Original Research Article

Assessment of soils water erosion in the department of Vélingara by application of the RUSLE model

Abstract

In Senegal, water erosion poses a serious risk to the productivity and quality of agricultural land. This study aims to assess soil water erosion in the Vélingara department by applying the RUSLE model to estimate soil losses. According to the results, losses vary between 0 to 64 tons/ha/year, with an average of 0.51 tons/ha/year. 99% of areas have losses of less than 5 tons per hectare per year, which is relatively modest for the majority of the territory. However, some areas in the east of the department, close to the Gambie and Koulountou rivers, have greater losses (>20 tons/ha/year). The comparison between the RUSLE model soil loss map prediction and field data showed a significant impact on erosion processes due to the topography and the hydrographic network. This study contributes to decision-making and the development of more effective policies in soil management.

Keywords : Soil, water erosion, RUSLE, GIS, Vélingara department.

1. INTRODUCTION

Soil erosion is a worldwide major environmental challenge, profoundly affecting food security, biodiversity, ecosystem sustainability and agricultural yields [1, 2]. It leads to tragic consequences on soil fertility, pollution and watercourses sedimentation, carbon storage in soils, and therefore significant economic impacts [3, 4, 5]. Among the different forms of erosion, water erosion is the most widespread [6]. Every year, millions of tons of fertile soil are washed away by runoff, reducing soil fertility and increasing the risk of desertification in many regions of the world [7].

In Senegal, much research has been carried out on water erosion, aiming to describe, quantify, model and to prevent its effects through various approaches such as mapping, remote sensing, modeling and field studies. This work has provided a better understanding of the processes, factors and impacts of water erosion in different spatial and temporal scales. According to Sané and al. [8] soil losses in Senegal are mainly caused by the concentration of agricultural activities on slopes and the abandonment of fallow land. To Boissy and al. [9], agricultural activities, market gardening, livestock breeding, gold panning and timber exploitation are the causes of high soil losses in the department of Saraya (Kédougou). Gallo and al. [10], demonstrated that the hydro-sedimentary processes of the Ferlo basin are influenced by past and present geological structure and climatic conditions. Dia [11] showed that the Ogo watershed (north-eastern Senegal) is particularly vulnerable to water erosion due to the absence of anti-erosion practices, from the weak vegetation cover and the predominance of friable geological formations (25%). Moreover, the work of Diouf and al. [12] revealed an increase in precipitation in southern Senegal between 1980 and 2016, which led to an increased erosivity of rainfall and a higher risk of water erosion.

Modeling is widely used by scientists because of its simplicity of application and reliable results over large geographic areas [13]. Field measurements, often costly and difficult to implement on a large scale, makes modeling an economical and practical alternative to assess erosion and guide conservation strategies [14]. Models for assessing soil water erosion rely on empirical, conceptual, physical, multi-criteria, statistical or based on machine learning approaches [15]. Among these models, Revised Universal Soil Loss Equation (RUSLE) is the most commonly used, for its simplicity and flexibility [16]. RUSLE is an empirical model which estimates water erosion soil losses in tonnes per hectare per year [17]. It takes into account several factors: erosivity of precipitation (R), soil erodibility (K), length and steepness of the slope (LS), vegetation cover(C) and soil management practices (P) [18].

The main objective of this article is to assess soil water erosion in the department of Vélingara by applying the RUSLE model. This assessment allows to map the most vulnerable areas to erosion and to identify the factors influencing soil degradation. The results thus provided essential information for the implementation of sustainable soil management measures.

2. Materials and methods

2.1. Presentation of the study site

The department of Vélingara, located in the south of Senegal in Kolda region, extends between latitudes 12°40' and 13°32' North and longitudes 13°20' and 14°10' West, covering an area of 5,434 km^2 (Fig. 1). The climate is Sudanian, with a short rainy season from June to October and a long dry season from November to May, and average annual precipitation of 600 to 1,300 mm. The hydrographic network mainly includes the Gambia River and its tributary the Koulountou, as well as the Kayanga-Anambé complex and various temporary watercourses fed during the rainy season. The landscape is mainly flat overall, dotted with vast lateritic plateaus of the Saloum formation which extend towards the East. These plateaus are intersected by several valleys. The vegetation is mainly composed of wooded savannas and wooded shrub savannas, heavily affected by human activities such as swidden and wood cutting [19].

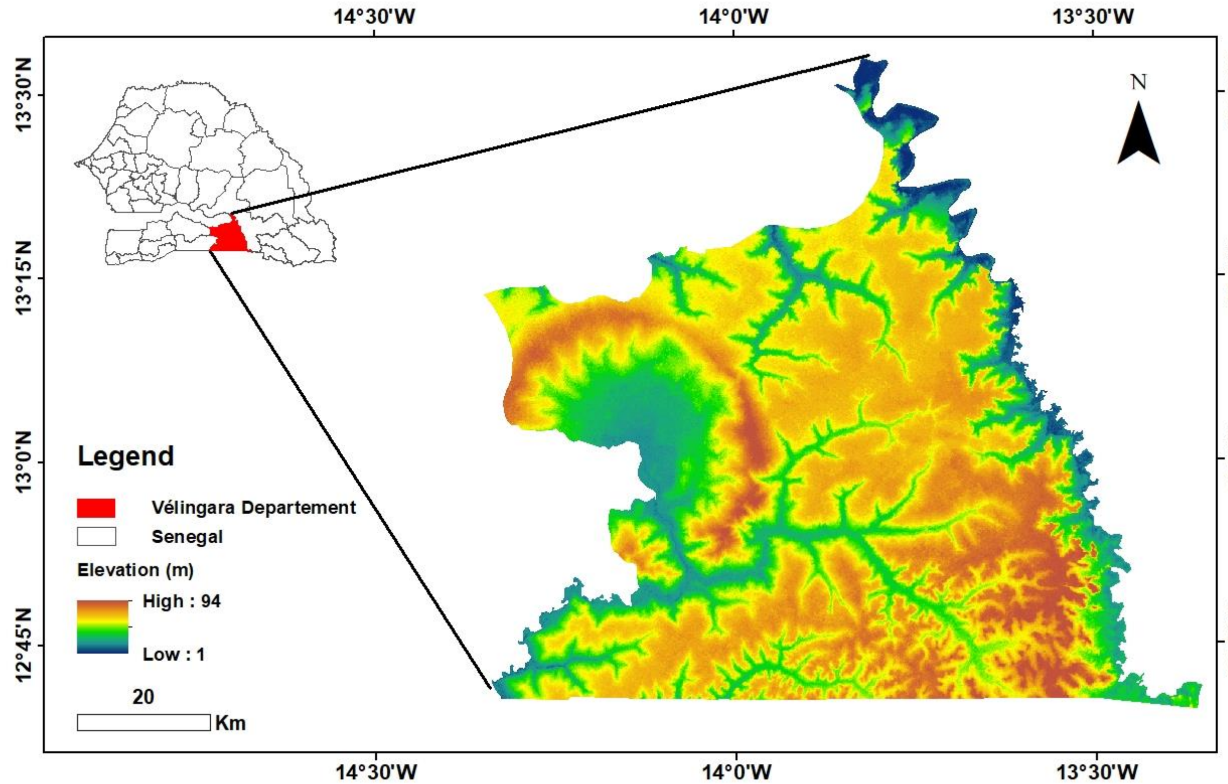

Fig. 1. Location of the study site

The area is predominantly characterized by savannas, which cover more than two thirds or 70% of its total surface (Fig. 2a). Cultivation areas are the second largest class, occupying about a quarter of the territory (22.70%). Forest represents 3.37% of the territory, while the other classes (water bodies, floodplains/marshes, residential areas) are less extensive with less 4% of the occupied territory.

The soils of the Vélingara department are dominated by tropical ferruginous soils, which cover 48.62% of the area (Fig. 2b). They are followed by hydromorphic soils (20.65%), regosols (17.54%) and lithosols (12.16%). Vertisols, are the least spread, representing only 1.02% of the territory.

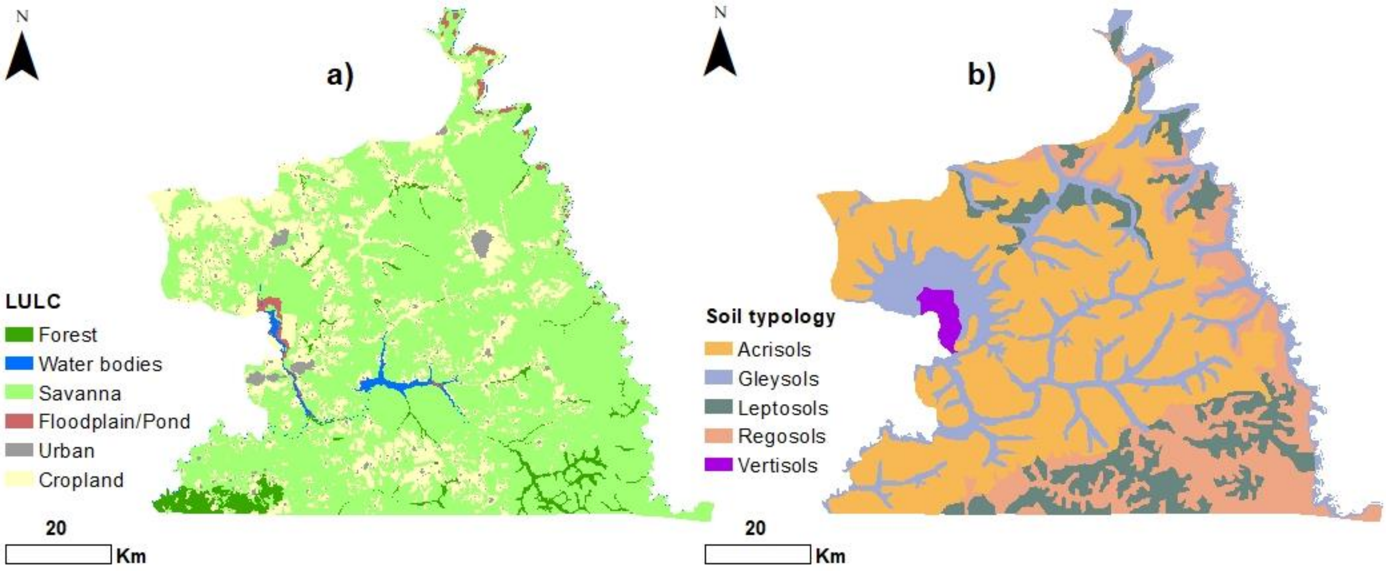

Fig. 2. (a) Land use map, (b) Soil map

2.2. Methodology

The RUSLE model, revised version of the USLE model [20], is an empirical method of soil loss estimation [17]. It allows to calculate the average annual soil losses due to sheet and rill erosion. The RUSLE model equation is (equation 1):

$$\boldsymbol{A = R \times K \times LS \times C \times P} \qquad (\mathbf{1})$$

Where A is the annual soil loss (t/h/year); R the erosivity factor of rain in (MJ.mm.ha^{-1}.h^{-1} year^{-1}); K the soil erodibility factor (t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1}); LS the topographic factor; C the management factor of vegetation cover; P the supporting practice factor.

In this study, the RUSLE model has been integrated into a geographic information system (GIS) to effectively incorporate and analyze the spatial data to the different factors of the model. This integration makes it possible to produce soil erosion maps, valuable tools for identifying erosion high risk areas. ArcGIS 10.8 software has been used for georeferencing, projection, clipping and calculations for the analysis.

The methodology adopted in this study is presented in the organization chart below (Fig. 3).

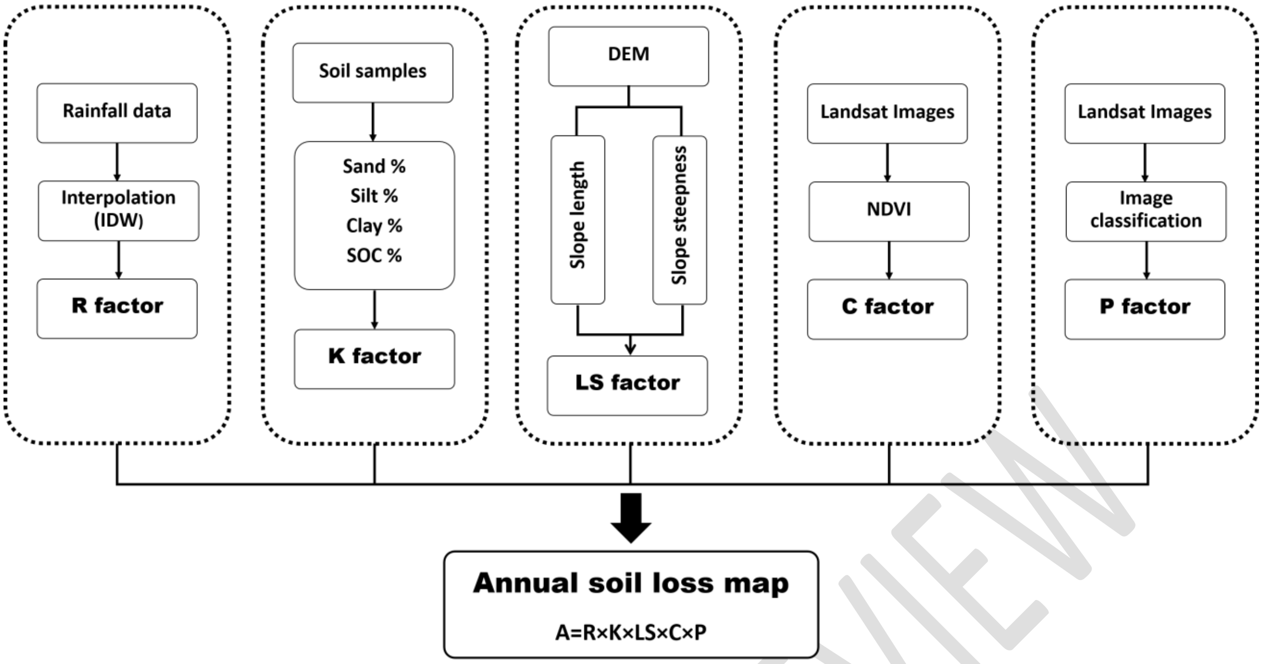

Fig. 3. Methodological organization chart of the study

2.2.1. Rainfall erosivity factor (R)

The R factor is a parameter that characterizes the erosive power of the rain water on the soil. It has been determined from the equation of Nguyen [21] applied by Pham and al. [22] and Yamégo and al. [23]. The average annual rainfall data from different stations in Senegal over a 30-year period (1990-2020) provided by the National Agency for Civil Aviation and Meteorology (ANACIM) have been used. The data were imported into ArcGIS 10.8, then spatially interpolated using the IDW method. Finally, the study area and calculated R have been divided in the "raster calculator" using equation 2.

$$\boldsymbol{R = 0.548 \times P - 59.9} \tag{2}$$

Where R the erosivity of rainfall and P, the average annual rainfall

2.2.2. Soil erodibility factor (K)

The Soil erodibility factor (K) is a parameter that determines the susceptibility of soil to be eroded by water. It is influenced by the physical and chemical properties of the soil, such as the texture, structure, permeability and organic matter content. In this study, the EPIC model equation has been used to determine K (equation 3-4) [24]. The data used are the proportions of sand, silt, clay and organic carbon content in the soil from 611 soil samples with a depth of 0-20 cm provided by the National Institute of Pedology (INP). The results of the calculation of the erodibility were exported to ArcGIS 10.8. Then an interpolation by the IDW method has been performed to determine the K factor.

$$\boldsymbol{K = 0.1317\left[0.2 + 0.3\exp\left[-0.0256SAN\left(1 - \frac{SIL}{100}\right)\right]\right] \times \left[\frac{SIL}{CLA + SIL}\right]^{0.3} \times}$$

$$\left[1-\frac{0.25C}{C+\exp(3.72-2.95C)}\right]\times\left[\frac{0.75SN1}{SN1+\exp(-5.51+22.9SN1)}\right] \tag{3}$$

$$SN1 = 1 - \frac{SAN}{100} \tag{4}$$

Where SAN= Sand (%); SIL= Silt (%); CLA= Clay (%); C= Organic Carbon (%)

2.2.3. Topographic factor (LS)

The LS factor represents the topography effect on soil water erosion. It is determined based on the slope's (S) length (L) and steepness. The LS factor calculation is based on equations 5 and 6 proposed by McCool and al. [25] and Liu and al. [26]. In this study, a digital elevation model (DEM) with a spatial resolution of 90 m has been utilized, downloaded from the BaseGéo Senegal platform (https://www.geosenegal.gouv.sn, accessed on December 15, 2023).

$$L = (\lambda/22.13)^m \qquad m = \begin{cases} 0.2 & si\ \theta < 1^\circ \\ 0.3 & si\ 1^\circ \le \theta \le 3^\circ \\ 0.4 & si\ 3^\circ \le \theta \le 5^\circ \\ 0.5 & si\ \theta \ge 5^\circ \end{cases} \tag{5}$$

$$S = \begin{cases} 10.8\sin\theta + 0.03 & \text{si } \theta < 5^\circ \\ 16.8\sin\theta - 0.05 & \text{si } 5^\circ \le \theta \le 14^\circ \\ 21.91\sin\theta - 0.96 & \text{si } \theta > 14^\circ \end{cases} \tag{6}$$

where λ = length of the slope; m = slope-dependent exponent; θ = the slope.

2.2.4. Cover Management Factor (C)

Factor C represents the management of soil vegetation cover. It depends on land occupation and agricultural practices [27]. The C factor ranges from 0 to 1. The more vegetation cover there is, the closer the C factor is to 0, and the more resistant the soil is to erosion. To determine the C factor, bands 4 and 5 of the Landsat 8-9 ORLI C2L1 images from 2020 have been downloaded from the United States Geological Survey (USGS) website (http://earthexplorer.usgs.gov/, accessed January 10, 2024). We selected images from June to October, corresponding to the rainy season when erosion is more intense. An atmospheric correction was applied to remove the atmosphere effects. Then, the vegetation index has been calculated by normalized difference (NDVI) then the average for each month with equation 7. Finally, the C factor has been calculated from equation 8 proposed by Durigon and al. [28] for tropical regions.

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{7}$$

Where NDVI = Normalized Difference Vegetation Index; NIR = Near Infrared (band 5) and Red = reflectance of red channels (band 4).

$$C = \frac{1 + NDVI}{2} \quad (8)$$

2.2.5. Support practice factor (P)

The P factor evaluates the effectiveness of soil management and conservation practices in order to reduce erosion. It depends on implemented techniques, such as grass strips, terraces, contour plowing, as well as other practices designed to reduce runoff and protect soil. It ranges from 0 to 1, where 0 corresponds to an optimal practice and 1 to no practice. In this study, the P factor was determined from the land occupation map. For the latter, Landsat 8-9 images from 2020 have been used and with ArcGIS software, a supervised classification has been performed and the P factor value assignment methods of Gafforov and al. [29] and Ruksajai and al. [30] has been adopted. A value of 1 was assigned to savannah, forest, floodplains, to ponds and bare soils. A value of 0.5 was assigned to cultivation areas and 0 for residential areas and water bodies. These values were integrated into the land use shapefile attribute table with ArcGIS software, then the shapefile has been converted to raster format.

Also, this study was complemented by an active field campaign in order to compare the predictions of the RUSLE model with in situ observations to validate and understand the reasons for the observed loss variations. The soil loss map generated by the model was used to identify the areas. In the field, we characterized the landscape to understand the factor(s) influencing the losses and validate the erosion risk predictions. We have used GPS for navigation and coordinate taking in the field, and an Android mobile phone to take illustrations.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Spatial distribution of RUSLE model factors

The spatial distribution of the RUSLE model factors highlights the geographical variations of these different factors which contribute to soil erosion. The rain erosivity R ranges from 364.35 to 434.64 MJ.mm.ha^{-1}.h^{-1}.year^{-1}, with an average of 405.74 MJ.mm.ha^{-1}.h^{-1}.year^{-1}. R values increase gradually from northeast to southwest (Fig. 4a).
The spatial distribution of soil erodibility shows a general homogeneity, with some local variations (Fig. 4b). K values range from 0.0174 to 0.025 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1} for the majority of the departement.

K values ranging from 0.0096 to 0.0174 t.ha.h.ha^{-1}.MJ^{-1}.mm^{-1} are dispersed and occupy smaller portions of the territory, with a noteworthy concentration in the Southwest.

The LS factor, which combines the slope length (L) and its inclination (S), is mainly influenced by the field topography. The LS factor ranges from 0 to 30, with higher values found in areas where the slopes are steeper, mainly the eastern part of the department (Fig. 4c).

C Factor assesses the impact of vegetation cover on erosion. This factor was determined by calculating the average of the satellite images' NDVI recorded between June and October. The C factor values range from 0.19 and 0.55 with a mean of 0.33 and a standard deviation of 0.04 indicating a relatively uniform vegetation cover (Fig. 4d).

The land management practices factor is a crucial parameter that assesses the effectiveness of land management practices in reducing erosion. A P factor close to 1 indicates little or no erosion reduction. Conversely, a P factor close to 0 indicates maximum erosion reduction. P factor values vary considerably, ranging from 0 to 1 (Fig. 4e). The distribution of P factor classes shows that the majority of lands have management practices that are not effective enough to reduce erosion.

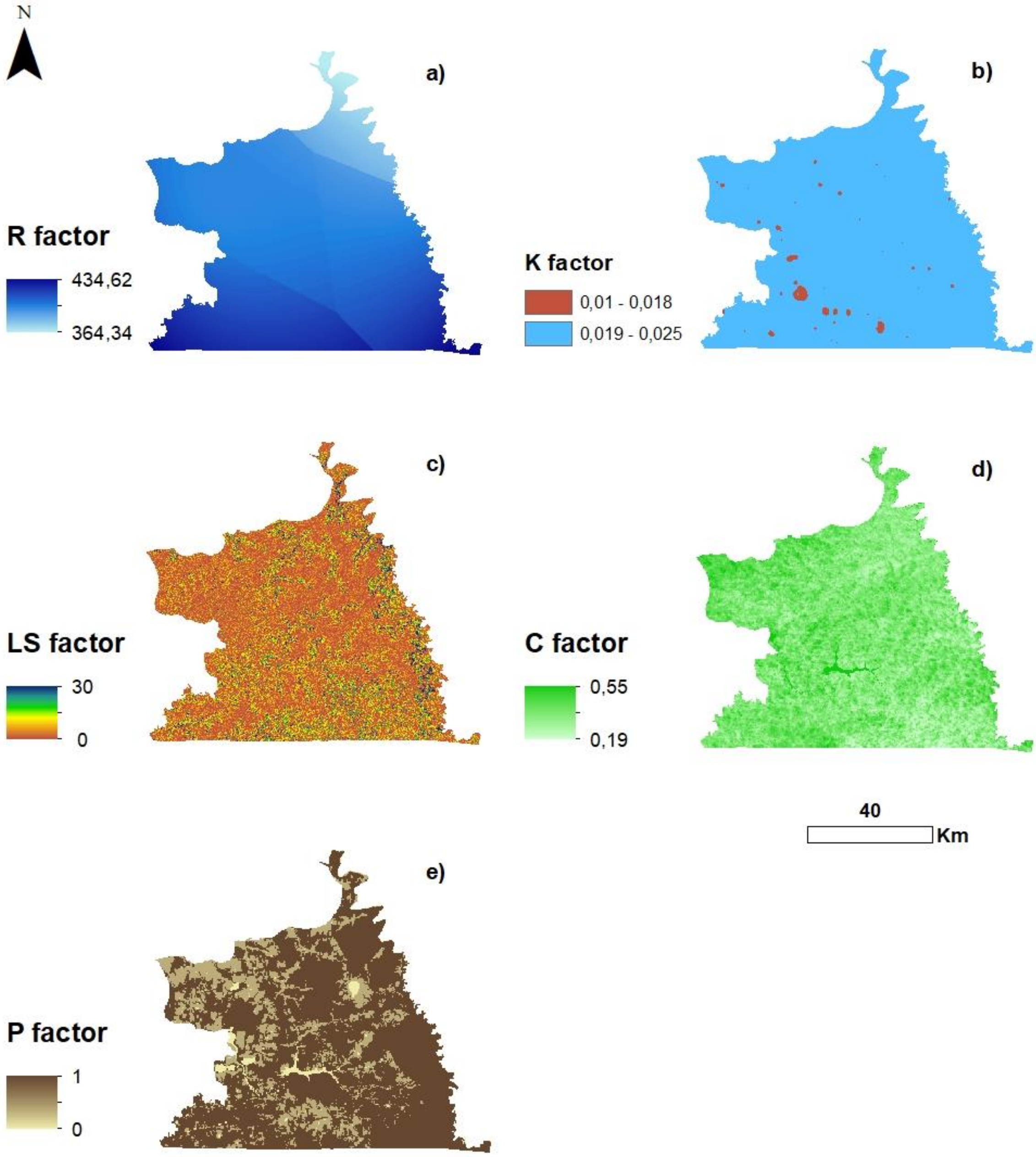

Fig. 4. Spatial distribution of RUSEL factors: (a) Rainfall erosivity factor map, (b) soil erodibility factor map, (c) Topographic factor map, (d) Cover management factor map, (e) support practice

3.1.2. Soil loss estimations

Using RUSLE equation to overlay maps of the primary factors of erosion has enabled the generation of a detailed soil loss map for Vélingara department (Fig. 5). The model results indicate a low erosion rate in the department, with an average of 0.51 t/ha/year. However, spatial variability is notable, with soil losses fluctuating between 0 and 64 t/ha/year. The integration of the hydrographic network on the soil loss map shows that losses closely follow this network, with a greater dispersion near watercourses. This is typical of regions where erosion is influenced by runoff, particularly on slopes close to watercourses. Gravity accelerates the flow of water, increasing its erosive power, especially in areas where runoff converges, which reinforces water kinetic energy and amplifies erosion.

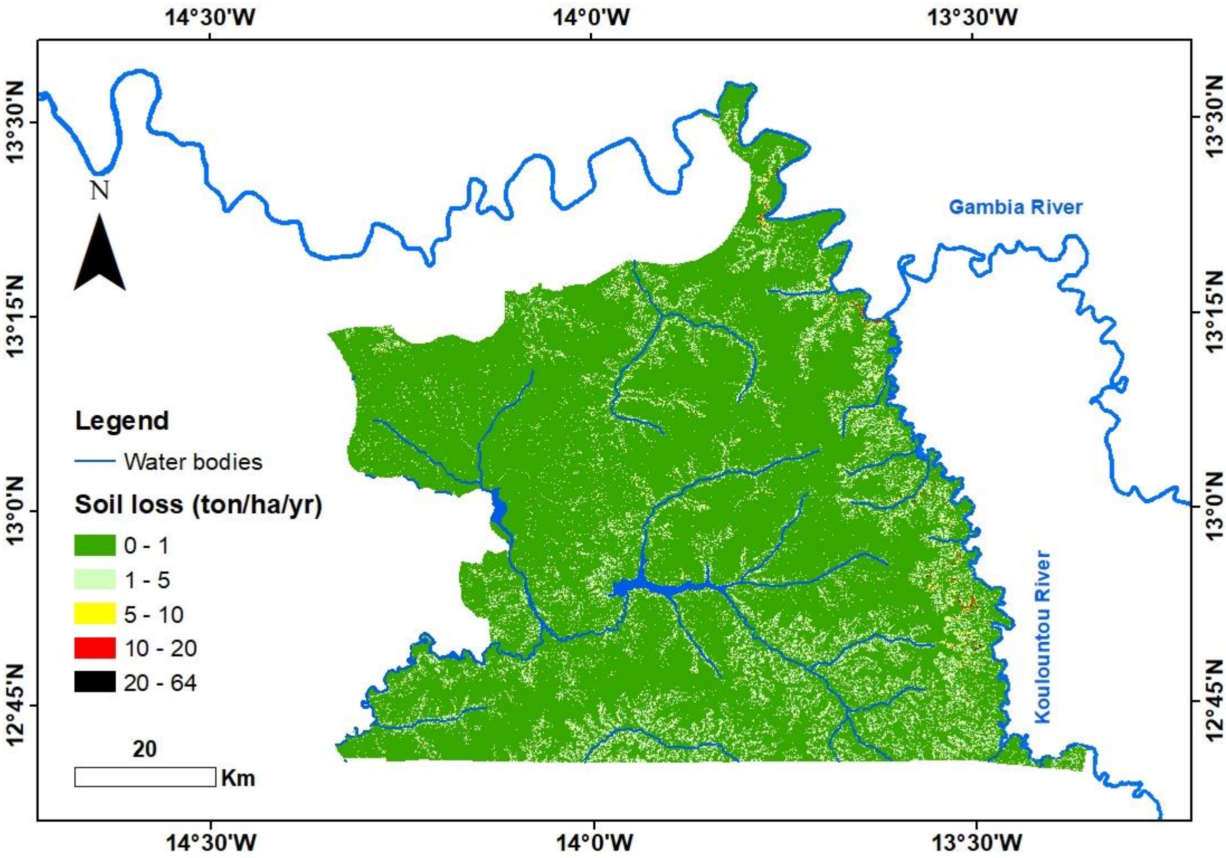

Fig. 5. Soil loss map of Vélingara department

Based on the erosion risk classification proposed by Sharma [31], soil losses were classified into very low (<5), low (5-10), moderate (10-20) and high (>20) with ton/ha/yr unit for all values (Table 1). According to this classification, more than 99% of the area of the department has very low losses. Low and moderate losses cover respectively 0.37% and 0.12% of the area. Finally, high losses affect a tiny proportion of the territory, i.e. only 0.024% of the total area.

Table 1. Classification of soil losses (t/ha/year)

Loss (t/ha/year)	Class	Area (ha)	Percentage (%)

< 5	Very low	540532	99.49
5-10	Low	2029.91	0.37
10-20	Moderate	631.09	0.12
>20	High	117.92	0.024

The comparison between the soil loss map predicted by the RUSLE model and field observations reveals that the highest losses in the Vélingara department are located on slopes greater than 15%, mainly in the East near the Gambia River and Kouloutou. These areas are characterized by plateaus and hills, featuring sedimentary deposits as well as ravines and rills at the bottom of slopes (Fig. 5). Conversely, low soil losses are found on slopes less than 7%. The highest losses for agricultural land are located near the watercourses banks.

The results of this field validation broadly confirmed the predictions of the RUSLE model. Erosion processes appear to be strongly affected by topography and the hydrographic network.

Fig. 5. Illustrations of the impact of water erosion of soils in the study area: (a) erosion on the slopes, (b, c, d) various rills erosion (Photos taken by the authors)

3.2. Discussion

The RUSLE model results indicate that the Vélingara department has a low level of erosion, with an average value of 0.51 t/ha/year. However, there is a high spatial variability in soil losses ranging from 0 to 64.31 t/ha/year. A comparison of the results with those obtained in other regions of southern Senegal, such as Casamance and Kédougou, shows significant disparities. For example, Boissy and al. [9] estimated soil losses in the Saraya department between 0.01 and 134.64 t/ha/year, with an average of 33.46 t/ha/year. Similarly, Faye and al. [32] assessed an average of 0.032 t/ha/year in the Sangourou watershed in 2019. These variations can be attributed to differences in topography. Indeed, the department of Saraya has steeper slopes, reaching 61.57% along the Senegalese-Guinean border, while the Sangourou watershed has more moderate slopes (maximum slope of 13%). Zhang and al. [33] demonstrated that topography is one of the predominant factors affecting soil loss rates. Further research is essential to better understand erosion processes and their spatial variability in Senegal.

The variations in soil losses noted in the department of Vélingara are guided by several factors. Indeed, the low erosion observed on 99% of the territory, where losses are less than 5 t/ha/year, is mainly explained by the existence of gentle slopes, with an average of 1.43% and low soil erodibility. Vegetation cover, with a C factor varying between 0.19 and 0.5, also plays a protective role against erosion, as shown by Lense and al. [34]. However, some areas record high soil losses, exceeding 20 t/ha/year, particularly in the East where the slopes are steeper. This observation is supported by the work of Byizigiro and al. [35], Noma and al. [36], who found that losses are greater in areas with steep slopes. Also, high losses are located on steep slopes near the Gambia River and its tributary the Koulountou. These geomorphological characteristics are confirmed by the work of Räsänen and al. [37] who identified a correlation between the intensification of erosion and the proximity of the steep slopes to the bodies of water in the sub-basin of Aura.

Like any study, this one has certain limitations. Indeed, the RUSLE model requires good quality and high resolution data, which are not always available or accessible. In addition, this study did not take into account the spatio-temporal variation of land use, although it is essential to assess the impact of land use changes on soil losses. These limitations open up perspectives for future research. In particular, it would be interesting to monitor the impact of land use change on water erosion by analyzing time series of satellite images and integrate more higher resolution data.

This study helps to better understand the soil erosion process in the Vélingara department, paving the way for more effective soil preservation strategies. For the future, it is important to design a soil conservation policy that is both sustainable and adapted to local needs.

4. Conclusion

This study has analyzed soil losses in the department of Vélingara by applying the RUSLE model, coupled with geographic information system (GIS) tools. Several datasets integrated in ArcGIS have been used to produce maps of the different factors of the RUSLE model. The combination of these factors has facilitated the generation of a multifactorial map of soil losses.

The results reveal that soil losses are generally very low, with an average of 0.51 tonnes per hectare per year. However, marked disparities were observed across the territory, with some areas recording significant losses reaching 64 tonnes per hectare per year. These variations are mainly shaped by the topography and the hydrographic network. The most affected areas are located in the eastern part of the department, near the Gambie and Koulountou rivers, where the slopes are steeper.

The study helps to better understand the soils erodibility in this part of the Senegalese national territory.

REFERENCES

1. Pimentel D. Soil Erosion : A Food and Environmental Threat. Environment, development and sustainability. 2006 ; 8 :119–137. https://doi.org/10.1007/s10668-005-1262-8
2. Nawazuzzoha M, Rashid MM, Mishra PK, Abdelrahman K, Fnais MS, Naqvi HR. Empirical Modeling of Soil Loss and Yield Utilizing RUSLE and SYI : A Geospatial Study in South Sikkim, Teesta Basin. Land. 2024 ; 13(10) : 1621. https://doi.org/10.3390/land13101621.
3. Huber G, Schaub C. Soil fertility: the importance of organic matter. Agriculture and terroir, Chamber of Agriculture Bas Rhin. 2011. French. https://agriculture-de-conservation.com/sites/agriculture-de-conservation.com/IMG/pdf/ca67-amendements_organiques.pdf.
4. Panagos P, Standardi G, Borrelli P, Lugato E, Montanarella L, Bosello F. Cost of Agricultural Productivity Loss Due to Soil Erosion in the European Union : From Direct Cost Evaluation Approaches to the Use of Macroeconomic Models. Land Degradation & Development. 2018 ; 29.https://doi.org/10.1002/ldr.2879.
5. Chenu C, Chotte JL, Luu P. Carbon storage in soils. Annals of Mines-Responsibility and environment. 2022; (1): 72–77. https://doi.org/10.3917/re1.105.0072.
6. Eswaran H, Lal R, Reich PF. Land Degradation: An Overview. In : Response to Land Degradation. 1st ed. Bridges, E. M., Ed.; CRC Press ; 2001.https://doi.org/10.1201/9780429187957.
7. FAO & ITPS. Status of the World's Soil Resources : Main Report. Rome.2015. http://www.fao.org/3/a-i5199e.pdf.
8. Sané B, Faye C, Sané T. Assessment of soil water erosion in two ungauged watersheds, Djibonker and Agnak, (Lower Southern Casamance, Senegal). Environmental Dynamics. 2022; (49–50): 128–156. French. https://doi.org/10.4000/dynenviron.7178.
9. Boissy R, Ndiaye M, Diatta M, Mbaye M. Use of a GIS for the Assessment and Mapping of Water Erosion Risks by the Revised Universal Soil Loss Equation (RUSLE) in the Department of Saraya (Senegal). VertigO - the electronic journal in environmental sciences. 2022; 22(2). French. https://doi.org/10.4000/vertigo.38034.
10. Gallo N, Abdoulaye F, Guilgane F. Water Erosion in the Sahelian Context: Case of the Ferlo Watershed. Case of the Ferlo Watershed. ESI Preprints. 2023; 21: 73. French. https://doi.org/10.19044/esipreprint.9.2023.p73.

11. Dia AT. Mapping and Modeling of Water Erosion in the Ogo Watershed (North-Eastern Senegal) by Bivariate Statistical Approach of the Informative Value and Frequency Ratio. European Scientific Journal, ESJ. 2023; 13:435. French. https://doi.org/10.19044/esipreprint.1.2023.p435.
12. Diouf R, Faye C, Dieye S, Diatta. Spatial Distribution and Temporal Trends of Precipitation Erosivity in Southern Senegal Watersheds (Gambia and Casamance). Links, International Journal of Educational Science and Technology. 2022; (1). French. http://webtest.ucad.sn/LIENS/index.php/liens/article/view/21.
13. Waseem M, Iqbal F, Humayun M, Umais Latif M, Javed T, Kebede Leta M. Spatial Assessment of Soil Erosion Risk Using RUSLE Embedded in GIS Environment: A Case Study of Jhelum River Watershed. Applied sciences. 2023 ; 13 (6) :3775.
14. Ganasri BP, Ramesh H. Assessment of Soil Erosion by RUSLE Model Using Remote Sensing and GIS: A Case Study of Nethravathi Basin. Geoscience Frontiers. 2016 ; 7(6) : 953–961. https://doi.org/10.1016/j.gsf.2015.10.007
15. Fadil A, Wahidi FE. Towards a New Classification of Water Erosion Assessment and Prediction Models. Physio-Géo. 2023; 19: 83–112. French. https://doi.org/10.4000/physio-geo.15783.
16. Borrelli P, Alewell C, Alvarez P, Anache JA, Baartman J, Ballabio C, Panagos P. Soil Erosion Modelling: A Global Review and Statistical Analysis. Science of the total environment. 2021 ; 780 : 146494. https://doi.org/10.1016/j.scitotenv.2021.146494.
17. Renard KG, Foster GR, Weesies GA, McCool D,Yoder D. Predicting Soil Erosion by Water : A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook No. 537 ; US Department of Agriculture, Agricultural Research Service: Washington, DC, USA ;1997.
18. Benavidez R, Jackson B, Maxwell D, Norton K. A Review of the (Revised) Universal Soil Loss Equation ((R)USLE) : With a View to Increasing Its Global Applicability and Improving Soil Loss Estimates. Hydrology and Earth System Sciences. 2018 ; 22 : 6059–6086. https://doi.org/10.5194/hess-22-6059-2018.
19. Solly B, Dieye E, Mballo I, Sy O, Sané T, Thior M (2020). Spatio-Temporal Dynamics of Forest Landscapes in Southern Senegal: Case of the Vélingara Department. Physio-Géo. 2020; 15. French. https://doi.org/10.4000/physio-geo.10634.
20. Wischmeier WH, Smith DD. Predicting Rainfall Erosion Losses a Guide to Conservation Planning. Agriculture Handbook No. 537; US Department of Agriculture: Washington, DC, USA ; 1978.
21. Nguyen TH. Identify the Factors Effect to Soil Erosion and Forecast Soil Erosion on Slope Land. Water Resources University of Vietnam (Thuyloi University), Hanoi ; 1996.
22. Pham TG, Degener J, Kappas M. Integrated Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for Soil Erosion Estimation in A Sap Basin : Central Vietnam. International Soil and Water Conservation Research. 2018 ; 6 (2) : 99–110. https://doi.org/10.1016/j.iswcr.2018.01.001.

23. Yamégo A, Somé YS, Palé S, Sirima BA, Da DE. Application of GIS/RUSLE to the Estimation of Erosion by Sheet Runoff in the Upper Sissili Watershed (Burkina Faso). Geo-Eco-Trop. 2021; 45 (2): 299–310..
24. Williams J. The EPIC model, in Computer Models of Watershed Hydrology. V. P. Singh,Colorado, USA. **1995** : 909-1000.
25. McCool DK, Foster GR, Mutchler CK, Meyer LD. Revised Slope Length Factor for the Universal Soil Loss Equation. Transactions of the ASAE. 1989 ; 32 (5) : 1571–1576.
26. Liu K, Tang G, Jiang L, Zhu AX, Yang J, Song X. Regional-Scale Calculation of the LS Factor Using Parallel Processing. Computers & Geosciences. 2015 ; 78 : 110–122. https://doi.org/10.1016/j.cageo.2015.02.001
27. Panagos P, Borrelli P, Meusburger K, Alewell C, Lugato E, Montanarella L. Estimating the Soil Erosion Cover-Management Factor at the European Scale. Land Use Policy. 2015 ; 48 : 38–50. https://doi.org/10.1016/j.landusepol.2015.05.021.
28. Durigon V, Carvalho D, Antunes M, Oliveira P, Fernandes M. NDVI Time Series for Monitoring RUSLE Cover Management Factor in a Tropical Watershed. International journal of remote sensing. 2014 ; 35(2) : 441–453. https://doi.org/10.1080/01431161.2013.871081.
29. Gafforov K, Bao A, Rakhimov S, Liu T, Abdullaev F, Jiang L, Mukanov Y. The Assessment of Climate Change on Rainfall-Runoff Erosivity in the Chirchik-Akhangaran Basin, Uzbekistan. Sustainability. 2020 ; 12(8) : 3369. https://doi.org/10.3390/su12083369.
30. Ruksajai N, Konyai S, Sriboonlue V. Forecasting Soil Erosion Risk Using GIS and Remote Sensing for the Nam Un Basin, Sakon Nakhon Province, Thailand. Polish Journal of Environmental Studies. 2023 ; 32(2) : 1767–1780. https://doi.org/10.15244/pjoes/156791.
31. Sharma A. Integrating Terrain and Vegetation Indices for Identifying Potential Soil Erosion Risk Area. Geo-Spatial Information Science. 2010 ; 13 : 201–209. https://doi.org/10.1007/s11806-010-0342-6.
32. Faye C, Dieye S, Fall A. Impacts of Human Behavior Change on Water Erosion in Senegal: Case of the Soungrougrou Watershed (Tributary of the Casamance River). Moroccan Journal of Geomorphology. 2022; (6): 60–82..
33. Zhang J, Yang M, Deng X, Liu Z, Zhang F. The Effects of Tillage on Sheet Erosion on Sloping Fields in the Wind-Water Erosion Crisscross Region of the Chinese Loess Plateau. Soil Soil and Tillage Research. 2019 ; 187 : 235–245. https://doi.org/10.1016/j.still.2018.12.014.
34. Lense G, Lämmle L, Ayer J, Lama G, Rubira F, Mincato R. Modeling of Soil Loss by Water Erosion and Its Impacts on the Cantareira System, Brazil. Water. 2023 ; 15(8) : 1490. https://doi.org/10.3390/w1508149.
35. Byizigiro RV, Rwanyiziri G, Mugabowindekwe M, Kagoyire C, Biryabarema M. Estimation of Soil Erosion Using RUSLE Model and GIS : The Case of Satinskyi Catchment, Western Rwanda. Rwanda Journal of Engineering, Science, Technology and Environment. 2020 ; 3(1). https://doi.org/10.4314/rjeste.v3i1.2S.

36. Noma AS, Gourfi A, Abdourhamane TA, Daoudi L. Water Erosion in Southwestern Niger: Impacts of Natural and Anthropogenic Factors on Soil Losses. Geomorphology Relief Process Environment. 2022; 28(2): 77–92. French. https://doi.org/10.4000/geomorphologie.16744.
37. Räsänen TA, Tähtikarhu M, Uusi-Kämppä J, Piirainen S, Turtola E. Evaluation of RUSLE and Spatial Assessment of Agricultural Soil Erosion in Finland. Geoderma Regional. 2023 ; 32 : e00610. https://doi.org/10.1016/j.geodrs.2023.e00610.