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THE ASSESSMENT OF THE RAIN EROSIVITY IN THE AURES MASSIF (EASTERN ALGERIA)

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Abstract. In eastern Algeria and particularly on the Aures Massif, the phenomenon of erosion takes several forms and manifests itself spectacularly, especially on vulnerable and less-vegetated soils. Some soil scientists link soil genesis with the erosivity of rainfalls. This work aims at a spatio-temporal representation of rainfall erosivity according to a geostatistical approach that begins with the estimation of certain erosivity indices and ends with a precise zoning.

The study showed that the physical characteristics of this space are varied, but the mountainous areas are most sensitive, with erosivity index values ranging from 20 to 50, and some stations on the piedmonts record average values. By contrast, the desert zones offer low values of below 5 according to the index of Arnoldus. The stations exposed to the north have markedly the highest erosivity values. In addition, rainfall erosivity increased according to altitude, and the correlation between rainfall and rainfall erosivity was very significant. Zoning of erosivity will provide decision-makers and technicians with a tool for management and decision-making to protect and ensure soil sustainability.

Key words: erosion index, zoning, geostatistical approach, precipitation, altitudinal gradient

Introduction

The eastern Saharan Atlas of Algeria, because of the aggressiveness of its climate, is strongly exposed to erosion, especially in mountainous areas. Our study area is part of this vast area that extends from the east to the west of the country. This work deals with the analysis of rainfall erosivity in its climatic and topographic dimension through a cartographic approach. Erosion is a serious environmental and agricultural problem affecting the study area. The most remarkable consequences are: generalised impoverishment of soils, decline in fertility, and soil sterilisation (Abdassamed 1980; Mostephaoui *et al.* 2013). The Aures Massif suffers from water erosion triggered by the effect of erosive rains, and this limits agricultural areas, and especially in land used for arboriculture; the study area accounts for a high share of the apple production

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of the nation and of the Maghreb. This apple production was 348 200 quintals in 2014 and reached 1.8 million quintals in 2021–22 (Ministry of Tourism… 2023).

In this region, for 1955, soil degradation due to water erosion was estimated at between 200 and 500 tonnes of solid elements for the Oued El Abiod catchment upstream of the Foum El-Gherza dam, which is part of the massif. This degradation corresponds to an average value of surface erosion over the entire catchment that varies between 0.2 and 0.5 mm per year (Abdassemed 1984).

The massif attests to very accelerated gully erosion favored by the intensity of torrential erosive rains, particularly in autumn and spring, which tear off around 450 to 670 $t \cdot km^2 \cdot y^{-1}$ from the catchment of this massif (Meharzi 2010; Khentouche 2021). Mebarki (2010) showed that the impact of water erosion on the sedimentation of dams in this area is very clear. Meharzi (2010) has shown that erosivity is the capital factor of water erosion and has a significant effect on the degradation of agricultural soils and among the factors accelerating the siltation of dams in the study area.

The erosivity of rainfall is of major importance among the natural factors that affect soil erosion (Roose 1977; Andoh *et al.* 2012). According to Arnoldus (1977), the Wischmeier climatic erosivity index (R) is widely used in the estimation of rainfall erosivity. However, in the absence of certain data (in particular, the intensity of rainfall), we lean towards the use of the Fournier index or Arnoldus index (Boukheir 2002). To best estimate land loss for the stated watershed in the light of the absence of such data, many researchers have looked to use different models than the R coefficient. In this study we have dealt with this issue by applying the two widely used indices of Fournier and of Arnoldus. These indices were later remodeled by several researchers, who, after several years of research, developed many formulas and other empirical indices to estimate the R factor. These indices are to be applied when one of the parameters needed to calculate the universal index is not available (Fournier 1960; Arnoldus 1980; Meddi 1992; Gabriels 2006). In this work, we will also study the Precipitation Concentration Index (PCI) proposed by Oliver (1980), which expresses the seasonal and annual variability of precipitation.

Our essential goal was to make an evaluation of the erosivity of rain, which represents the main element of water erosion and to leave by a cartography or zoning of this erosivity as a tool supporting decision-makers and technicians by informing them as to the classification of areas exposed to erosion and facilitating the management of this mountain area dominant agricultural activity is based on vulnerable soils.

Study area and methodology

The study area consists of the Aures and some plains overlooking the desert to the east of the Saharan Atlas, which separates the high Constantine plains from the Sahara. It is a clearly individualized region; it is raised massively over the quaternary plain of Biskra, located 100 km south of Constantine and 500 km south-east of Algiers (Fig. 1), and lies at 35° and 34° north and 6° and 7° east. The zone is placed at the joint of large ensembles that constitute the Algerian–Tunisian Saharan Atlas. The climate is semi-arid at the medium and higher-lying areas and arid in the landscapes overlooking the Sahara. The area has irregular annual precipitations of between 150 mm and 470 mm on the mountains and between 10 mm and 120 mm on the areas that approach the Sahara. The Biskra station in a Saharan area records an average annual temperature of 22.5 °C and a maximum of 41 °C in July (Khentouche 2021). The massif has a markedly varied rainfall, with most precipitation falling in autumn and spring, which gives a preliminary image for predicting the state of erosion.

The massif is dominated by slopes greater than 12.5° that cover around 75% of the study area and accelerate all the phenomena associated with flows (gullying, regressive erosion, undermining of banks). Forest and dense maquis develop at the highest altitudes, while light maquis generally occupies the foothills and especially southern slopes (Beghami 2013). The Aures Massif has soils that are generally poorly evolved (aeolian accumulation soils, aeolian ablation soils, basic alluvial soils).

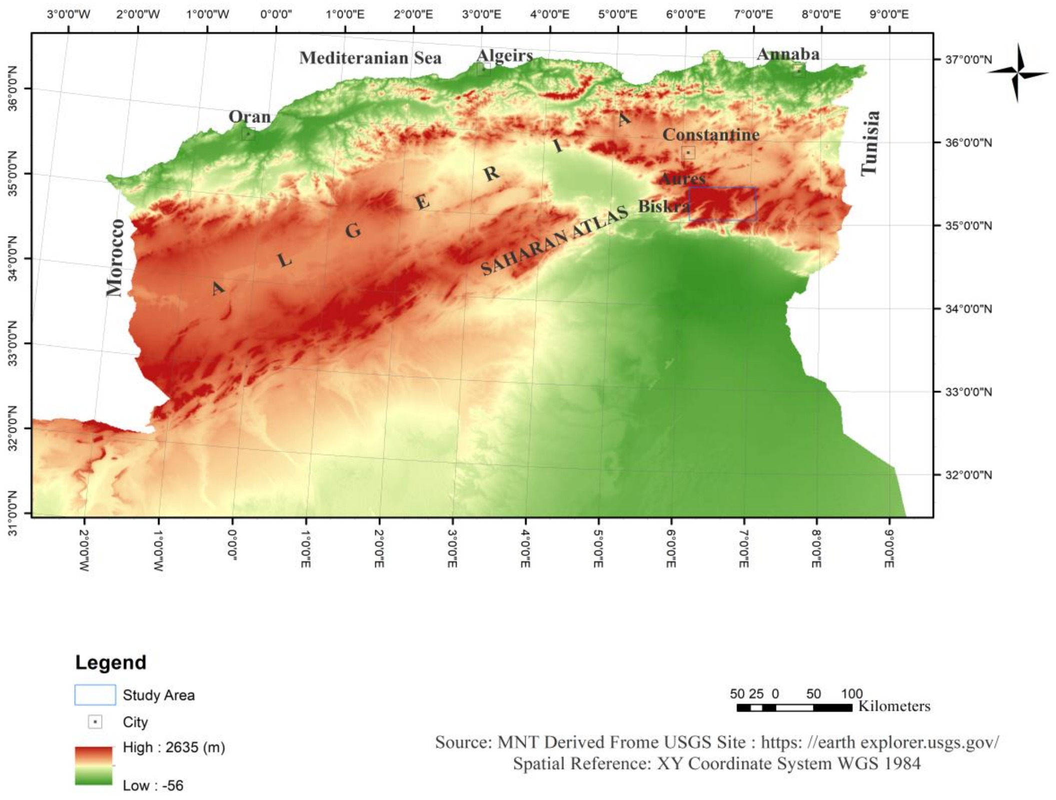

Fig. 1. Location of the study area

Indices used

In the study area, the absence of accurate and complete rainfall intensity data does not allow the application of the Wischmeier universal index of erosivity (E_{I30}) (Wischmeir 1959) in a professional and scientific manner. To quantify and represent the spatial distribution of erosivity; we will focus on the use of three indices widely used in erosion studies.

Fournier (1960) defined a precipitation distribution index (FI) as the ratio of precipitation for the wettest month of the year (P_m) to annual precipitation (P) using the formula:

$$\mathrm{FI} = \left(\frac{{P_m}^2}{P}\right) \qquad (1)$$

The rainfall erosivity according to the Fournier Index (FI) is presented in six classes as follows: (0–20) very low, (20–40) low, (40–60) moderate, (60–80) severe, (80–100) very severe and (>100) extremely severe (CEC 1992).

Arnoldus (1980) showed that the correlation between (FI) and E_{I30} was not significant (R^2=0.55). Based on this result, he proposed the Modified Fournier Index (MFI). This index takes into account the precipitation (mm) of all months of the year. It achieved satisfactory results for 164 stations in the United States and 14 stations in West Africa. This index of Arnoldus was given by the following equation:

$$\mathrm{MFI} = \frac{\left(\sum_{i=1}^{12} {P_i}^2\right)}{P} \qquad (2)$$

where: MFI – modified Fournier index; P_i – – monthly precipitation [mm]; P – annual precipitation [mm].

According to Arnoldus (1980), the results obtained from the application of this index are considered as a good approximation of the factor R of the universal equation whose relation is linear. The classes of this index proposed in CEC (1992), gives the state of erosivety with respect to well-defined limits between 0 and 160, the classes of rainfall erosivity proposed by Arnoldus are: (0–60) very low, (60––90) low, (90–120) moderate, (120–160) severe, (>160) very severe.

The Precipitation Concentration Index (PCI) proposed by Olivier in 1980, expresses the seasonal and annual variability of precipitation. Low PCI values indicate a uniform distribution of rainfall over the year, whereas high values represent a high concentration of monthly rainfall or seasonality (Hevesti *et al.* 1992). The formula which represents this rainfall index is given as follows:

$$\mathrm{PCI} = 100 \cdot \left(\frac{\sum_{i=1}^{12} P_i^{\,2}}{P^2} \right) \qquad (3)$$

where: PCI – precipitation concentration index [%], symbols in accordance with equation 2. According to Oliver (1980), PCI index values are organised into five classes as follows: (8.3–10) uniform distribution, (10–15) moderate, (15–20) seasonal distribution, (20–50) strong seasonal effects, (50–100) irregular distribution.

Hudson (1996) has demonstrated that the PCI was appropriate for assessing and comparing rainfall concentration between rainfall stations.

Cartographic representation of rainfall erosivity

The cartographic process begins with integrating the index calculation results into maps according to a geostatistical method; this approach is widely used in the Earth sciences, unlike the conventional interpolation technique. The geostatistical approach uses a linear combination of the measured data while also taking into account the geographical position of the point considered and the randomness of the phenomenon in question (Ajward *et al.* 2000). We have chosen to specialise the presentation of the variability of the indices; the simple kriging is better-suited to our issue and ensures a good spatial and temporal distribution of erosivity (Fig. 2). Modelling andmapping the potential risks of water erosion of soils is of great importance in the management and planning of catchments (Boughalem *et al.* 2020).

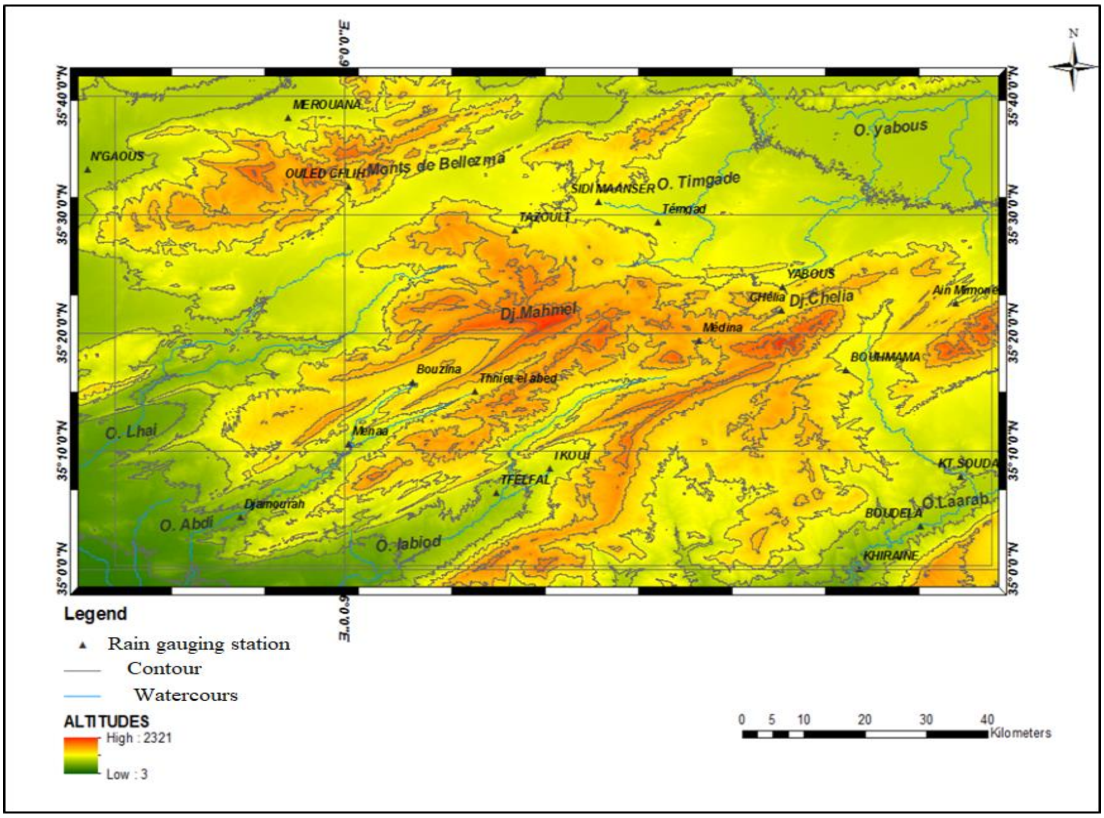

Fig. 2. Location of rain gauging stations used in the study area
(The SRTM is extracted from USGS Site (USGS 2023)

Results

Precipitation

Table 1 groups the values of the three rain indices used for each station in the study area.

The annual rainfall distribution in the study area expresses the irregular nature of the rains between the stations of south and those of the north (Fig. 3). The northern stations show strong rainfall, exceeding 400 mm, while the south of the massif is less watered, with only from 50 mm to 150 mm on areas overlooking the Sahara; valleys and some foothills have relatively moderate rainfall.

Table 1

Rainfall erosivity values

Stations	P [mm]	FI	FMI	PCI [%]
Djemoura	147.67	2.38	14.87	10.07
Foum Gherza	112.10	2.24	11.30	10.08
Doucen	94.43	2.62	9.57	10.14
Tifelfel	163.80	3.09	14.98	9.15
Tkout	278.12	2.68	24.21	8.71
Babar	333.01	4.93	29.62	8.89
Yabous	382.46	5.57	35.18	9.20
Boudella	222.27	3.19	21.17	9.52
khierane	210.04	3.91	20.56	9.79
Kh.S. Nadji	60.83	2.00	6.84	11.24
Batna	378.63	4.98	34.89	9.21
Ouled Chlih	322.45	4.28	30.63	9.50
Marouna	348.13	5.13	34.02	9.77
N'gaous	250.47	4.00	20.59	9.82
Tazoult	365.92	4.47	34.19	9.34
S^{d} Mancer	323.67	4.52	29.90	9.24
Bouhmama	408.02	4.54	35.84	8.78
Medina	445.31	5.16	39.53	8.88
Chelia	507.87	7.51	46.27	9.11
A.Mimoun	443.56	6.84	40.15	9.05
Menaa	263.50	4.62	25.35	9.62
Bouzina	321.90	5.43	30.79	9.57
Th^{t} Abed	247.90	6.45	24.21	9.76
Siar	67.02	1.36	6.71	10.01
Chechar	287.90	5.46	26.77	9.30
M'ziraa	57.63	1.43	6.61	11.47
Timgad	291.90	5.10	27.29	9.35
Ktef Souda	186.19	4.54	17.46	9.37
Ain Touta	288.76	4.00	24.00	9.28
Toufana	390.59	4.66	26.02	9.59
Baiou	377.27	4.90	34.00	10.07
Reboa	287.03	4.50	30.00	9.11
Foum Toub	470.00	6.20	40.00	9.16
Biskra	60.00	1.48	6.65	10.86

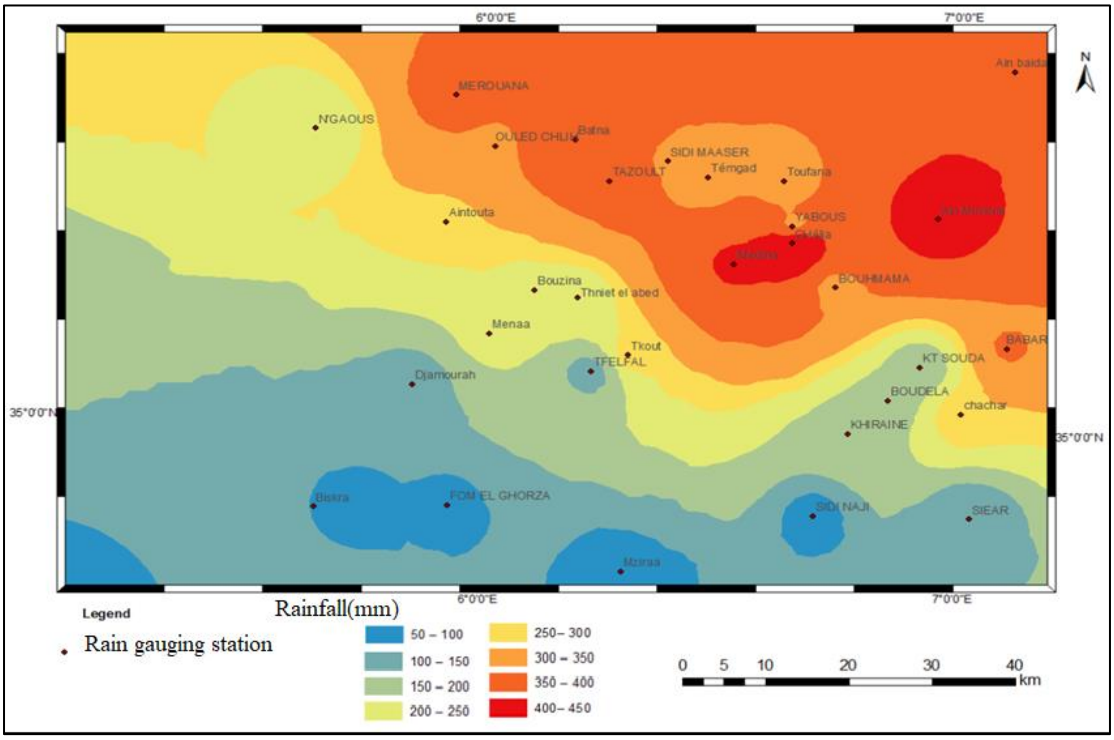

Fig. 3. Distribution of annual rainfall for the period 1969–2010 (ONM 2021)

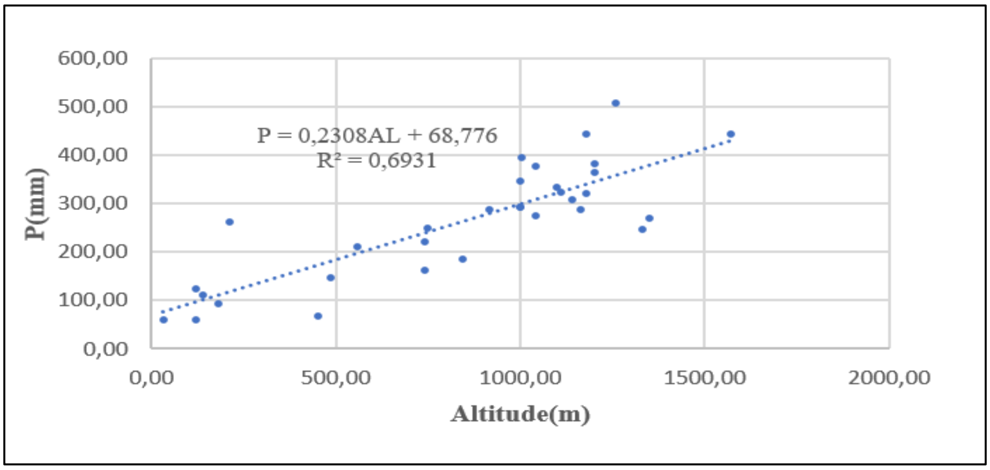

Fig. 4. Relationship between altitude and rainfall distribution

It should be noted that the precipitation distribution is a function of altitude (Mebarki 2005; Gabriels 2006). The stations at high altitudes record significant levels, namely Chélia (1260 m a.s.l.) and Medina (1600 m a.s.l.). This observation is well confirmed in several places around the world (Haidu 2003). The importance of altitude in the rainfall distribution in the study area is confirmed by Figure 4.

The value of the correlation coefficient indicates a positive linear relationship between rainfall and altitude of stations, with a value of 0.83. Eighteen stations at altitudes above 1000 m a.s.l. receive a quantity greater than 200 mm; this observation explains the role of altitude in the distribution of rainfall in the Aures Massif. Some stations are at average altitudes but have high rainfall; this can be interpreted as the effect of the exposure (Khentouche, Dridi 2019). The northern and north-western exposure are the most influential because the most abundant and much the most torrential precipitation comes mainly from the north and north-west (Beghami 2012; Khentouche 2019). The circular form of the curves is in agreement with the highest elevations (Fig. 5). For each station, the precipitation agrees well with the values of FI (the high values of FI represented in the form of isolines of erosivity correspond with the most important precipitations).

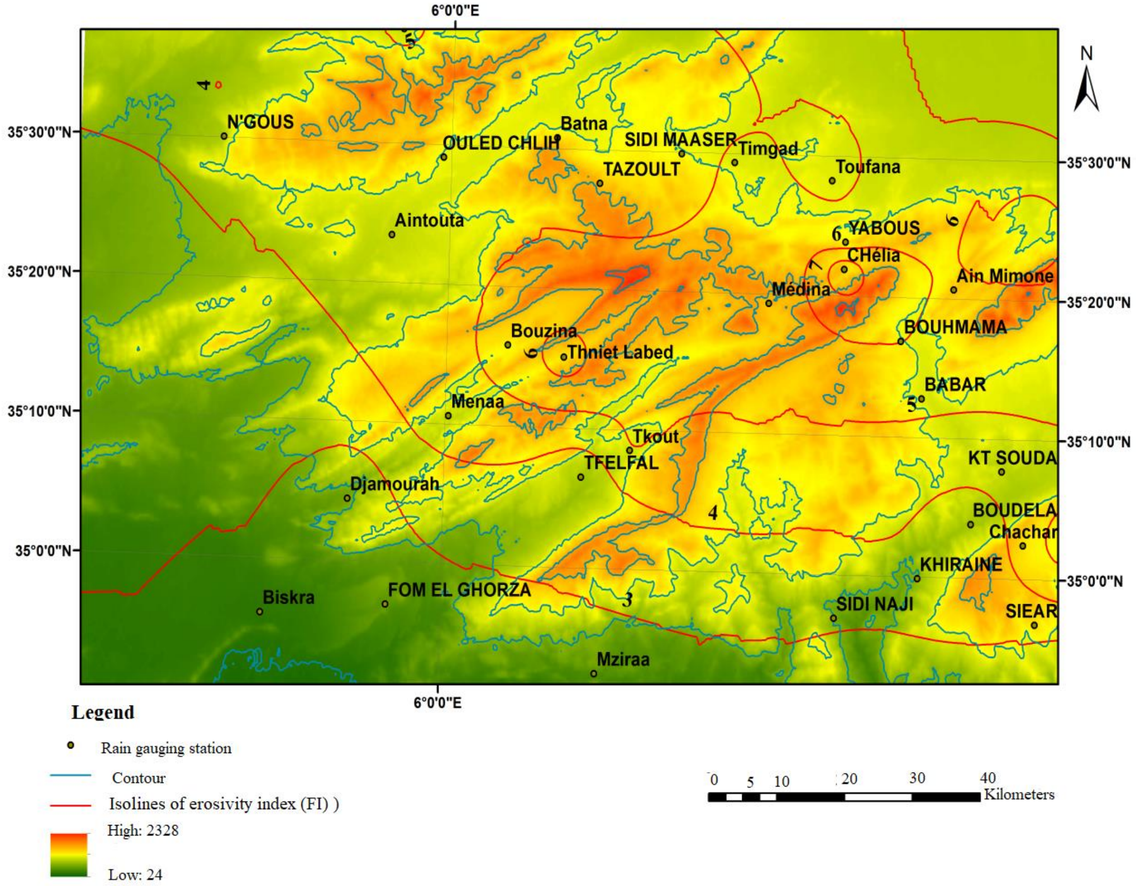

Fig. 5. The spatial distribution of rainfall erosivity index (Fournier index – FI)

Precipitation Concentration Index (PCI)

Arnoldus (1980), Oliver (1980) and Michiels *et al.* (1992) demonstrated that the PCI was appropriate for assessing and comparing rainfall concentration between rainfall stations.

Examination of Table 1 showed two varied classes:

- uniform distribution class includes 25 stations or 73% of the values recorded in the area;
- moderate distribution of precipitation was represented by 9 stations shared between the semi-arid dry and the arid zones with a maximum value of 11.47 to Mziraa.

We conclude the same as several authors that this index expresses the seasonal and annual variability of precipitation (Neira-Mendez *et al.* 2010). Low PCI values indicate a uniform distribution of rainfall across the year, whereas high values represent a high monthly or seasonal concentration of rainfall.

Fournier Erosivity Index (FI)

The obtained values of FI are well represented in Figure 5. It seems that the highest erosivity corresponds to the high altitude, but the south has low values compared to the north and north-west. Generally, erosivity values in the zone remain low and are grouped in category one (1) according to the Fournier classification. The effect of altitude is well explained in some similar and bordering regions in Algeria and Tunisia. In Morocco, for example, it is found that the area of the most erosion-prone areas has almost doubled under the effect of precipitation. These areas are characterised by an accentuated relief (Elbouqdaou *et al.* 2005; Meddi 2014).

The rainfall erosivity index of Arnoldus (FMI)

The studied massif is totally dominated by the first category according to the Arnoldus classification (Fig. 6), that of index values below 60. The difference between FMI calculated for the station of Chelia and Biskra reaches 35 (Tab. 1; Fig. 6). This difference between the values of rainfall erosivity was clearly controlled by the effect of altitude and exposure; this is confirmed by other research (Laibao *et al.* 2010). Meanwhile, the highest values are attributed to the region of the Chelia Mountains, Ain Mimoun and Medina, which have northern exposure. Low rainfall erosivity values were recorded at the stations whose exposure is southern and south-eastern (Biskra, Mzira, Siar, Khanguet Sidi Nadji). The highest values of the erosivity index correspond to high rainfall (Mannaerts, Gabriels 2000). The north and north-eastern stations are characterised by strong precipitation, reflecting a high index value. Figure 7 shows a correlation between the two studied indices. The relationship between the two indices – the Arnoldus index (FMI) and the Fournier index (FI) – is positive and linear (Fig. 7), and it turns out to be very significant.

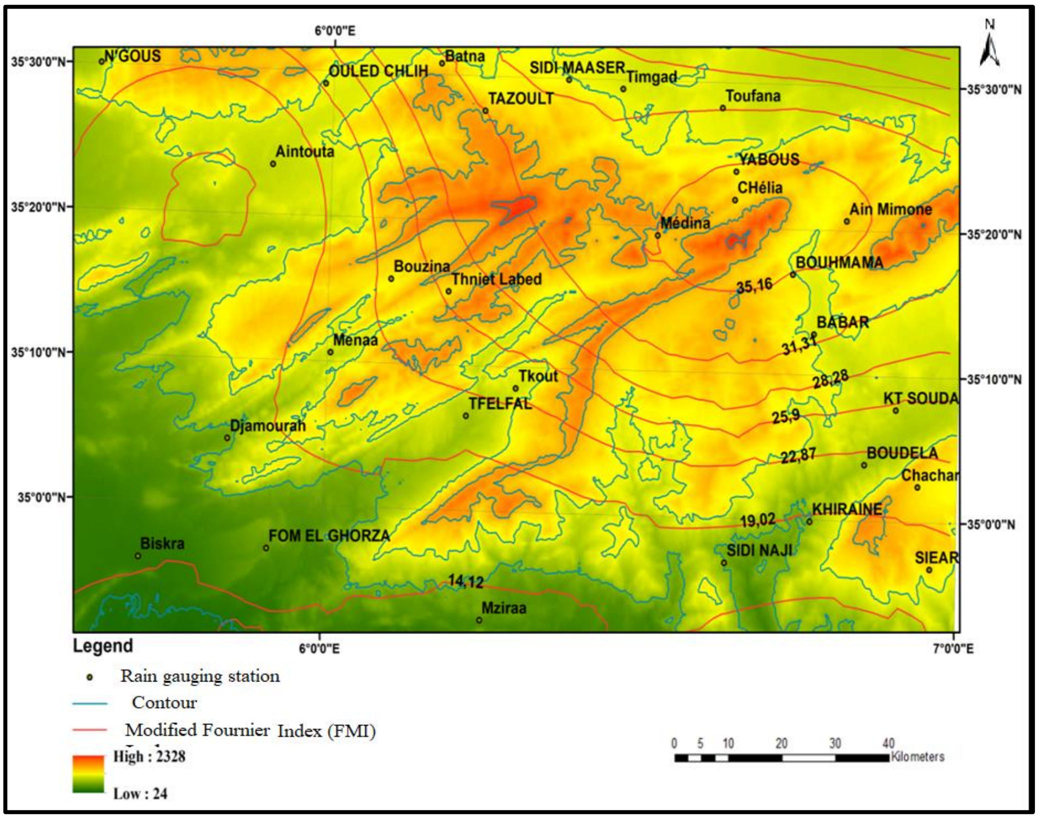

Fig. 6. Isolines of erosivity index of Arnoldus (FMI)

Correlation between FMI and P

The degree of relationship between annual rainfall and annual rainfall erosivity was established using the Pearson's Coefficient of Correlation (r). The calculated Pearson's correlation coefficient value of 0.95 (at 0.01 level of significance) showed a positive degree of relationship between the amount of annual rainfall and the corresponding rainfall erosivity index – r calculated is 0.95 while the value of R taken from the table was 0.435 for a risk of 0.01, so it could be said that calculated r is greater than the theoretical R, which gives this test a good efficiency in the study area. This is the same observation as presented by Kouidri (1993).

Correlation between FMI and FI

At first, we talked about the weak relationship between the Wischmeier index and that of Fournier. It seems logical to look for another correlation between FMI and FI to positively conclude our work (Fig. 7). The regression between the Arnoldus index (FMI and the Fournier index (FI) gives a significant linear correlation coefficient at the 5% threshold and r=0.88.

The regression equation is then written as:

$$FMI = 6.17979\ FI + 0.98 \qquad (4)$$

The point cloud has a regression line form; there is a strong connection between the Arnoldus index and the Fournier index (Fig.7). The intensity and power of this correlation is reinforced by the t-test. We can use this test when the size of the sample is greater than 25 (Ricco 2017).

Table 2

Test z for two independent samples/bilateral test

Difference	21.059
z (observed value)	11.172
|z| (critical value)	1.960
p-value (bilateral)	<0.001
alpha	0.05

The results above are determined according to a confidence interval at 95% around the difference in means from 17.365 to 24.753. The calculated correlation coefficient gave a high value of 0.88, which expresses a strong positive relationship. In the same sense the variable (p-v) calculated using XLSTAT Software equal to 0.001 appears less than 0.05; which confirms a very good power to the proposed model. Since the calculated p-value is below the level of significance alpha=0.05, we must reject the null hypothesis H_0, and retain the alternative hypothesis H_a.

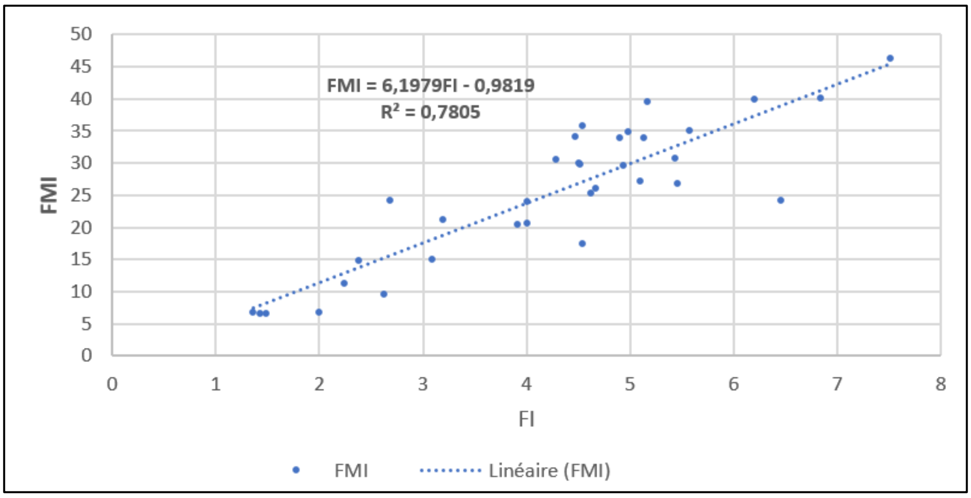

Fig. 7. Correlation between the Arnoldus index (FMI) and the Fournier index (FI)

Discussion

The calculated values of the two indices FMI and FI are similar to those obtained by some authors working on Algeria (Meddi 1992; Lujan *et al.* 2005) ranging on average between 6 and 46 for FMI and 1.36 to 7.51 for FI. According to Remini (2018), water erosion is very active in the catchment of Oued El Abiod ending with the dam of Foum El-Gherza which attests to accelerated siltation. The matter coming from this water erosion increases this siltation, the dam reservoir received a volume of 1 million m^3 of mud brought by the density currents. By 2015, a total of 32 million m^3 had been deposited since 1950, an annual average of 0.50 hm^3 of silt that settles in the basin of the dam.

Northern and north-western exposures present high values of FI and FMI erosivity values, while southern exposure presents low values of erosivity. Rainfall erosivity values are clearly controlled by topography.

The difference between the value of the rainfall erosivity index of the Arnoldus (FMI) recorded at the Chelia station, which is located at an altitude of 1260 m, and that recorded at the Biskra station, which lies at 120 m a.s.l. is of the order of 40. Generally, erosivity values in the zone remain low and are grouped in category one (1) according to the FMI classification. The effect of altitude is well explained in some similar and bordering regions in Algeria and Tunisia. In Morocco, it is found that the area of the most erosion-prone areas has almost doubled under the effect of precipitation, these areas are characterised by an accentuated relief, (Elbouqdaou *et al.* 2005). The altitudinal gradient and its effect on the erosivity and rainfall distribution is mentioned by some authors (Ribeiro *et al.* 1998; Neira-Mendez *et al.* 2010; Meddi 2013).

The calculated values of the precipitation concentration index (PCI) are grouped into two distribution categories – uniform and moderately seasonal – which give the impression of a seasonality effect. The spatial representation of the data obtained will allow for a better understanding of the behaviour of erosivity with respect to topography (Roose 1994). The relationship between the amount of annual precipitation and the corresponding precipitation erosivity index showed that r calculated is 0.95 while the value of R taken from the table was 0.435 for a risk of 0.01. It could thus be said that calculated r is greater than the theoretical R.

Conclusion

The highest rainfall erosivity index values (>30) are recorded at high altitude areas, characterised by heavy rainfall. More than 50% of the total area of the zone is exposed to rainfall of 250 mm to 400 mm.

The classes of medium and high erosivity (20–50) were located particularly in the mountains and piedmonts. Conversely, the lowest erosivity class was found on the plains and the Saharan zone, with Arnoldus index values below 19 and Fournier index values below 4. It can be judged that the results are well justified by solid models and tests and help us to understand the behaviour of erosivity in the massif, and the contribution of other factors such as rain and altitude.

Our results show that the studied area is clearly dominated by a low to medium erosivity, which increase strongly at the highest altitudes, as confirmed by several authors. According to Meddi (2014), the amounts of rainfall in autumn contribute effectively to the erosivity of the rains on the north of Algeria and especially on the mountainous regions.

Land degradation is defined as a process that reduces the productive potential of natural resources (Yjjou 2014). It should also be recognised that, in most arid and semi-arid areas, current agricultural and land-use systems are not sustainable and lack the means to accurately estimate the quantities of soils lost and the areas actually exposed to high soil losses.

Soil erosivity mapping could be one of the most effective tools in soil prediction and prevention (Roose 1994). Soil sustainability is not only based on effective biophysical solutions. Solutions must also be economically viable and socially acceptable. The results obtained in this study, although the values are only relative, are valuable and can serve as a basis to help in the planning of activities for soil conservation and reduced siltation of dams.

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