American Journal of Mechanics and Applications
2023; 11(1): 1-5
http://www.sciencepublishinggroup.com/j/ajma
doi: 10.11648/j.ajma.20231101.11
ISSN: 2376-6115 (Print); ISSN: 2376-6131 (Online)

Temporal Dynamic of Soil Erosion and Rainfall Erosivity Within Srou River Basin (Middle Atlas / Morocco)

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To cite this article:
Ouakhir Hasan, Mohamed El Ghachi. Temporal Dynamic of Soil Erosion and Rainfall Erosivity Within Srou River Basin (Middle Atlas / Morocco). *American Journal of Mechanics and Applications*. Vol. 11, No. 1, 2023, pp. 1-5. doi: 10.11648/j.ajma.20231101.11

Received: March 16, 2023; **Accepted**: April 6, 2023; **Published**: May 25, 2023

Abstract: Soil erosion is a major cause of land degradation worldwide, particularly in arid and semi-arid regions. In Morocco, soil loss is the most prevalent form of land degradation. The Srou river basin, located in the Middle Atlas Mountains of Morocco, has been greatly affected by soil erosion due to physical and human factors. The basin is characterized by an arid and semi-arid climate, with high temperatures, low rainfall, and flash floods, making it particularly vulnerable to soil erosion. Furthermore, the soil is shallow and lacks proper protection from vegetation cover. Livestock and agriculture, mainly consisting of sheep and goats, are the dominant activities in the area. This study employs the rainfall erosivity index (RI) and GIS techniques to evaluate soil erosion in the Srou river basin during three representative years (1995, 1996, and 2010). The objective is to assess the temporal dynamics of soil erosion and its impact in this region. The results indicate that rainfall is irregular and often characterized by intense showers due to climate change. During wet years, the rainfall erosivity index is high, exceeding 200 in 1996 and 2010, while during the dry season of 1995, it was very low, less than 85.

Keywords: Soil Erosion, Rainfall Erosivity Index, Srou River Basin, Middle Atlas

1. Introduction

Morocco faces significant environmental challenges and soil and water resource pressure due to only 19% of its land being arable. The central and western Rif regions experience an average erosion rate of about 20 t/ ha $^{-1}$ yr^{-1}, while the Pre-Rif and Mediterranean coastal areas have a higher range between 100 to 300 t/ha $^{-1}$/yr^{-1} [1]. The Middle and High Atlas experience an annual average ranging from 50 to 100 t/ha–1yr–1. As a result, soil erosion causes a loss of essential soil elements, a scarcity of land resources, and endangers the richness of species and the balance of ecosystems, leading to a decline in global agricultural production and economic development [1, 2]. Many methods have been developed to quantify and calculate erosion rates, including direct field measurements, soil analyses, and empirical models and equations that consider all variables of soil erosion. This study aims to evaluate the temporal dynamics of soil erosion in the Srou river basin located in the Moroccan Middle Atlas by measuring the rainfall erosivity index (Ri).

2. Study Area

The Srou basin is located in the Middle Atlas of Morocco and is bordered to the north by the city of Khénifra, to the east by Itzer commune, to the south-east by the plain of the upper Moulouya, and to the west by the Ahmed El Hansali dam. It covers an area of about 1473 km^2 and is a mountainous region drained by the Srou river and its tributaries flowing into the big Oum Er Bia River. The area's climate is Mediterranean with arid and semi-arid influences, and the average annual rainfall is 689.4 mm, with significant spatial and temporal variability [3]. The wettest year was 1995-1996 with 1179.5 mm precipitation, while the driest year was 1994-1995 with precipitation of 237.2 mm. The average monthly temperature shows that August is the hottest month (T = 25.8°C) while January is the coldest (9.5°C). The altitude ranges from 652 to 2332 m a.s.l, and the geology of the basin is characterized by

Cretaceous sub-tabular limestone formations upstream and Triassic doleritic basalts, quartzites, and red clay downstream at lower altitudes. The soils in the area are calcimagnesic, isohumic, vertisols, and fersialitic.

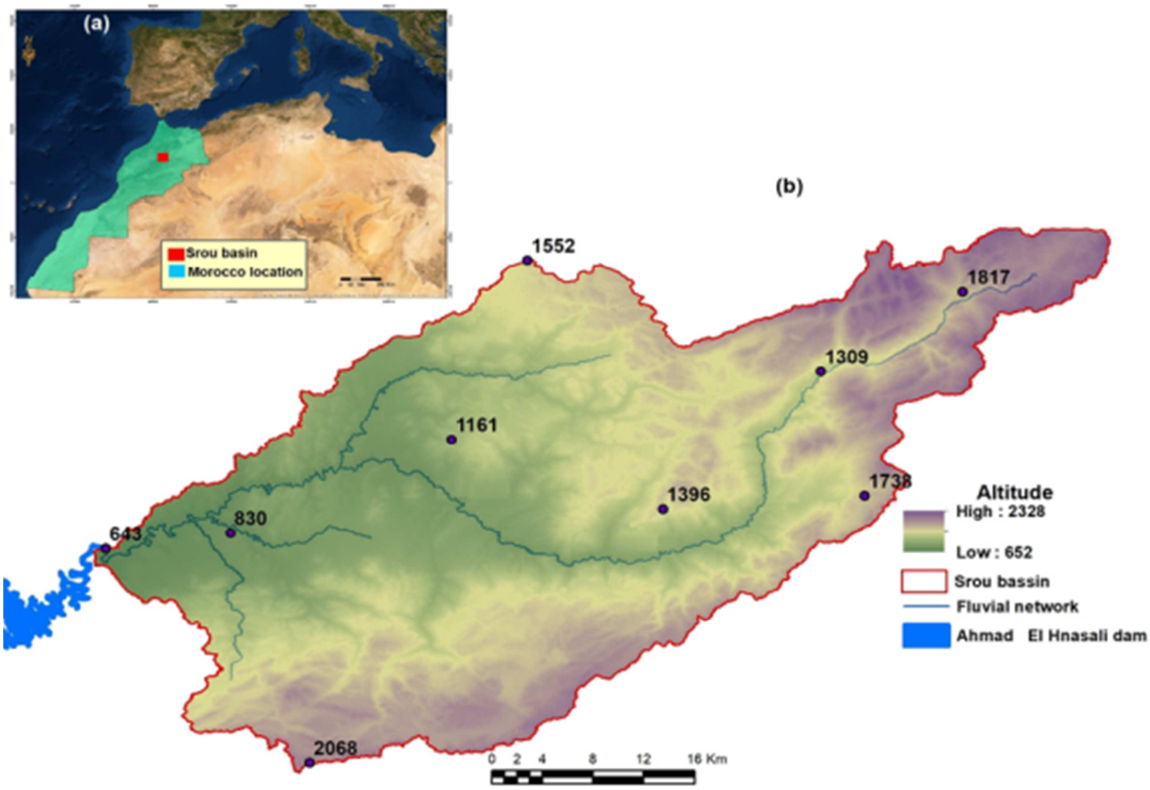

***Figure 1.** a) location of Srou river basin in Morocco, and b) the Srou river basin.*

3. Data and Methods

3.1. Used Data

The used data in this article was collected from Hydraulic Basin Agency of Oued Oum Err Bia (HBAOER). The annual and monthly rainfall and discharge data recorded at Chacha N Mellah, Taghat, El Heri, Ahmed El Hanssali and Kerrouchen gauging stations were obtained from HBAOER (Table 1).

***Table 1.** Presentation of the used gauging stations data.*

Gauging station	X (km)	Y (km)	Z (m)	Mean (mm^{-1})
Chacha N Mellah	467.500	243.250	736	471.6
Taghat	476.220	266.940	873	550.1
El Heri	478.500	251.125	835	616.7
Ahmed El Hanssali	461.850	235.350	720	485.2
Kerrouchen	508.500	246.000	1350	575.9

3.2. Methods

The rainfall erosivity factor (Ri) was calculated using annual rainfall data obtained from the meteorological gauging stations managed by the hydraulic agency of Oum Err Bia River. The estimation of the R-factor was based on the formula developed by Wischmeier and Smith [6], which involves determining the kinetic energies (Ec) and average intensity over 30 minutes (I30) of raindrops for each rainfall event [21]. These values are determined using the empirical formula provided by Wischmeier and Smith [21].

$$R = K\,E_c\,I_{30.} \tag{1}$$

Sadiki et al [17] presented the work of Kalman [6] Arnoldus [2] and Rango & Arnoldus [16] who proposed different formulas to calculate the R factor using only annual and monthly rainfall data. The researchers applied the formula of Rango & Arnoldus [16] to five stations located in or near the Wadi Srou watershed and provided the annual and monthly precipitation data as well as the corresponding R-factor values calculated using this formula.

$$\text{Log } R = 1.74.\log \sum \left({Pi^2}/{p} \right) + 1.29 \tag{2}$$

where Pi is the monthly precipitation and P the annual precipitation in mm.

4. Results and Discussion

4.1. Hydrological Response of Srou River

The irregularity of flow regimes in Moroccan rivers has dramatically demonstrated the sensitivity of semi-arid areas to climatic fluctuations, as noted by Legesse et al [7] and Ouakhir et al [12]. The Srou river basin, characterized by a warm Mediterranean climate with dry summers, receives an average annual rainfall of 500 to 700 mm, with the majority falling between December and April, resulting in an erosivity of 1444.48 MJ.mm/(ha.h.yr) [9]. The mean annual temperature is 20.6°C. Hydrological response of the Srou river at the Chacha N Mellah gauging station, located at the basin's outlet, is depicted in Figure 2. The results reveal a quick hydrological response of the Srou river, with peak discharge (Q) corresponding to the rainfall (R) during the 1980 to 2019 data series. The wet year of 2010 saw the maximum rainfall (689.9 mm) and generated the highest discharge of 28.6 m3/s-1 (Figure 2).

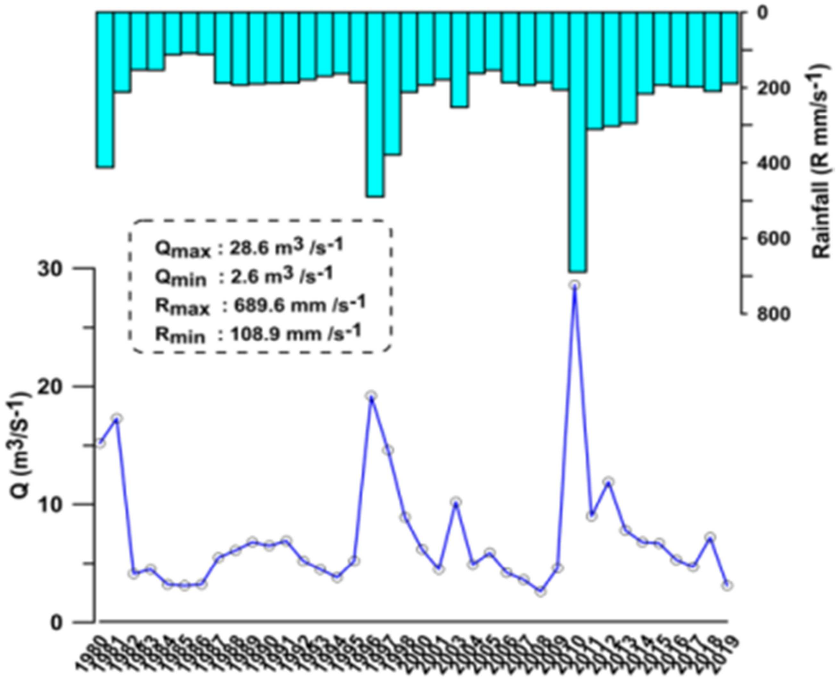

Figure 2. *Hydrological response of the Srou river basin. (Chacha N Mellah gauging station 2019).*

4.2. The Effect of Rainfall Erosivity Index on Srou River Basin

Rainfall erosivity is the capacity of rain to cause soil erosion, and this depends on factors such as rainfall intensity, duration, and frequency [8]. Higher erosivity values indicate greater potential for soil erosion, as rainfall can detach soil particles and transport them downhill, resulting in soil loss and degradation that can adversely affect agriculture, water quality, and ecosystem health. It is crucial to comprehend the connection between rainfall erosivity and soil erosion and to adopt erosion mitigation measures like conservation tillage, contour farming, and vegetative cover [10]. The figure provided reveals high erosivity levels at the studied rain gauging stations during two wet seasons in 1996 and 2010 (>200 MJ mm ha^{-1} yr^{-1}), while the dry season of 1995 showed low values (<90 MJ mm ha-1 yr^{-1}).

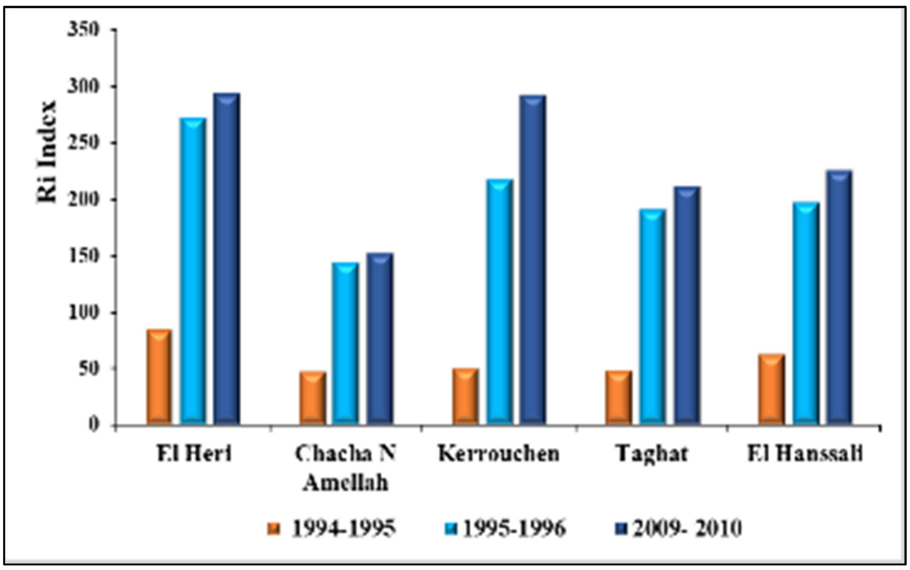

Figure 3. *Rainfall erosivity index (Ri) in the rain gauging stations within Srou river basin.*

The results obtained in this study were compared with those of Da Silva [5], who reported annual rainfall erosivity values in Brazil ranging from 3116 to 20,035 MJ mm ha-1 yr^{-1} [13]. These values were classified as strong or very strong. In addition, our findings were compared with those of Panagos et al. [14] who noted that the spatial distribution of the highest erosivity values corresponded to extreme rainfall events, and defined intense storms based on the convective vertical velocity of rain [15]. However, the authors' global erosivity map indicated that the highest values of erosivity were observed in Southeast Asia (Cambodia, Indonesia, Malaysia, the Philippines, and Bangladesh), Central Africa (Congo and Cameroon), South America (Brazil, Colombia, and Peru), Central America, and the Caribbean [20]. Conversely, the lowest erosivity values were mainly found in Siberia, the Middle East, Northern Africa, Canada, and Northern Europe. The Polar Regions were excluded from the global erosivity map [18].

4.3. Validation of Results

The rainfall-runoff erosivity factor (R) is a commonly used indicator to assess the risk of water erosion, as highlighted in the field by Bonilla and Vidal [4] and Ouakhir et al. [11]. Figure 4 illustrates various forms of soil erosion that are taking place within the Srou river basin, including the formation of Badlands.

Figure 4. *Photos of soil erosion forms in the Srou basin.*

The erosive capability of rainfall is determined by a factor called rainfall-runoff erosivity factor R, which takes into consideration the duration, magnitude, and intensity of each rainfall event [19]. To calculate the R factor, the average annual sum of the product of a storm's kinetic energy E and its maximum 30-min intensity I30, also known as the EI30, is traditionally used [4, 21, 22, 23, 24].

5. Conclusion

This research assesses changes in precipitation and discharge characteristics, as well as land use practices, in a mountainous area of the Middle Atlas region in Morocco, to evaluate erosion. The Srou basin was found to have a rainfall erosivity factor (R) ranging from 90 to 200 MJ*mm/ha/h, similar to central and western Rif and the Rif foreland. The study identified erosion-prone areas and estimated sediment deposition at the outlet of the Srou basin. Erosion can lead to farmland damage and water quality degradation, and sediment transport. To address this risk, measures should be implemented in areas where runoff is produced and sensitive regions that receive precipitation. This can be achieved by reducing surface runoff and controlling detachment and transportation of runoff, by limiting its speed and concentration.

Conflict of Interests

The authors declare that they have no competing interests.

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