmast basin in 2015 and 2021 (Tribak et al., 2015), as well as 43 tonnes per hectare per year for the Oued Ourtza basin (Tribak et al., 2021). In the Oued Nakhla basin in the Western Rif, average losses amount to 65 tonnes per hectare per year in fields (Naimi et al., 2005), while in the Oued Boussouab basin in the Eastern Rif, losses reach approximately 55 tonnes per hectare per year (Sadiki et al., 2004). In 2009, the same author assessed an average of about 22 tonnes per hectare per year in the respective basin.

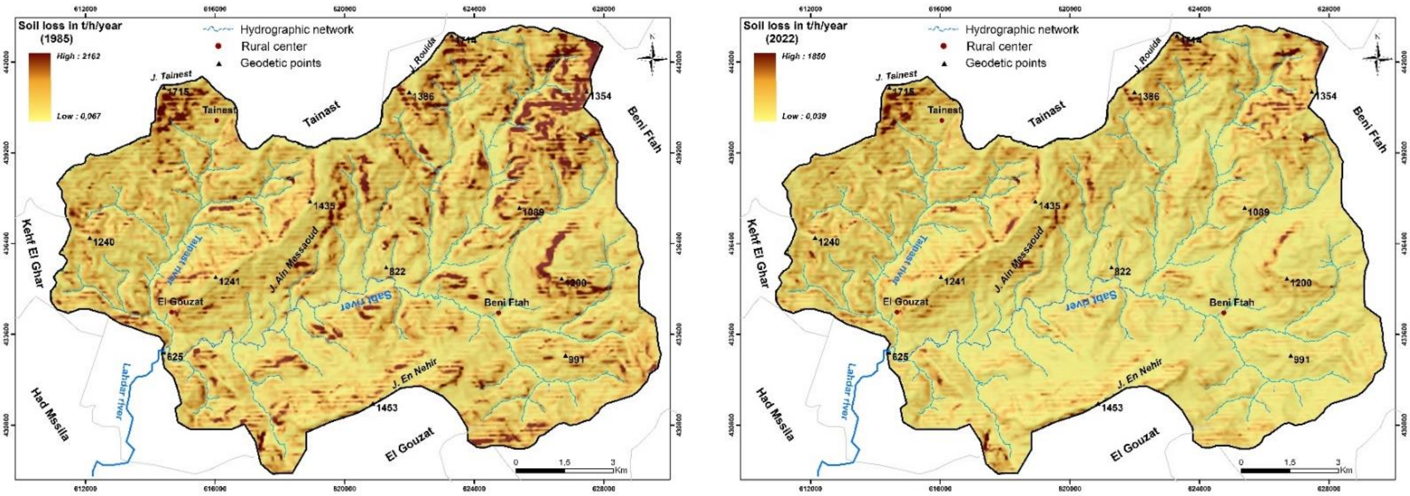



**Fig 9: RUSLE soil loss map for the upstream Inaouène watershed**

## 5. Conclusion:

This study relied on the use of the Revised Universal Soil Loss Equation (RUSLE) in conjunction with a Geographic Information System (GIS) and spatial remote sensing. The results reveal a significant decrease in the amount of soil loss in the study area between 1985 and 2022, attributable to various factors, including changes in forested areas and reforestation operations involving various plant species, as previously discussed in the discussion phase. It can be concluded that while reforestation efforts have had a positive impact to a certain extent, it remains insufficient given the magnitude of soil loss in the region. This justifies the need to undertake multiple projects aimed at reforesting areas most exposed to degradation caused by rainfall erosion.

In light of these results and during field visits, several solutions can be considered to mitigate this issue, including:

- ✓ Intensifying reforestation operations in the region by expanding their scope, not limiting them solely to mountainous areas and steep slopes but also including areas with low to moderate slopes exposed to forms of initial erosion to prevent their deterioration.
- ✓ Exploring more effective plant varieties for soil stabilization without depleting it, ideally favoring fruit trees over pines (conifers) that deplete the soil and have fewer effective roots for stabilizing the soil.
- ✓ Promoting socio-economic initiatives that generate income for the local population, thereby compensating for the loss of their land while encouraging them to diversify their sources of income away from the exploitation of forested areas.
- ✓ Designating certain areas of this region as national parks due to their rich plant and animal diversity, as well as their significance as tourist sites (caves, waterfalls, natural landscapes, etc.).

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