

Impact of watershed management practices on vegetation, land use changes, and soil erosion in River Basins of the Atlas, Morocco

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Abstract

Soil erosion, a land degradation process triggered by natural and anthropogenic factors, seriously impacts landscapes and water resources. The influence of vegetation cover and land use changes on intensity of soil erosion of two catchments in mountainous regions of Morocco is evident, as it alters hydrologic response and sediment dynamics. This research aims to analyze the interactions among plants, soil, geology, meteorology, and orography, assessing soil erosion responses using the process-oriented IntErO model - Erosion Potential Method to determine erosion rates. The obtained results indicate that the Tiguert river basin experiences higher soil losses ($G_{god} = 5184.47 \text{ m}^3/\text{god}$) and soil losses per square kilometre ($G_{god}/\text{km}^2 = 508.28 \text{ m}^3/\text{km}^2 \text{ god}$) compared to the Wanmroud catchment ($G_{god} = 2555.66 \text{ m}^3/\text{god}$, $G_{god}/\text{km}^2 = 381.44 \text{ m}^3/\text{km}^2 \text{ god}$), confirming the theory that areas with denser and more effective vegetation cover experience lower soil erosion rates. Furthermore, the Wanmroud basin exhibits a more regular shape and lower watershed development coefficient, implying lower human impact. This study has shown the relationships between land use changes, vegetation cover, and soil erosion dynamics, offering valuable insights for sustainable land management practices in mountainous regions of Morocco.

Keywords: catchments; IntErO; land use; Morocco; soil erosion; vegetation cover

Introduction

Soil is universally understood as vital element to all life on Earth, and it is necessary to balance the need for its use with the implementation of sustainable human activities in order to ensure the long-term survival of our society. Improper management of natural resources or exploitation of nature disrupts the natural balance, which results in many ecological problems. Since soil is a basic element of nature, soil-related issues are of

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utmost importance in the field of environmental protection (Bashir *et al.*, 2024). It is commonly accepted fact that soil erosion is a widespread ecological problem that significantly affects ecology, the natural environment, agricultural productivity and is a threat to the survival of human societies and natural ecosystems (Novara *et al.*, 2018; Chalise *et al.*, 2019).

Estimating erosion within a watershed is of utmost importance as it tackles numerous environmental concerns and allows for the assessment of sediment movement, transportation, and deposition both within the basin and beyond. To directly measure erosion in a watershed, one can conduct multi-year measurements of sediment transport at the outlet, offering valuable insights into the erosional processes at play (Tazioli, 2009).

Models and modelling processes, especially in watersheds without hydrometric stations, serve as valuable and indispensable tools for assessing soil degradation and sediment generation (Wischmeier and Smith, 1965, 1978). Different and various models have been created, and developed for this objective in order to evaluate and assess quantities of soil erosion, and sediment transport (De Vente *et al.*, 2013).

The IntErO program is a model developed and calibrated by Spalevic (2011). It incorporates the Erosion Potential Method – EPM (Gavrilovic, 1972) in its algorithm, which was introduced by Gavrilovic in 1972. This platform and graphic method are utilized to assess the peak of runoff, discharge, and the extent of soil erosion at a catchment scale. This model's widespread adoption applied and spans within numerous countries, including Bosnia and Herzegovina, Bulgaria, Italy, Iran, Montenegro, Serbia, Morocco, Brazil, Nepal and Romania. Furthermore, the IntErO model's effectiveness in forecasting peak outflow, soil erosion, and sediment yield has been tested in various areas, demonstrating its versatility and applicability to watersheds of different sizes, scales, and land uses (Spalevic, 2011).

Morocco serves as a prime example of an unprotected region coping with the adverse effects of soil erosion, which significantly affect its economy and environment. Since the mid-20th century, the state services have actively pursued the study of soil erosion, striving to attain a thorough understanding of this pressing issue and develop effective solutions to address it (Ouallali *et al.*, 2020). The main goal of this study was to use the IntErO model to make predictions regarding soil erosion, sediment yield, and peak outflow. The study focused on Tiguert and the Wanmroud catchments situated within the Ououamana basin.

Materials and Methods

Study area

Two catchments were chosen from the Ououamana basin to ensure accurate results on smaller scales, based on different land uses. The catchment of Tiguert (a) is dominated by agricultural land, while the catchment of Wanmroud (b) has a spread of forest and dense cover. Studied area is presented in the Figure 1.

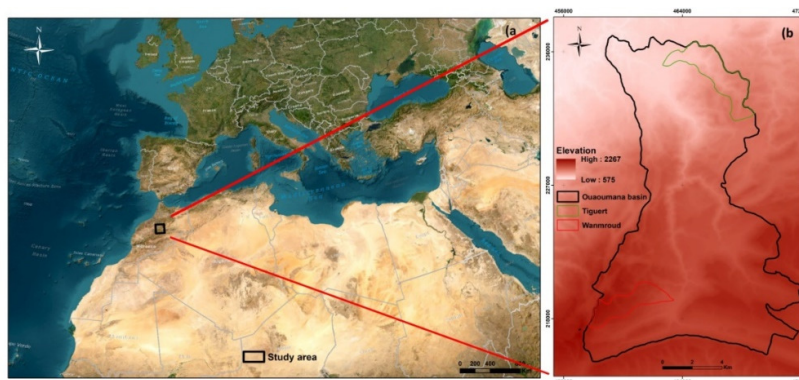


Figure 1. Position of the Ououamana basin in Morocco within the south of the Mediterranean region; the localization of the two river basins within the Ououamana basin

The Tiguert catchment is situated downstream, while the Wanmroud catchment is located upstream within the Ennaji *et al.* (2022) studied area. The Ououmana basin, which belongs to the Middle Atlas of Morocco, occupies 172.4 km².

Geology and soil

At the geological scale, the studied basins exhibit a variety of rock formations, including limestone formations which encompass 21% of these regions. In contrast, quaternary deposits and shale extend over the downstream part of both basins. Additionally, red clay and marl compose the middle of the study area, representing the most dominant lithological formations. (Ennaji *et al.*, 2022). The region's soil is characterized by extensive land degradation caused by soil erosion processes. It is composed of calcareous and ferritic soil formed based on the lithological type.

Meteorology

The climate in this area is semi-arid, with a mean annual rainfall at the El Herri gauging station of 475 mm. Temperatures range from 5 to 45 °C. The study area, located in mountainous regions, experiences significant irregularities in precipitation quantity and a decrease in forest cover caused by human activities (Ennaji *et al.*, 2022).

Vegetation and land use

Vegetation plays a crucial role in stabilizing soil, reducing surface runoff, and preventing erosion (Moreno-de las Heras *et al.*, 2009). Besides, the process of detecting changes in vegetation and land use cover has been driven by physical factors and significant alterations to the earth's surface occurring over an extended period (Mohan Rajan *et al.*, 2020).

Analysing the results in conjunction with vegetation cover maps or data could provide insights into the relationship between soil loss classes and the state of vegetation in both studied basins. Areas in higher soil loss classes may indicate locations where vegetation cover is less effective in mitigating erosion, possibly due to deforestation, land use changes, or other factors (Figure 2).



Figure 2. a) Cedar trees from the Middle Atlas; b) Juniper forests; c) Green Oak forests; and d) Matorral forests from the upper part of the Tiguert and Wanmroud basins (Source: Field research of Spalevic, 2018)

Conservation efforts and land management strategies could then be targeted towards these higher soil loss classes to enhance, and restore vegetation cover, thereby reducing soil erosion in the studied areas (Figure 3).

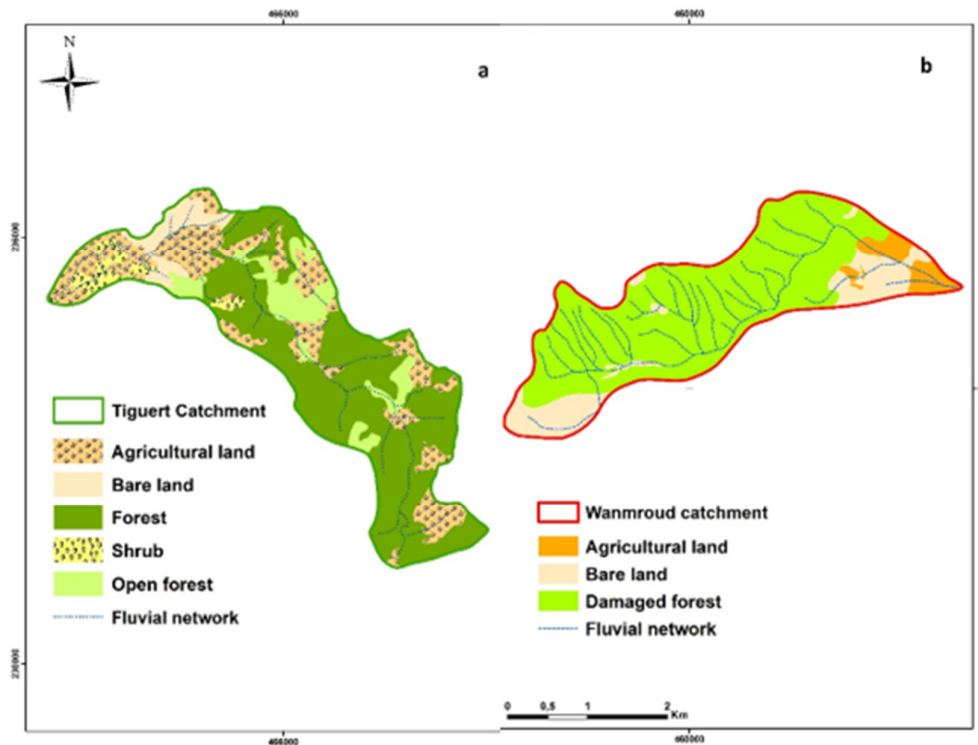


Figure 3. The dynamics of land use/land cover in the Tiguert (a) and Wanmroud (b) basins

IntErO Model

Numerous soil erosion models have undergone development and extensive testing worldwide.

These models incorporate various methodologies, like *AGNPS* (Agricultural Nonpoint Source Pollution Model), *ANSWERS* (Areal Nonpoint Source Watershed Environment Response Simulation), *CREAMS* (Chemical Runoff and Erosion from Agricultural Management Systems), *RUSLE* (Modified Universal Soil Loss Equation, Revised Universal Soil Loss Equation), *USLE* (Universal Soil Loss Equation), and *WEPP* (Water Erosion Prediction Project) (Tavares *et al.*, 2019). Furthermore, supplementary models exist, such as *SDR* (Sediment Delivery Ratio), *SEDD* (Sediment Distributed Delivery), *TLSD* (Transport Limiting Sediment Delivery), and *USPED* (Unit Stream Power Erosion and Deposition Model), specifically crafted to replicate sediment removal, transportation, and outflow mechanisms.

The application of the precedent models to estimate, and assess erosion severity at specific locations has gained popularity due to the laborious, expensive, and time-consuming nature of field-based erosion studies. Instead, these models offer a rapid assessment of soil loss, assuming that relevant data are readily available. In this particular study, Chalise *et al.* (2019) calculated soil loss in the study area using the IntErO, and the RUSLE models. Subsequently, the same authors compared the results with actual observations of soil loss (Chalise *et al.*, 2019).

To obtain data on soil erosion loss from the representative catchments, IntErO model (Intensity of soil Erosion and Outflow - program package by Spalevic (2011) was applied incorporating with the Erosion Potential Method (EPM) which established by Gavrilovic in 1972 within its computer-graphic algorithm. The

model can acquire all essential input data from readily accessible maps, which encompass topography or the Digital Elevation Model (DEM), geology map, land use/land cover map, and easily obtainable climatic variables like temperature and precipitation (Getachew *et al.*, 2021).

Erosion Potential Method is a semi-quantitative empirical model (Gavrilovic, 1972, Dragicevic *et al.* 2017). In this method, four characteristics including erosion coefficient of the watershed (ψ), land use coefficient (X_a), rock and soil sensitivity to erosion (Y) and mean slope of basin (I) in different land units or in created networks are investigated on the map. For each of the components of the land unit or networks the coefficient of erosion intensity (Z) is calculated as follows (Ahmadi *et al.*, 2020; Spalevic, 2011), Equation 1:

$$W = H * T * \pi * Z^{1.5} \quad (1)$$

In the given equation, W represents the erosion rate in cubic meters per square kilometre per year. H stands for the annual average of rainfall in the basin. T denotes the coefficient of temperature, which is calculated using this present equation:

$$T = \left(\frac{t}{10} + 0.1 \right)^{0.5} \quad (2)$$

Where t is mean annual of temperature within the basin ($^{\circ}\text{C}$). Lastly, Z represents the erosion intensity and is calculated using the Equation 2:

$$Z = Y * X_a (\varphi + I^{0.5}) \quad (3)$$

where:

(φ) Represents the erosion coefficient of the watershed.

(X_a) Represents the land use coefficient.

(Y) Represents the sensitivity of rock and soil to erosion.

(I) Represents the mean slope of the basin.

The IntErO model represents an enhanced version that builds upon the capabilities of the Surface and Distance Measuring and River Basins programs of Spalevic (2011). It has been upgraded to efficiently handle a substantial volume of data, accommodating 27 input variables while delivering 22 final result parameters.

Results

The analysis of the Tiguert and Wanmroud river basins reveals significant disparities in their characteristics, including differences in coefficients of river basin form, watershed development, average width and altitude, slope, erosion energy, water retention, and soil losses. These findings underscore the necessity of tailored management strategies to preserve and manage the distinct features of each basin effectively.

In the Tiguert basin, the surface area of the river basin (F) spans 10.2 km^2 , with a perimeter (O) of 20.06 km . The main watercourse's natural length (L_v) measures 8.5 km , while the distance from the source to the mouth (L_m) is 6.04 km . The cumulative length of the primary watercourse and its tributaries (ΣL) totals 24 km , and the measurement of watershed length using parallel lines (L_b) is 6.69 km . The basin is divided into a larger portion (F_v) covering 6 km^2 and a smaller portion (F_m) spanning 4.2 km^2 . The first contour line altitude (h_0) is at 750 m , with equidistance (Δh) of 50 m . The minimum altitude of the basin (H_{\min}) is 736 m , while the maximum altitude (H_{\max}) reaches 1434 m . In contrast, the Wanmroud basin exhibits a surface area (F) of 6.7 km^2 , with a perimeter (O) of 14.74 km . Its main watercourse's natural length (L_v) is 5.73 km , and the distance from the source to the mouth (L_m) measures 5.14 km . The cumulative length of the primary watercourse and its tributaries (ΣL) amounts to 25.88 km , with a watershed length measured by parallel lines (L_b) at 5.93 km . The larger portion of the basin (F_v) covers 4 km^2 , while the smaller portion (F_m) spans 2.7 km^2 . The first contour line altitude (h_0) is significantly higher at 1750 m , with equidistance (Δh) of 50 m . The basin's altitude ranges from 1750 m (H_{\min}) to 2156 m (H_{\max}).

Furthermore, the Tiguert basin is characterized by a segment with highly porous rocks (f_p) covering 20% of its area, a portion with moderate geological permeability (f_{pp}) at 53%, and another with poor water

permeability (f_o) at 27%. Forested areas (f_s) constitute 0.52 of the basin, while grasslands, pastures, meadows, and orchards (f_t) cover 0.42. Plough, bare land, and areas lacking grass and vegetation cover (f_g) occupy just 6% of the river basin area. According to our calculations, the basin experiences torrential rainfall volume (h_b) of 42.1 mm, with a return period incidence (U_p) of 25 years. The main yearly air temperature (t_o) is 18°C, and the annual precipitation average (H_{god}) is 580.9 mm. Soil types (Y) are categorized as 1.1, and the coefficient of the basin planning (X_a) is 0.66, with numeral equivalents of visible erosion processes (ϕ) at 0.50. In contrast, the Wanmroud basin exhibits different characteristics with a segment of highly porous rocks (f_p) covering 0.34, moderate geological permeability (f_{pp}) at 0.66, and no portion with poor water permeability (f_o). Forested areas (f_s) account for 0.77, while grasslands, pastures, meadows, and orchards (f_t) cover none of the basin. Plough, bare land, and areas lacking grass and vegetation cover (f_g) occupy 0.23. The basin experiences a torrential rainfall volume (h_b) of 21.1 mm, with a return period incidence (U_p) also at 25 years. The main yearly air temperature (t_o) remains at 18°C, and the annual precipitation average (H_{god}) is consistent at 580.9 mm. Soil types (Y) are categorized as 1.2, and the coefficient of the basin planning (X_a) is slightly higher at 0.69, with numeral equivalents of visible erosion processes (ϕ) at 0.47.

The program outputs are detailed in Table 1, generated by the IntErO model. This table provide comprehensive insights into the outputs essential for understanding the analysis and interpretation of the Tiguert and Wanmroud river basins' characteristics.

Table 1. The IntErO program outputs for the Tiguert and Wanmroud basins

Outputs (Symbol)	Tiguert basin	Wanmroud basin	Unit
The basin form Coefficient (A)	0.46	0.50	
Coefficient of the watershed development (m)	0.75	0.62	
Average basin width (B)	1.52	1.13	km
The Bassin symmetry (a)	0.35	0.39	
The river network density (G)	2.35	3.86	
Tortuosity coefficient of the basin (K)	1.41	1.11	
Mean elevation of the river basin (Hsr)	1113.59	2003.93	m
Mean altitude variation of the river basin (D)	377.59	253.93	m
The mean decline of river basin (Lsr)	27.01	18.04	%
The local erosion base height of the basin (Hleb)	698	406	m
The erosion energy coefficient of the river basin's relief (Er)	124.32	80.33	
The permeability coefficient of the river basin (S1)	0.72	0.60	
Vegetation cover coefficient of the river basin (S2)	0.71	0.69	
Water retention in inflow and its analytical presentation (W)	0.4241	0.4290	m
The potential energetic of water flow among torrent rains	274.89	182.70	m km s
The maximum Discharge within the basin (Q_{max})	27,40	16,27	m ³ /s
The river basin erosion coefficient (Z)	0.77	0,724	
The river basin production of erosion material (W_{god})	17424,95	10389,5	m ³ /god
The deposit retention Coefficient (Ru)	0,298	0,246	
Real soil losses (Ggod)	5184,47	2555,66	m ³ /god
Real soil losses per km2 (Ggod/km ²)	508,28	381,44	m ³ /km ²

The obtained results from the Tiguert, and Wanmroud river basins reveal distinct differences in their characteristics. The coefficient of the river basin form refers to a used parameter in hydrological or geomorphological modelling to describe the shape or form of a river basin, which can influence various hydrological processes such as runoff generation, sediment transport, and flood risk.

The Wanmroud basin has a slightly higher coefficient of the river basin form (0.50) compared to the Tiguert basin (0.46) that implies that the Wanmroud basin may have a somewhat more elongated and less

compact shape than the Tiguert basin. Additionally, the coefficient of watershed development is lower within the Wanmroud basin (0.62) compared to the Tiguert basin (0.75), indicating a reduced human impact in the former. Besides, the average river basin width is narrower in the Wanmroud (1.13 km) than the Tiguert basins (1.52 km). The average river basin altitude is significantly higher in the Wanmroud basin (2003.93 m) than the Tiguert basin (1113.59 m). Moreover, the Wanmroud basin demonstrates a gentler average decline of 18.04% compared to the Tiguert basin, which exhibits a steeper decline of 27.01% (Figure 4).



Figure 4. Land degradation in the studied catchments of the Ououmana basin in Morocco

According to our analysis, the Wanmroud basin has a lower coefficient of erosion energy ($E_r = 80.33$) compared to the Tiguert basin ($E_r = 124.32$), suggesting potentially lower erosion intensity in the former. While the Wanmroud basin shows slightly better water retention ($W = 0.4290$ m) than the Tiguert basin ($W = 0.4241$ m), this basin has a higher maximal outflow ($Q_{max} = 27.40$ m³/s) compared to the Wanmroud basin ($Q_{max} = 16.27$ m³/s). Furthermore, the Tiguert basin experiences higher real soil losses ($G_{god} = 5184.47$ m³/god) and soil losses per km² ($G_{god}/km^2 = 508.28$ m³/km² god) than the Wanmroud basin ($G_{god} = 2555.66$ m³/god, $G_{god}/km^2 = 381.44$ m³/km² god). These numerical disparities underscore the importance of considering these factors in managing and conserving each basin's unique characteristics appropriately.

As a result, the both Tiguert and Wanmroud catchments reveal notable differences in their characteristics. The Wanmroud basin demonstrates a slightly more regular shape and a lower coefficient of watershed development, implying a potentially lower human impact compared to the Tiguert basin. Additionally, the Wanmroud basin has a narrower average width and higher average altitudes, suggesting a more confined and elevated terrain. This is further supported by its gentler slope and marginally better water retention capacity. On the other hand, the Tiguert basin exhibits higher erosion energy, greater soil losses, and a higher maximal outflow, signifying higher erosion potential and peak water flow. The disparities between these basins underscore the significance of tailored approaches for water resource management, erosion control, and environmental conservation to address the unique characteristics of each river basin.

Discussion

Over the past century, anthropogenic activities have exerted significant pressure on agricultural land in the studied area, leading to the degradation of vegetation cover and subsequent loss of fertile soil. Water erosion, primarily driven by precipitation and runoff, along with fluvial erosion in streams, has emerged as the dominant erosion type in this region, exerting a strong influence on the landscape due to the prevailing precipitation patterns.

The values of potential erosion obtained through the IntErO model based on the EPM method appear reasonable when compared to similar studies conducted in various regions, including Iran (Yousefi *et al.*, 2014; Haghizadeh *et al.*, 2009; Abadi and Ahmadi, 2011), Bosnia, and Herzegovina (Tosic and Dragicevic, 2012), Northern regions of Italy (Milanesi *et al.*, 2015), Mountains of Greece (Efthimiou *et al.*, 2016), Brazil (Tavares *et al.*, 2019; Tangestani, 2006), Nepal (Chalise *et al.*, 2019), Romania (Sestras *et al.*, 2023), Bulgaria (Pavlova-Traykova and Petrova, 2023) and various research in Montenegro mostly of the team of Spalevic in the period from 1997-2024 (Spalevic, 2011; Spalevic *et al.*, 2020).

However, the application of the IntErO model based on the EPM method in the Moroccan territory remains limited, with only a few studies exploring sediment mobilization, and soil losses. Some recent research efforts include a sediment mobilization study by Ouallali *et al.* (2020) in an external Rif catchment, an estimation of soil losses and reservoir sedimentation in the Tillouguite sub-basin by Sabri *et al.* (2022) within the High Atlas region, and El Mouatassime *et al.* (2019) investigated the modelling of soil erosion and runoff within the El Abid river basin.

Comparative analysis with other erosion models commonly used in Morocco reveals consistent erosion values ranging from 23 to 62.72 t ha⁻¹ yr⁻¹, similar to those observed in the Tiguert and Wanmroud river basins, as presented in the Table 1. While models like USLE, RUSLE, MUSLE, and SWAT have been employed in previous studies, the IntErO model offers unique advantages by calculating sediment yield, peak discharge, and various basin characteristics, providing a comprehensive understanding of erosion dynamics. The IntErO model based on the EPM method demonstrates the impact of erosion factors and the spatial distribution of erosion categories, emphasizing the significance of vegetation cover, land-use, topography, and climatic conditions in erosion processes.

While the model effectively captures erosion patterns, its application is subject to certain limitations, including assumptions of uniformity in input parameters and uncertainties in qualitative categorization, especially in areas with heterogeneous characteristics.

Verification of model outputs through field measurements and comparison with other validation methods reaffirms the reliability of the IntErO model based on the EPM method in estimating sediment yield, and erosion rates in the basins with similar conditions. However, challenges persist in addressing rapid changes in vegetation cover, climatic variability, and variations in input parameters, necessitating further research and model refinement.

The analysis of the Tiguert and Wanmroud river basins underscores significant differences in basin characteristics, erosion intensity, and hydrological dynamics, emphasizing the need for tailored management strategies to conserve and manage these unique landscapes effectively.

The IntErO model based on the EPM method offers valuable insights into erosion processes, but ongoing research and refinement are essential to address inherent limitations and improve its applicability under diverse environmental conditions.

Table 1 provide detailed insights into the input parameters and model outputs, facilitating a comprehensive understanding of erosion dynamics in the Tiguert and Wanmroud river basins. To relate these results to vegetation cover, it's reasonable to assume that areas with denser and more effective vegetation cover may experience lower soil erosion rates. Land use structure – vegetation cover in the studied catchments of the Ououmana basin in Morocco is presented in Figure 5.

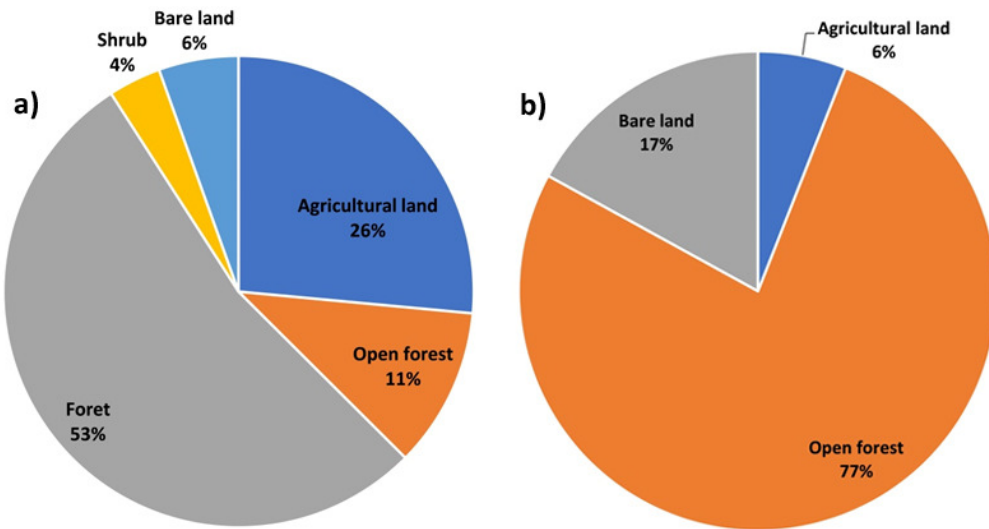


Figure 5. Land use structure – vegetation cover in the studied catchments of the Ououamana basin in Morocco: a) Tiguert basin; b) Wanmroud basin

It is evident that the impact of land use on soil erosion intensity can be determined by comparing the results of real soil losses per km² between the two basins as presented in Table 1: the Tiguert basin (508 m³/km²) and the Wanmroud basin (381 m³/km²). Additionally, assessing the vegetation cover, particularly the areas under agricultural land (Figure 5) further emphasizes this difference, with the Tiguert basin having 26% of agricultural land compared to the Wanmroud basin's 6%. Moreover, considering both bare land and agricultural land collectively, the Tiguert basin (32%) exhibits higher coverage compared to the Wanmroud basin (23%). All of this confirms the impact of anthropogenic factors, and vegetation cover on soil erosion intensity in the two studied river basins within the Middle Atlas of Morocco.

Conclusions

Soil erosion considered as a widespread environmental challenge with profound implications, influencing ecosystems, and reducing agricultural productivity and societal well-being. In response, the IntErO model has emerged as a pivotal tool globally, enabling the assessment of peak outflow, soil erosion, and sediment yield in watersheds. Our study, focused on two catchments within Morocco's Ououamana basin, delineated disparities between the Tiguert and Wanmroud basins, stressing the need for tailored approaches to water resource management, erosion control, and conservation. The application of the IntErO model in Morocco introduces innovative techniques for analyzing soil erosion intensity in the Mediterranean region, furnishing valuable insights into basin characteristics, erosion dynamics, and management strategies. Comparative analysis with other erosion models underscores the significance of the IntErO model's capabilities, despite inherent limitations necessitating ongoing refinement. Overall, our research represents a significant advancement in understanding soil erosion processes, crucial for preserving the sustainability of natural ecosystems and human well-being in this Moroccan context, and offers potential applicability in similar Mediterranean basins with comparable geographical characteristics.

Authors' Contributions

Conceptualization was undertaken by E.N, H.O, M.A., V.S., and B.D. The methodology was developed by E.N, H.O, M.A., V.S., and B.D. Software contributions were made by H.O., E.N and V.S. Validation was conducted by E.N, H.O, M.A., V.S., and B.D. Formal analysis involved E.N, H.O, M.A., V.S., and B.D. Investigation tasks were carried out by E.N, H.O, M.A., V.S., and B.D. The writing, review, and editing process were collectively handled by E.N, H.O, M.A., V.S., and B.D. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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