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Assessment of Water Erosion by Integrating RUSLE Model, GIS and Remote Sensing – Case of Tamdrost Watershed (Morocco)

Naïma El Assaoui[1*], Charaf Eddine Bouiss[1], Abdelaziz Sadok[2]

[1] Water and Environmental Laboratory, Earth Sciences, Faculty of Sciences, Mohammed V University in Rabat, Morocco

[2] Department of Civil Engineering, Mohammedia School of Engineers Mohamed V University, Rabat, Morocco

* Corresponding author's email: nelassaoui@gmail.com

ABSTRACT

Water erosion caused by rainfall and runoff, in the Morocco is the main threat of fertile agricultural soil losses causing important silting-up of dams. Most watersheds are characterized by excessive values of Soil Specific Degradation (Average annual soil loss per year and per km^2), exceeding in many regions 2000 T/km^2/year. The main objective of this study is to investigate this phenomenon in the Tamdrost watershed located in northwestern Morocco. The methodology is based on integrating water erosion RUSLE model to Geographic Information System and satellite image processing. The aim of the study is to develop digital mapping for the main factors involved in the erosion processes as well as the variation of the average annual quantity of soil losses. The results outcome are: (i) the average value of the specific degradation is about 80 (T/ha/year), reaching a maximum value of 800 T/ha/year and a minimum value of 3 T/ha/year; (ii) The main factors that control water erosion by order of importance are successively: R, LS, K, and C factors. Finally, different maps representing erosion and the main factors involved, are be very helpful for decision makers to better assess this phenomenon and to implement anti-erosion measures in the threatened areas to support and control the water erosion.

Keywords: RUSLE, watershed soil loss, thematic maps, GIS, remote sensing, erosion yield.

INTRODUCTION

Water erosion is the main cause of soil degradation in Morocco, and the most threat phenomena for watershed management and planning. This is due to an irregular climatic regime characterized by alternating a long duration period of storms and dry periods. The phenomenon is accentuated in many Moroccan's regions by the presence of highly erodible soils and often by the nature of mountainous reliefs, like for example in the Rif located in the northern region of Morocco. This complex phenomenon is mainly related to surface water rainfall and runoff and linked to natural and anthropic factors involved in this phenomenon. If the first factors depend on the nature of the climate especially the rainfall pattern, the nature of the soil, the soil cover, the topography and geomorphology of the land; the last factors depend on human activities both in terms of preventive and curative support and management practices implemented to mitigate and control the water erosion phenomenon. More than 40% of the fertile agricultural land is threatened by water erosion. Therefore, more that 12.5 million hectares of cropland are actually affected by erosion. The specific soil loss degradation of the watersheds varies between mountainous zones with strong slopes and strong rainfalls like in the Rif region exceeding 2000 T/km^2/year and desert regions in the south characterized by weak slopes and little rainfalls values generating a specific degradation of soil which does not exceed 500 to 2000 T/km^2/year (Lahlou, 1996; 1994).

Previous studies to assess the water erosion in Morocco have starting in the 60's and the 70's especially Fournier works (Fournier, 1960; 1967), and Heusch investigations in Sebou watershed (Heusch, 1970). Also Lahlou, (Lahlou, 1996; Lahlou, 1994) developed empirical equations based on collected data especially in dam's silting studies taking into account run-off, soil structure and topography of lands. (Sadok and Kamal, 1995) make a peer-review study of models of estimating water erosion and their feasibility in the Moroccan's context. In the last decade USLE model and its improved versions MUSLE and RUSLE and but other models like SWAT are used to investigate the water erosion in many Moroccan's watershed, (Brahim et al., 2020; Moudden et al., 2022). Also, the recent development of GIS and remote sensing techniques give opportunity to improve the quality of these investigations by linking erosion models with these new technologies. (Aoufa et al., 2022; Amellah et al.,2021).

This research paper aims to contribute in that way by estimating water erosion and its spatial and temporal distribution in the Tamdrost watershed. The main objectives are to assess the response of the watershed's factors to the water erosion processes and to help decision-makers by identifying the most vulnerable parts of the watershed and therefore to guide in implementing efficient support and conservation practices to reduce soil losses. The approach used is based on integrating RUSLE erosion model (Renard et al., 1996), GIS and remote sensing. The natural and entropic factors taken into account are respectively: Slope, Soil sensitivity to erosion, climatic sensitivity, vegetation cover, as well as anti-erosion practices related to human actions. Specific maps for the main factors involved in the water erosion processes of the Tamdrost watershed and for annual average soil losses are developed.

MATERIALS AND METHODS

The study area

The Tamdrost basin (Figure 1) is part of the Settat plateau located in the North-West of Morocco and extends over an area of 656 km^2 with a perimeter of 194 km. Its water supply contributes to the Berrechid aquifer which is among the most important groundwater aquifers especially during flood periods. Its topography is very irregular with elevations varying between 803 m in the upstream part and 300 m at the basin outlet. Very steep slopes greater than 25% represent more than 64% of the total study area.

The geology is characterized by morpho-structural units strongly altered crushed locally. The basin consists of a large cover of Meso to Cenozoic age with a lithology predominated by facies of medium mechanical strength essentially marl. There are resistant rocks such as limestone for example, soft rocks in the alluvium and clays (Aunis and Michard, 1976; El Assaoui, 2017). The rainfall regime is Mediterranean under a semi-arid climate with temperate winter. The real evapotranspiration average is estimated to 320 mm/year. A value that remains lower than the average annual precipitation (530 mm/year),

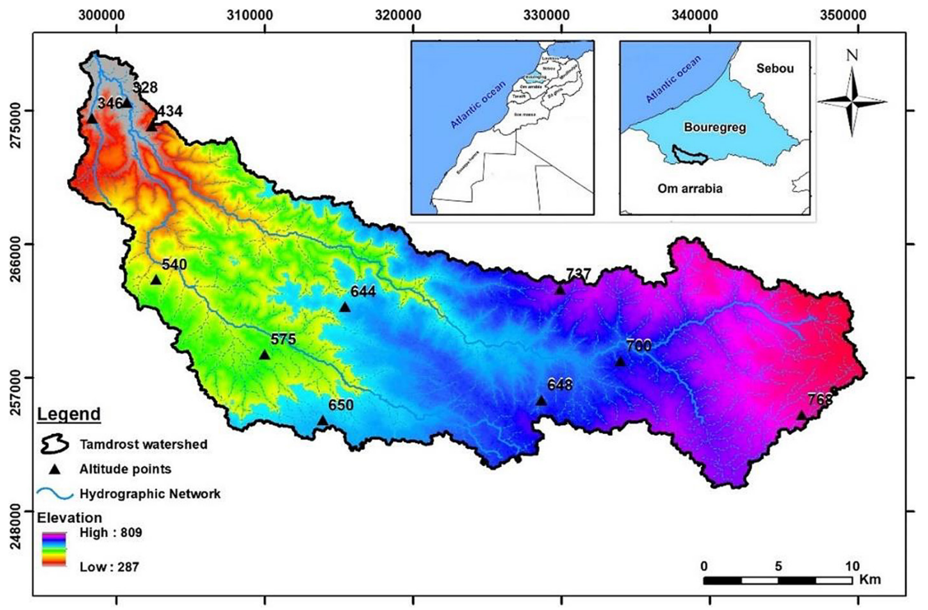

Figure 1. Localization of the study area

which contributes to groundwater's recharge and runoff. From the water balance of the catchment area, we can distinguish four different periods: deficit (June to September), restitution of soil water reserves (October to November), surplus (November to February) and exhaustion of easily usable reserves (March to May). The demography is characterized by a very high density compared to the average of Morocco, despite the regression of the growth rate in the last twenty years (1994/2014). However, the distribution of the population remains very strong causing great pressure on water and soil resources, in a vulnerable environment which accentuates its fragility by clearing and degradation of vegetation cover as well as the cultivation of steeply sloping land (El Assaoui, 2017).

Datasets

Each of the RUSLE-factors excluding the P factor representing human impacts, was estimated separately by adapting the data available and equations developed for similar environmental conditions of the Tamdrost basin. The generation of the erosion factors maps is explained in detail in the corresponding parts of this paper.

The use of satellite images permits to better estimate P-factor and C-Factor. We use NDVI to compute the C-factor based on land satellite image during summer for a better characterization.

Due to lack of some climate Data, we use the "wordclim.org/version 2 (Terraclimate) platform", developed by (Fick and Hijmans, 2017) and based on satellite-acquired climate data. It is a database that aggregates the global climate of all continents (except Antarctica) with a spatial resolution of 30 second arcs or 1 km².

To develop the vegetation cover map, we exploited Remote Sensing data for mapping canopy intensity factors. Landsat 8 satellite images of the summer season specifically the month May of the years 2002, 2005 and 2015 were used for a supervised classification. We assess the vegetation cover map from the formula proposed by (Van der Knijff et al., 2000), using the NDVI (Normalized Difference Vegetation Index), which is widely used to calculate the vegetation cover in erosion modeling to estimate the K-factor estimation due to lack of data we used the web site of HDWS (digital soil map of Word) to download complete needed informations.

Methodology

The methodology adopted consists in the integration of RUSLE model, GIS and remote sensing techniques to estimate the average annual spoil loss of the Tamdrost watershed basin through a representation of cartographic and descriptive information of the five erosion factors involved in a geographic information system. A spatially referenced database containing the quantitative information concerning the study area adopting a systemic approach based on a multi-criteria method allow to produce the factors maps. These maps are representing the different factors variation representing different aspects involved in this phenomenon (lithology, rainfall, topography, vegetation cover and management and also support and conservation to reduce erosion). This approach is summarized in the following flowchart (Figure 2):

The erosion model RUSLE

The RUSLE model, (Renard et al., 1996) is a revised version of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965). It's recognized as the most widely used, especially in the case of lack of data. This equation predicts the long-term loss soil due to water erosion. The average annual soil loss (specific degradation named A) is estimated by multiplying the five factors representing natural and anthropic effects. These factors are namely: rainfall and runoff erosivity (R), soil erodibility(K), topography (LS), cover and management of crops (C), and support and control practices (P). This equation retains the same form as the USLE model, which is presented in the following relationship (Equation 1).

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

where: A – estimated annual soil loss per unit area (t/ha/year);
R – rainfall erosivity factor (MJ × mm/ha × h × year);
K – soil erodibility factor (t × ha × h/ha × MJ × mm);
LS – combining the effect of slope length (L) and the effect of slope steepness (S) (dimensionless);
C – vegetation cover and management factor (dimensionless); P is Anti-erosion practices representing support and conservation actions (dimensionless).

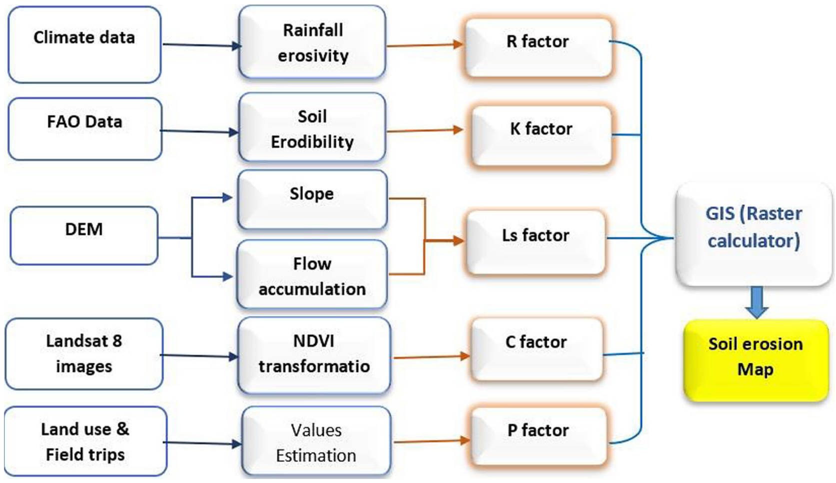

Figure 2. Chart of the study's methodology

Each factor study will be explained in details in specific parts of this paper.

RESULTS AND DISCUSSION

Rainfall erosivity index (R)

Rainfall is one of the main factors of soil erosion, wich on rainfall and runoff processes eroding and transporting sediment (Mrabet et al., 2004). Thus, the role of the R-factor is to characterize the erosive force of precipitation on the soil. It considers regional differences in climate according to the type, intensity and frequency of rainfall. The estimation of the R factor according to the Wischmeier and Smith formula (Wischmeier and Smith, 1978) requires data related to the kinetic energy (*Ec*) and the maximum intensity over 30 minutes (I30) of the raindrops in each rainstorm. They are given by the following formula (Equation 2):

$$R = k_R \times Ec \times I_{30} \quad (2)$$

where: k_R – a coefficient depending on the system of measurement units.

This equation cannot be applied in this study due to the lack of data. The available meteorological stations for rainfall data are in the vicinity out of the area providing annual averages. Therefore, we are using equations 3 and 4 to estimate R-Factor. The Formulae (Equation 3) is widely used and due to (Renard and Freimund, 1994), and modified by (Sharma, 2011) (Equation 3).

$$\text{For } Pi < 850\ mm,\ R = 0.0483 \times P^{1{,}61}$$
$$\text{For } Pi > 850\ mm,\ R = (587.8 - 1.219P + 0.004105 \times P^2) \quad (3)$$

where: P representing annual precipitation in (mm).

However, (Lo et al., 1985) developed a formula based only on the average values of annual precipitation, and based on experiments data in some Hawaii areas. It's widely used (Equation 4):

$$R = (38.46 + (3.48 \times P)) \quad (4)$$

In this study Equations 1 and 2 are used to estimate the erosivity factor R in order to compare with the value obtained with formula 3 developed by (Arnoldus, 1980) taking into account the characteristics of Moroccan's climate, and improved later by (Rango and Arnoldus, 1987). This formula involves monthly and annual precipitation to determine the *R*-Factor (Equation 5).

$$\text{Log } R = 1.74 \times \log \sum_1^{12} (Pi^2/P) + 1.29 \quad (5)$$

where: Pi – Average monthly precipitation (mm), P – average annual precipitation (mm).

The formula 5 were applied for Tamdrost area on the basis of the data collected from the "wordclim.org/version 2 (Terraclimate) platform" (Fick and Hijmans, 2017), and using satellite-acquired climate data. It is a database that aggregates the global climate of all continents (except Antarctica) with a spatial resolution of 30 second arcs or 1 km². The mean annual precipitation was obtained by combining the 12 monthly mean precipitation maps. (Equation 5) was integrated into ArcGIS and processed with the Map Algebra function to calculate the R factor. The climatological measurements used correspond to the period 1981 to 2021, for which errors related to the measurement stations were corrected (wordclim.org, 2016). The data are acquired on images in Geotiff format, which each one represents the monthly average during 30 years. The result obtained represented in Figure 3 shows that the value of the R-factor varies from 215 to 443. The high values are observed in the center of the basin, while the lowest values are recorded downstream and upstream. On the other hand, for the years 2002 and 2015 the values with an interval of 245 to 380 are distributed.

Topographic factor (LS)

The RUSLE model can either increase or decrease soil degradation. As it is one of the key factors promoting erosion and particle removal in runoff areas which are involved in land surface degradation. This topographic factor LS represents the combined effect of slope length (L) and slope steepness (S) on water erosion in RUSLE model (Renard et al., 1996). The slope has a significant influence on the water erosion process of the catchment. The steeper the slope, the more water runoff will erode sediments. Slope length determines runoff velocity and particle transport McCool et al., 1989). The Tamdrost watershed is characterized by very high susceptibility to erosion. The LS-factor map was elaborated from the ASTER DEM (Digital Elevation Model) with a spatial resolution of 30 m. The **L** and **S** factor were calculated using the fallowing equation (Renard et al., 1996; Bizuwerk et al., 2003), (Equation 6):

$$LS = \left(\frac{FA. \times r}{22.13}\right)^{n} \times (0.065 + 0.0456 \times S + 0.0065 \times S^{2}) \quad (6)$$

where: *FA* – the flow accumulation which represents a RASTER-based total of the accumulated flow to each cell of the DEM;

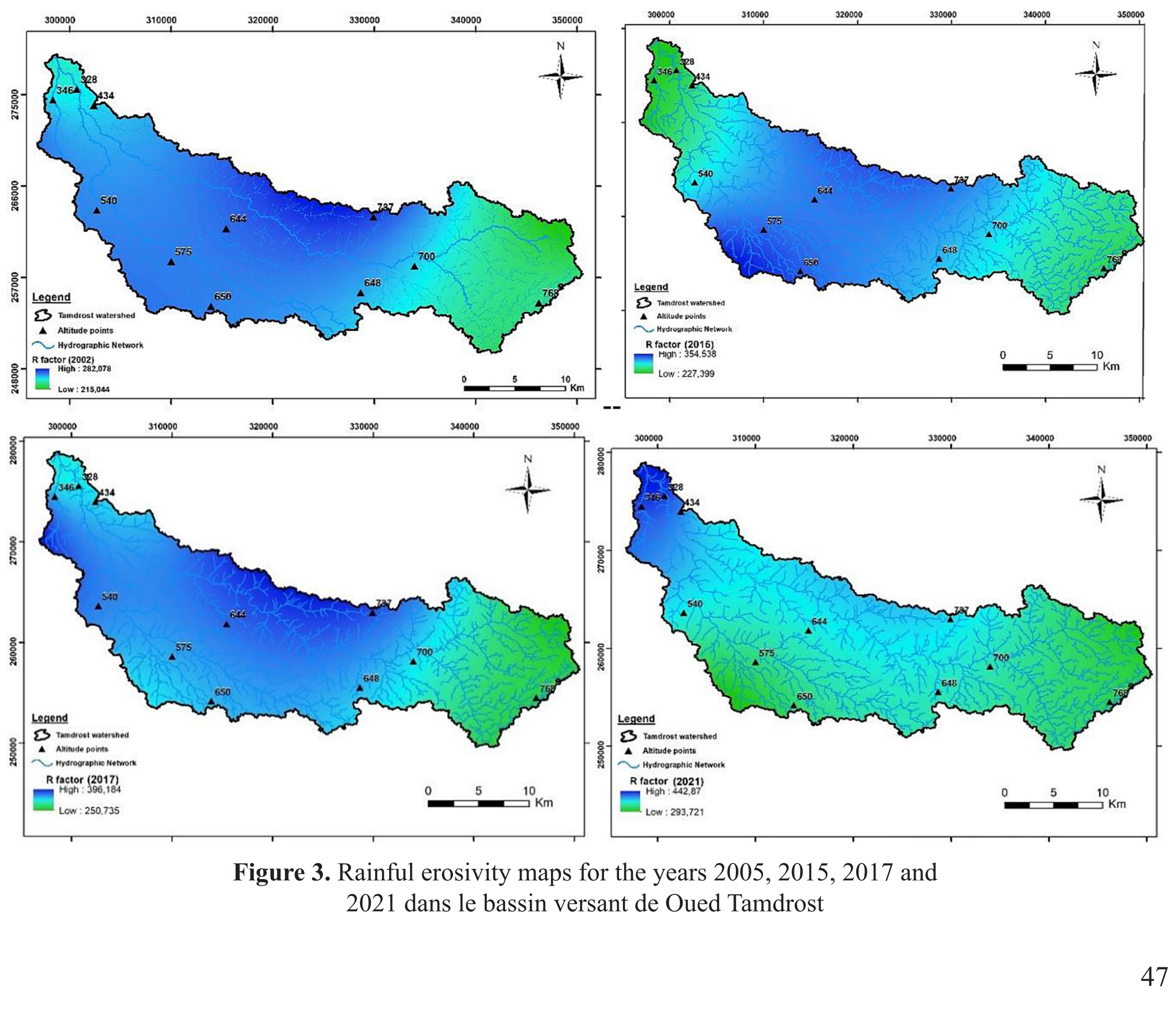

Figure 3. Rainful erosivity maps for the years 2005, 2015, 2017 and 2021 dans le bassin versant de Oued Tamdrost

r – the cell size of the DEM (30m);
S: the slope steepness (%);
n – an empirical coefficient (Table 1).

The factor LS, presented in Figure 4, shows that the topography is relatively rugged in the study area. This fact implies a distribution of LS values ranging from 0.18 to over 40. The analysis of the East Map of the database shows that the majority of the LS factor values are varying between very high to high. They cover a large part of the basin and are generally distributed in the downstream and central part of the basin, around the main river system. The Downstream part is Characterized by a less strong LS factor compared to the Northern and Northwestern region which are relatively high. The lowest values are recorded on the alluvial terraces of the quaternary (Figure 4).

Soil erodibility factor (K)

The Soil erodibility K characterizes the resistance of different soil types to erosion. It is related to the combination effect of rainfall runoff and infiltration on soil loss and represents the effects of soil properties and soil profile characteristics on soil loss (Renard et al., 1996). This K-factor is determined by soil characteristics: infiltration capacity, retention texture and susceptibility to stripping. It is expressed in [t·h/MJ·mm].

The most reliable model is due to Wischmeier with the integration of a corrective factor for coarse elements (Renard et al., 1996), in order to adapt the erodibility factor K to the Mediterranean and arid regions of the USA and North Africa. Soil erodibility was determined using the fallowing formulae (Equation 7):

$$K = ((2.1 \times 10–4 \times (12 – SOM) \times M^{1.14}) + + 3.25 \times (S_t-2) + 2.5 \times (P_R-3)) / 100 \quad (7)$$

where: *K* – soil erodibility; SOM: soil organic matter content in %;
M – textural term = (Silt + Fine sand) % × (100 – Clay %);
S_t – soil structure code (1 to 4): 1 for a very fine-grained structure and 4 for a massive or blocky structure.;
P_R – permeability class (1 to 6):1 for fast-draining soils to 6 for very slow-draining soils.

Due to the lack of data on the different values of organic matter, permeability, texture and structure, and due to the absence of a pedological study for Tamdrost watershed area, we are faced

Table 1. Variation of m depending on slope (%)

Slope < 1	1 ≤ Slope <3	3 ≤ slope < 5	Slope ≥ 5
0.1	0.3	0.4	0.5

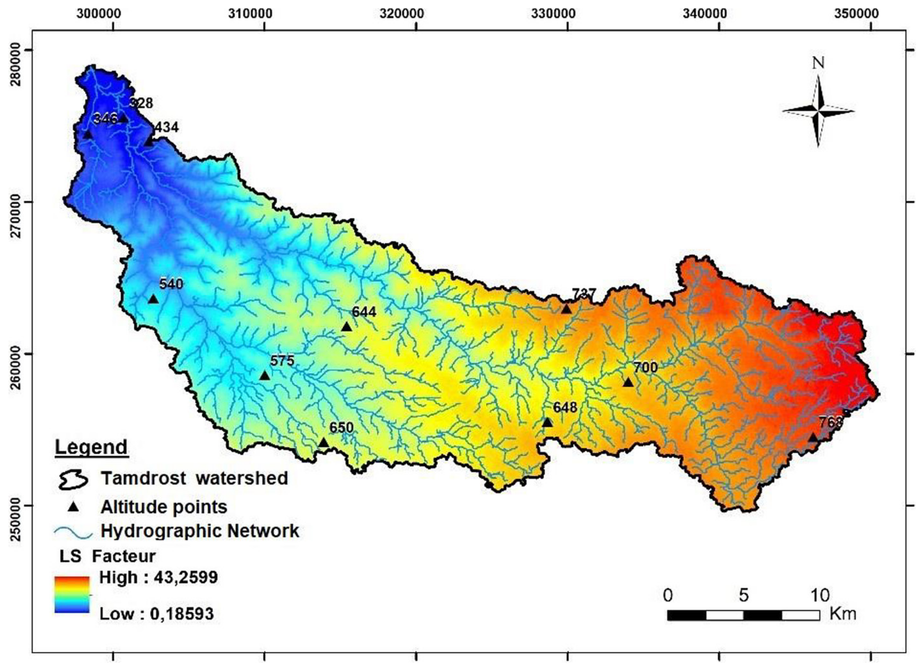

Figure 4. Map representing variation topographic factor (LS)

with a major difficulty to calculate the K-factor. In order to overcome this situation, we download from the HDWS (digital soil map of Word) site web, a complementary data to estimate the K factor. The spatial distribution of the soil erodibility factors map (K factor) varies from 0.13 to 0.16 (t·ha·h/ha·MJ·mm). The dominant class is characterized by an average K factor of 0.16.

The factor (C)

The cover management factor C represents the influence of cover vegetation cover and cultivation techniques. The risk of erosion increases when the soil is without or has little vegetation cover (Linda, 1995). C-factor can vary from zero for well-protected soils to one for soils without vegetation cover (bar lands) which are very sensitive to erosion (Angima et al, 2003). Indeed, a dense vegetation cover is more efficient to reduce erosion because it dissipates the energy of rain drops, slows down the runoff. (Aunis et al., 1976) To develop the vegetation cover map we exploited Remote Sensing data for mapping this erosion factor. Landsat 8 satellite images of the summer season (May month) of the years 2002, 2015, 2017 and 2015 were used for a supervised classification. We made the vegetation cover map from the formula proposed by (Van der Knijff et al., 2000) using the NDVI (Normalized Difference Vegetation Index). This formulae is represented in the following equation (Equation 8)

$$C = exp(-\alpha \times \frac{NDVI}{\beta - NDVI}) \quad (8)$$

With: $\alpha = 2$ and $\beta = 1$ are parameters that determine the shape of the NDVI curve.

The C-Factro map obtained (Figure 6) shows the distribution of vegetation cover impact values of the years 2005 and 2015. Values of C < 0.2 and C < 0.3 are representing a well developed vegetation cover and therefore a well protected soil. On the other hand values of C ≥ 0.3 confirms that there is a poor protection of the soil. In 2002 the vegetation cover C = 0.09 is larger than for the time period (2005–2015). On Figure 6 we observe that the percentage of well protected areas decreases. This change is explained by the transition from cultivated land to bare lands in the central and northeastern part of the study area. This tendency is due to the summer season impact which is well represented by the satellite image used. The edges of the river also show a very important vegetation rate, which corresponds to agricultural land and reforestation impact on the soil losses.

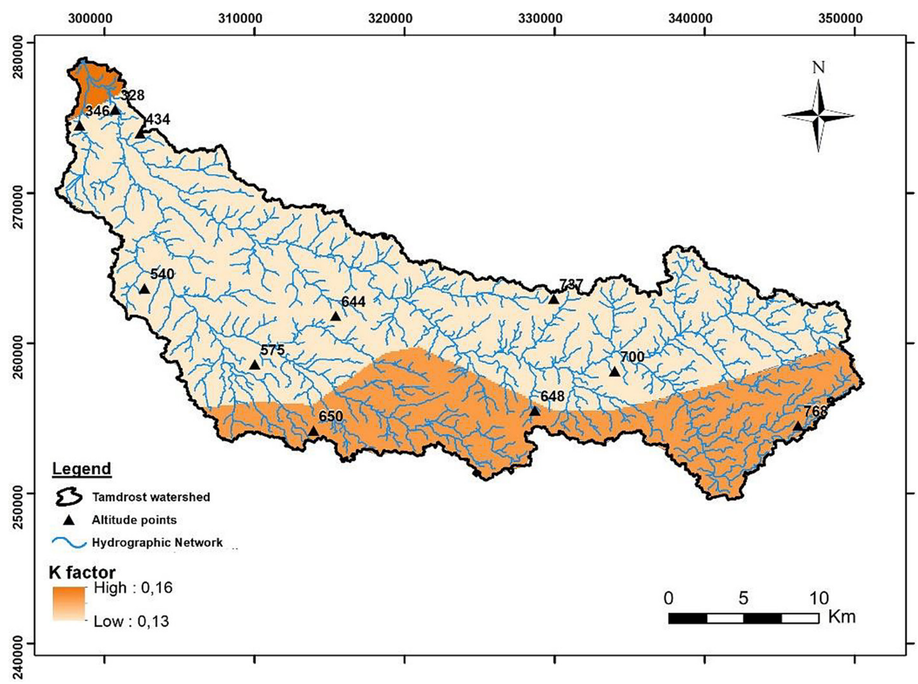

Figure 5. Map representing the (K) factor variation

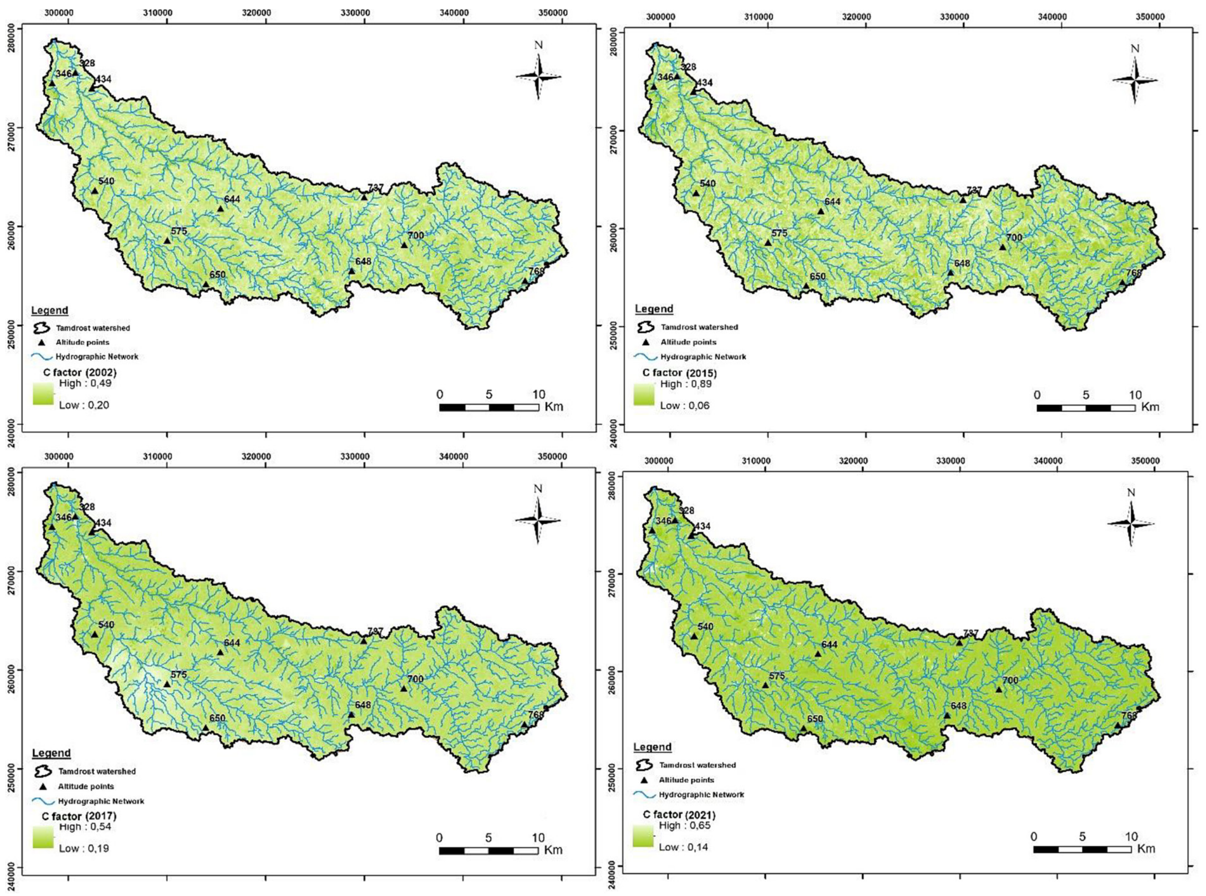

Figure 6. Maps of the *C*-factor generated from the NDVI-based transformation of Landsat 8 images

Support and control practices factor (P)

P-factor represents the efficiency of Support and control practices to reduce the erosion potential of rainfall and runoff. It have a tremendous impact on soil erosion by altering the profile of the slope, or by redirecting the runoff flow and flood control (Renard et al., 1983). The values of this factor vary between 0 and 1, depending on the slope and the practice adopted (contour, alternate strip or terrace cropping). It is generally determined by Shin's classification (Shin, 1999) (Table 2).

For Tamdrost watershed, we observe nearly the absence of anti-erosion actions according to the contour lines (small areas protected) and generally farmers don't use anti-erosion cultivation practices following recommendations of the agricultural experts. Important actions have been programmed in the strategic Moroccan's program Green Morocco and particularly the creation of farmer cooperatives to increase the reforestation of uncultivated lands in the region for shared management and sustainability. However, these measures remain insufficient compared to the extent of the phenomenon. For these reasons, we have assigned the value $P = 1$ to the entire area of the basin. This value has been retained by many Moroccan's studies in this field generally for the same reasons.

Estimation of average annual Soil loss (A)

To estimate and map the spatial distribution of soil loss in Tamdrost watershed, the maps related to the five factors, were projected to the same Lambert_Conformal_Conic coordinate system and geometrically corrected to a spatial resolution of 10 meters x 10 meters each using the Resample function.

Table 2. Variation of P-factor with slope [19]

Slope %	Contour cropping	Strip cropping	Terrace cropping
0–7	0.55	0.27	0.1
7–11.3	0.6	0.3	0.12
11.7–17.6	0.8	0.4	0.16
17.6–26.8	0.9	0.45	0.18
> 26.8	1	0.5	0.2

Table 3. Soil loss in the Tamdrost watershed according to RUSLE erosion model

Year	Min (t/ha/an)	Max (t/ha/an)	Average (t/ha/an)
2002	3.514	576.266	85.17
2015	6.136	887.089	95.12
2017	5.663	632.821	101.75
2021	4.122	767.108	130.45

The layers are then superimposed to proceed to the pixel-by-pixel calculation with the Raster calculator tool on ArcGis. The application of the model yielded significant results (Table 3), displaying the average values and distribution of soil loss rates in the Tamdrost watershed by performing the calculation following the empirical and spatialized RUSLE model (Renard, et al., 1996) on (ArcGIS, 2012).

We observe that the average soil loss increases over the years, varying from 85.17 t/ha/year for the year 2002 to 130 t/ha/year for the year 2021. The lowest soil losses values are observed in the major part of the watershed, mainly in the areas near the wadis where the land is flat with very low slopes and irrigated land characterized by dense vegetation that maintains a high resistance to erosion. However, a part of the watershed presents important erosion rates. These areas have friable materials and are devoid of vegetation and uneven land. These areas are located in the central part of the watershed and in the southwest and have high erosion rates that exceed 80 t/ha/year.

CONCLUSIONS

This study was based on a global methodology organized in several steps, which are complementary integrating both the RUSLE erosion model, GIS and Remote Sensing. First, the collection of data required representing the five key factors involved in the erosion processes. These multiple data obtained from different sources are processed and managed in a GIS using Arc GIS. The outcomes of erosion loss projections are for the five factors involved in RUSLE model are represented in specific maps. Then to quantify the average annual soil loss distribution over the watershed an erosion map was producted. The results obtained shows that the Tamdrost watershed

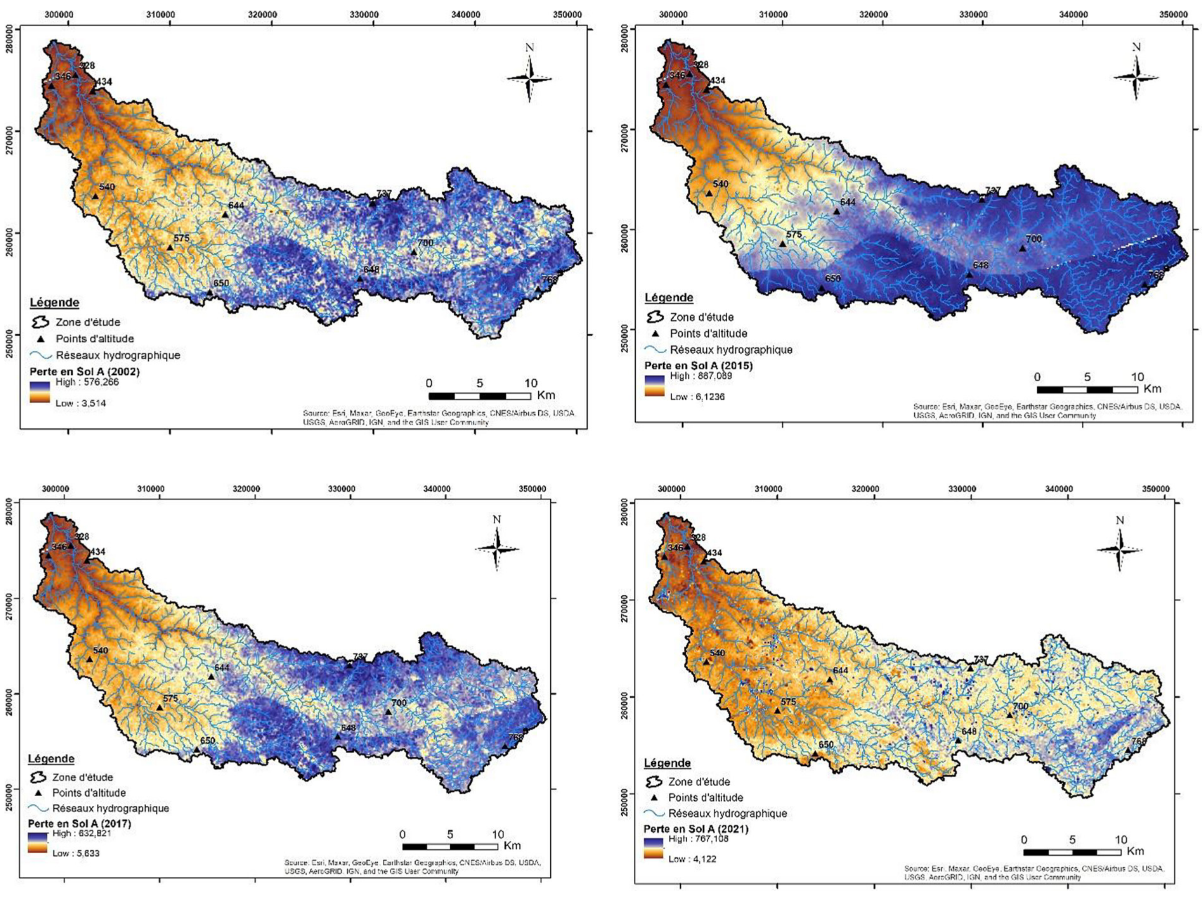

Figure 7. RUSLE soil loss maps for the Tamdrost watershed

has an important erosive potential due to the high rainfall and the erosive sensitivity of the soil. The average soil loss increases over the years, varying from 85.17 t/ha/year for the year 2002 to 130 t/ha/year for the year 2021. The lowest soil losses values are observed in the major part of the watershed, mainly in the areas near the wadis where the land is flat with very low slopes and irrigated land characterized by dense vegetation that maintains a high resistance to erosion. Therefore, a large part of the watershed, including its rural part, has an erosive potential of more than 80 t/ha/year. The use of an integrated approach based on RUSLE model is a relevant approach to investigate the water erosion processes. The development of erosion maps based on these modern techniques gives more visibility to decision makers to better orient and prioritize anti-erosion actions.

REFERENCES

1. Amellah, O., el Morabiti, K. 2021. Assessment of soil erosion risk severity using GIS, remote sensing and RUSLE model in Oued Laou Basin (north Morocco). Soil science annual, 72(3), 1–11.
2. Angima et al. 2003. Weesies Soil erosion prediction using RUSLE for central Kenyan highland conditions Agriculture, Ecosystems and Environment, 97(1–3), 290–292.
3. Aoufa, M., Baghdad, B., El Hadi, H., Chakiri, S., Hamoud, A., Zoraa, N., Moussa, K. 2022. Quantification and Evaluation of Water Erosion by RUSLE/GIS Approach in the Ykem Watershed (Western Morocco). Ecological Engineering & Environmental Technology, 23(5), 42–53.
4. ArcGIS, E.S.R.I. 2012. 10.1. Redlands, California: ESRI.
5. Arnoldus, H.M.J. 1980. An approximation of the rainfall factor in the Universal Soil Loss Equation, 127–132.
6. Arrebei, N., Sabir, M., Naimi, M., Chikhaoui, M., Raclot, D. 2020. Assessment of soil erosion with RUSLE 3D and USPED in the Nekor Watershed (Northern Morocco). Open Journal of Soil Science, 10(12), 631–642.
7. Aunis, D., Michard A. 1976. Eléments de géologie marocaine. Notes et Mém. Serv. Carte géol. Maroc, 252, 408 p. Sciences Géologiques, bulletins et mémoires, 29(4), 325–325.
8. Brahim, B., Meshram, S.G., Abdallah, D., Larbi, B., Drisss, S., Khalid, M., Khedher, K.M. 2020. Mapping of soil sensitivity to water erosion by RUSLE model: case of the Inaouene watershed (Northeast Morocco). Arabian Journal of Geosciences, 13(21), 1–15.
9. Bizuwerk, A., Taddese, G., Getahun, Y. 2003. Application of GIS for modeling soil loss rate in Awash River basin, Ethiopia. International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia, 1–11.
10. Bou-imajjane, L., Belfoul, M.A., Stokes, M., Elaloui, A., Labbaci, A., El Ayady, H., Ez-zaouy, Y. 2022. Adaptation of the revised universal soil loss equation (RUSLE) to soil loss modeling in a semi-arid watershed: a case study from western high atlas, Morocco. Modeling Earth Systems and Environment, 8(4), 4775–4792.
11. Boufala, M. H., El Hmaidf, A., Chadli, K., Essahlaoui, A., El Ouali, A., & Lahjouj, A. 2020. Assessment of the risk of soil erosion using RUSLE method and SWAT model at the M’dez Watershed, Middle Atlas, Morocco. In E3S web of conferences. EDP Sciences, 150, 03014.
12. Ed-Dakiri, S., Etebaai, I., El Moussaoui, S., Ikirri, M., Ait Haddou, M., Amarir, S.,... & Mourabit, T. 2022. Water Erosion Risks Mapping Using RUSLE Model in the Mohamed Ben Abdelkrim El Khattabi Dam Watershed (Central Coastal Rif, Morocco). In Soil-Water, Agriculture, and Climate Change Springer, Cham, 53–75.
13. El Aroussi, O., Mesrar, L., El Garouani, A., Lahrach, A., Beaabidaate, L., Akdi, B., Jabrane, R. 2011. Predicting the potential annual soil loss using the revised universal soil loss equation (RUSLE) in the oued El Malleh catchment (Prerif, Morocco). Present Environment and Sustainable Development, 5(2), 5–15.
14. El Assaoui, N. 2017. Contribution à l’étude méthodologique de l’impact des changements climatiques sur les ressources en eaux souterraines : cas de la nappe de Berrechid (Doctoral dissertation, Thèse de doctorat, Univ. Hassan II, Maroc).
15. Fick, S.E., Hijmans, R.J. 2017 WorldClim 2: New 1-km Spatial Resolution Climate Surfaces for Global Land Areas. International Journal of Climatology, 37, 4302–4315. https://doi.org/10.1002/joc.5086
16. Fournier, F. 1960. Climat et erosion p. 201. Paris: Presses universitaires de France.
17. Fournier, F. 1967. La recherche en érosion et conservation des sols sur le continent africain. Sols africains, 12(1), 5–53.
18. Heusch, B. 1970. L’érosion hydraulique au Maroc: Son calcul et son controle. Al Awamia, 36, 39–63.
19. Lahlou, A. 1994. Envasement des barrages au Maroc [Siltation of dams in Morocco]. Casablanca (Maroc). Wallada, 286.
20. Lahlou, A. 1996. Environmental and socio-economic impacts of erosion and sedimentation in North Africa. IAHS Publications-Series of Proceedings and

Reports-Intern Assoc Hydrological Sciences, 236, 491–500.

21. Lamane, H., Moussadek, R., Baghdad, B., Mouhir, L., Briak, H., Laghlimi, M., Zouahri, A. 2022. Soil water erosion assessment in Morocco through modeling and fingerprinting applications: A review. Heliyon, e10209.
22. Cyr, L., Bonn, F., Pesant, A. 1995. Vegetation indices derived from remote sensing for an estimation of soil protection against water erosion, Ecological Modelling, 79(1–3), 277–285. https://doi.org/10.1016/0304–3800(94)00182-H
23. Lo, A., El-Swaify, S.A., Dangler, E.W., Shinshiro, L. 1985. Effectiveness of El30 as an erosivity index in Hawaii. In: S.A. El-Swaify, W.C. Moldenhauer and A. Lo (Editors), Soil Erosion and Conservation. Soil Conservation Society of America, Ankeny, 384–392.
24. McCool, D.K., Foster, G.R., Mutchler, C.K., Meyer, L.D. 1989 Revised Slope Length Factor the Universal Soil Loss Equation. Transactions of the American Society of Agricultural Engineers, 32, 1571–1576. http://dx.doi.org/10.13031/2013.31192
25. Moudden, F., El Hafyani, M., El Ouali, A., Roubil, A., El Ouali, A., Essahlaoui, A., Brouziyne, Y. 2022. Diachronic mapping and evaluation of soil erosion rates using RUSLE in the Bouregreg River Watershed, Morocco. Journal of Water and Land Development, 53.
26. Mrabet, R., Lahlou, S., Le Bissonnais, Y., Duval, O. 2004. Estimation de la stabilité structurale des sols semi-arides marocains: Influence des techniques culturales simplifiées. Bulletin du Réseau Erosion, 23(2), 405–415.
27. Rango, A., Arnoldus, H.M.J. 1987. Aménagement des bassins versants. Cahiers techniques de la FAO, 36.
28. Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C. 1996. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture handbook, 703.
29. Renard, K.G., Freimund, J.R. 1994. Using monthly precipitation data to estimate the R factor in the revised USLE. J Hydrol, 157, 287–306.
30. Renard, K.G., Foster, G.R. 1983. Soil conservation: principles of erosion by water. Dryland agriculture/editors, HE Dregne and WO Willis.
31. Sabir, M., Roose, E. 2004. Influences du couvert végétal et des sols sur le stock de carbone du sol et les risques d'érosion et de ruissellement dans les montagnes méditerranéennes du Rif Occidental (Maroc). Actes des JSIRAUF. In Bulletin réseau érosion, 23.
32. Sadok A., Kamal A., Modèles d'estimation de l'érosion hydrique des bassins versants : Etude comparative. Rapport interne de recherche, CRR E/E, LPEE, Casablanca, 1995.
33. Sharma A., Tiwari K.N., Bhadoria P.B.S. 2011. Effect of land use land cover change on soil erosion potential in an agricultural watershed. Environ Monit Assess, 173, 789–801.
34. Shin, G.J. 1999. The analysis of soil erosion analysis in watershed using GIS (Doctoral dissertation, Ph. D. Dissertation, Department of Civil Engineering, Gang-won National University.
35. Van der Knijff, J.M., Jones, R.J.A., Montanarella, L. 2000. Soil erosion risk assessment in Europe, EUR 19044 EN. Office for official publications of the European communities, Luxembourg, 34.
36. Wischmeier, W.H., Smith, D.D. 1978. Predicting rainfall erosion losses: a guide to conservation planning (No. 537). Department of Agriculture, Science and Education Administration, Washington, DC.