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Estimation of rainfall erosivity by mapping at the watershed of macta (algeria)

Estimativa da erosividade da chuva por mapeamento na bacia de Macta (Argélia)

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ABSTRACT
Abstract The aim of the present study is to estimate rainfall erosivity in the Macta watershed of western Algeria. Mapping using GIS (geographical information system) allowed better visualization of the erosivity. Five indices of erosivity were tested on a rainfall series of 42 stations over a period of 41 years. The indices used were the Arnoldus index, the Arnoldus modified Fournier index (MFI), the Rango-Arnoldus index, the Leprun index and the Val et al. index. Rainfall of between 300 and 400 mm occurs in 24 stations (57% of the watershed) where the respective values of the Arnoldus, MFI and Rango-Arnoldus erosivity range from 86.54 to 123.93 MJ Mw/ha.year, 47.47 to 75.33 and 16.11 to 36.13, respectively. Monthly rainfall variability has an important role in the concentration of erosivity. Erosion values (MFI) at the watershed range from 19.22 to 126.78, which indicates a low erosivity potential. Rainfall of less than 300 mm recorded in 15 rain gauges (36%) has respective erosivity values ranging from 39.78 MJ Mw / ha.year, 19.22 and 3.34 to 109.73, 50.27 and 17.80. The erosivity index depends not just on the annual rainfall but also on the intra-annual rainfall pattern. The ratio of the MFI index to the Rango-Arnoldus R index will be closer to unity when rainfall is higher. The lower the rainfall, the more the ratio increases in favour of MFI index. The same indices are very close when the annual rainfall reaches and exceeds 500 mm. Our study has shown the importance of inter-annual variability and its influence on rainfall erosivity. The same index of erosivity can have different values for the same amount of annual rainfall, which means that it is the inter-annual variability of rainfall that leads to a high erosivity index. The method of calculating erosivity described by Paez proved effective, as it overcomes the constraint related to the unavailability of rainfall intensity data, especially in semi-arid areas.

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The present study could serve as a strategic support for socio-environmental decisions and could also complement any study, taking into account the different factors of water erosion. Our results can thus be taken as extra support to any study and decision on hydro-environmental development within the Macta watershed.

KEYWORDS: Rainfall erosivity. Erosion. Annual rainfall. Macta

RESUMO

O objetivo do presente estudo é o de estimar a erosividade da chuva na bacia hidrográfica de Macta, no oeste da Argélia. Usou-se o mapeamento por SIG (sistema de informações geográficas) para permitir uma melhor visualização da erosividade. Foram testados cinco índices de erosividade, i.e., índice de Arnoldus, índice de Fournier modificado por Arnoldus (MFI), índice de Rango-Arnoldus, índice de Leprun e índice de Val et al., para uma série de chuvas, registadasem 42 estações, durante um período de 41 anos. A precipitação a variar entre 300 e 400 mm ocorre na maior parte das estações, mais precisamente em 24 (57% da bacia) e os respectivos valores de erosividade de Arnoldus, MFI e erosividade de Rango-Arnoldus oscilam entre 86,54 e 123,93 MJMw/ha.ano , 47,47 e 75,33 e 16,11 a 36,13, respetivamente. A variabilidade mensal da precipitação tem um papel importante na concentração da erosividade. Na bacia hidrográfica, os valores de erosão (MFI) variaram entre 19,22 e 126,78, o que lhe confere um baixo potencial erosivo. Precipitaçõesinferiores a 300 mm, registadas em 15 estações pluviométricas (36%), possuem valores de erosividade que variam,respetivamente, de 39,78MJMw/ha.ano, 19,22 e 3,34 a 109,73MJ Mw/ha.ano, 50,27 e 17,80. O índice de erosividade depende não apenas da precipitação anual, mas também do regime intra-anual da precipitação. Assim, a razão índice MFI/índice Rango-Arnoldus R, estará mais próxima da unidade quando a precipitação aumenta e quanto mais a chuva diminuir, mais a proporção aumenta em favor do índice MFI. Os índices são muito próximos quando a precipitação anual atinge ou excede 500 mm.

Este estudo mostrou o interesse da variabilidade interanual e a sua influência na erosividade pluvial. O mesmo índice de erosividade pode ter valores diferentes, para a mesma quantidade anual de precipitação, pois é a variabilidade interanual da precipitação que induz um alto índice de erosividade. O método de cálculo da erosividade descrito por Paez mostrou-se eficaz, permitindo superar a restrição relacionada com a indisponibilidade de dados de intensidades de precipitação, especialmente em áreas semi-áridas. O estudo pode também servir como suporte estratégico para decisões socioambientais e pode servir como complemento para qualquer estudo, levando em consideração os diferentes fatores de erosão hídrica. Deste modo, os resultados apresentados podem ser considerados como suporte complementar a qualquer estudo e decisão de desenvolvimento hidro-ambiental sobre a bacia hidrográfica da Macta. das presentes instruções é orientar os autores de manuscritos a serem publicados na Revista Brasileira de Cartografia. O Comitê Editorial sugere que o autor faça uma cópia deste arquivo e aproveite a formatação existente. Não ultrapassar 250 palavras. Resumo em Century Schoolbook 10, espaçamento 1, recuo à esquerda de 1,25, recuo à direita de 1,5.

PALAVRAS-CHAVE: Erosividade da chuva. Erosão. Precipitação anual. Macta.

Introduction

With an estimated land loss of 24 million tonnes worldwide, the land degradation process is a global problem (DUBOIS, 2011). The universal soil loss equation (USLE) established by Wischmeier and Smith (1965) enables a quantitative prediction of soil losses caused by water erosion. This method is the most widely used (MILLWARD and MERSEY, 1999; JASROTIA and SINGH, 2006; BONILLA et al., 2010; XAVIER et al., 2016). Soil erosion by rain and runoff water is a widespread phenomenon (BĄK and DĄBKOWSKI, 2013). Rain and runoff water have a major effect on the erosion process, which is represented by the R factor (PETKOVŠEK & MIKOŠ, 2004). This factor is the product of the total rainfall energy and its maximum intensity for 30 minutes (WISCHMEIER and SMITH, 1978). This fact is a limitation due to the lack of data in many regions around the world (PETKOVŠEK and MIKOŠ, 2004), but it has been overcome using other methods involving monthly and annual rainfall data (ARNOLDUS, 1980; OLIVER JE, 1980; LEPRUN, J.C., 1981; VAL et al., 1986; RANGO and ARNOLDUS, 1987; OLIVEIRA et al., 1990; MORAIS et al., 1991; KASSAM et al., 1992; RENARD and FREIMUND, 1994; YU and ROSEWELL, 1996; SILVA, 2001; GRIMM et al., 2003). The modified Fournier index is also used to predict the rainfall erosivity factor (R) (LAL and ELLIOT, 1994). However, some authors have proposed using daily rainfall figures. The study by Santos Laureiro & Azevedo Coutinho (2001) found a significant relationship between the monthly R factor and the total rainfall over a period of 10 days in Algarve (Portugal). In Slovenia, Pintar et al. (1986) recommended using maximum daily rainfall to estimate the erosivity factor.

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The Algerian northwest region has great potential for agricultural production, however, the landforms are mostly slopes affected by high soil degradation (MORSLI et al. 2004). The climate is semi-arid Mediterranean, with an average annual rainfall of about 317 mm, which greatly restricts agricultural development and the management of hydrotechnical structures (MEGHRAOUI et al., 2017).

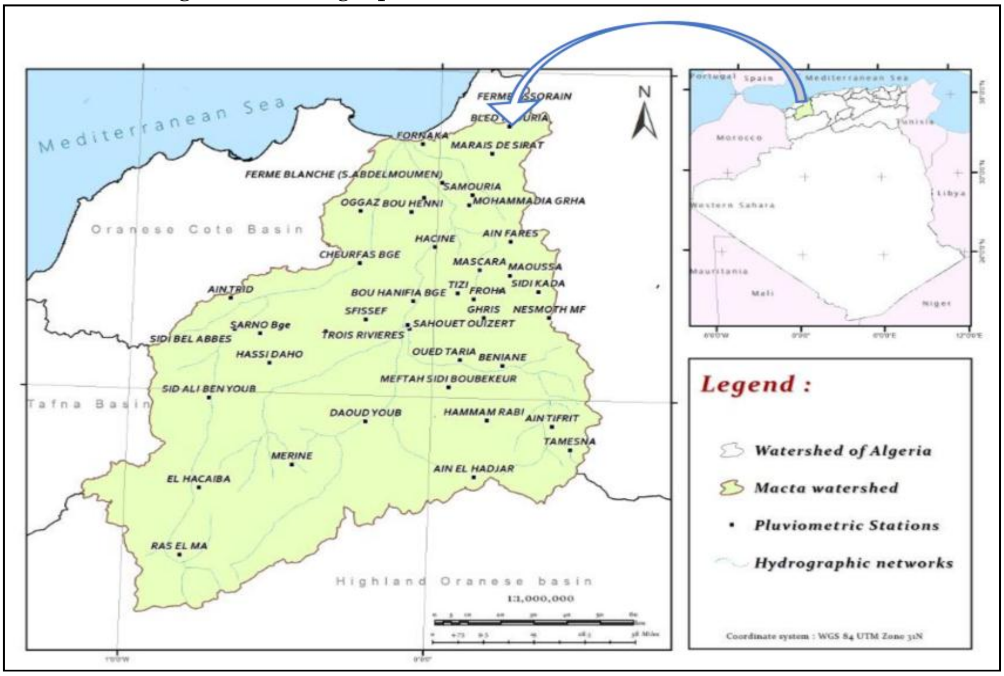
This study set out to evaluate the erosive effect of the rains in northwest Algeria, using different approaches to test and evaluate the methods used to calculate the R factor, before defining the approach most appropriate to the semi-arid Mediterranean climate in northwest Algeria.

1 Materials and methods

1.1 Study zone

The Macta watershed is located in northwest Algeria and it covers an area of 14,390 km2. It has a semiarid climate and an average annual rainfall of 317 mm. From the southwest to the northeast lies the Tessala mountains, the highest peak reaching 1061 m, the Tlemcen mountains with a height of 1412 m and the mountains of Beni Chougrane whose highest point is 932 m (Figure 1) (CHIBANE et al., 2015).

Figure 1 – Geographical location of the studied area



Fonte: Chibane et al. (2015).

1.2 Evaluation of rainfall erosivity (R factor)

a) rain induces erosion. This phenomenon is called erosivity, R, (HUDSON, 1981). It is the average annual erosion index and is calculated using methods requiring only monthly rainfall data. To estimate this factor, three different methods were applied to 42 rain gauges installed around the watershed, over a period of 41 years (1970-2011). The methods applied are:

b) Arnoldus, 1980: the following relationship developed by Wischmeier and Smith (1978) and modified by Arnoldus (1980):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5\log\left(\frac{P_i^2}{P}\right)-0.08188\right)} \quad (\text{MJ mmha}^{-1}\ \text{h}^{-1}\ \text{y}^{-1}) \qquad (1)$$

Where R is the rainfall erosivity factor whose unity is (MJ mm ha^{-1} h^{-1} y^{-1}) (ARNOLDUS, 1980), Pi is the monthly rainfall (mm) and P is the annual rainfall (mm).

c) Rango & Arnoldus Formula (RANGO and ARNOLDUS, 1987):

$$log\, R = 1.74 \times log \sum \left(\frac{{P_i}^2}{P}\right) + 1.29 \qquad (2)$$

Where:

Pi: monthly rainfall

P: annual rainfall in mm.

d) Modified Fournier Index Formula (MFI) (ARNOLDUS, 1980)
The modified Fournier Index (MFI), modified by Arnoldus (1980) from the Fournier (FI) Index, is takenas the result of the total annual precipitation (Pt) and monthly concentration of precipitation (PCI) (MFI = Pt × PCI) (APAYDIN et al., 2006).
This method is tested using the following formula:

$$MFI = \sum\nolimits_{1}^{12} \left(\frac{P_i^2}{P}\right) \qquad (3)$$

e) Formula of Leprun (1981):

$$R = 0.13 \times Mx^{(1.24)} \qquad (4)$$

Where:

Mx: Average monthly precipitation (mm)

f) Formula of Val et al.(1986):

$$R = 12.592 \times (\frac{Mx^2}{P})^{0.6030} \qquad (5)$$

Where:

Mx: average monthly precipitation (mm),

P: annual precipitation (mm).

The results are represented graphically, after interpolation by the Kriging method. The variability of the R factor across the watershed can be described by a semi-variogram model, which is a plot of the structure function that describes the degree of linear association between pairs of values separated by a given distance (NIELSEN and WENDROTH, 2003). Semi-variograms allow the interpolation of values at unmeasured points in the catchment study (LI and HEAP, 2011).

A geostatistical analysis is performed here using a linear model, which provides the best estimate of the goodness of fit index (DRAPER and SMITH, 1998).

The goodness of fit of the model was evaluated by cross validation and its results were satisfactory because the mean error was close to zero and mean squared standardized error was close to 1.

Four maps were developed, the map of distribution of the annual average rainfall and the maps of the rainfall erosivity given by the methods previously mentioned.

We also estimated the energy intensity of the rainfall using the relationship proposed by Paez et al. (1983). They developed a model to determine EI30 for the semi-arid zone (Western Llanos), in the form: $EI30 = -8.27 + 0.65p$

where p is the mean monthly rainfall.

Then we compared the intensity and the different erosivity indices, R Arnoldus, 1980; Rango and Arnoldus, 1987; and the Modified Fournier Index (MFI), calculated on the basis of rain data collected by the Agence Nationale des Ressources Hydrauliques (French National Agency for Hydric Resources - ANRH), and considered to be the most complete rainfall data from the study period (1970-2011) (BESSAKLIA et al., 2018).

2 Materials and methods

2.1 Comparison of theindices

The results were divided into 3 levels; the first corresponds to rainfall of more than 400 mm recorded for 3 stations (7%), with the Arnoldus index ranging from 160.22 to 205.74 MJ Mm/ha.an, Modified Fournier Index (MFI) from 93.06 to 126.78, and the Rango-Arnoldus index from 51.96 to 88.9. The level for rainfall between 300 and 400 mm is the largest part with 24 rain gauges (57%), where the respective erosivity values of the Arnoldus, MFI and Rango-Arnoldus indices range from 92.08 MJ Mw/ha.year, 47.47 and 16.11 to 123.93 MJ Mw/ha.years, 71.21 and 32.61. The lowest rainfall, less than 300 mm, was recorded in 15 rain gauges (36%). The respective index values range from 39.78 MJ Mw/ha/year, 19.22 and 3.34 to 109.73 MJ Mw/ha.year, 50.27 and 17.80 (Table 1). Comparing the 3 methods (Arnoldus, MFI and Rango-Arnoldus) we find the same tendency, where erosivity increases with higher rainfall; nonetheless, the values obtained by the 3 methods are significantly different. To show the impact of the three indices better, the rainfall data and erosivity indices have been divided into 3 categories: the first contains the indices relating to annual rainfall of more than 400 mm; the second corresponds to rainfall ranging from 300 mm to 400 mm; and the last concerns annual rainfall of less than 300 mm, and their linear regression has been tested. We represented the conclusive results as well as the inconclusive ones; the first represent the correlations between the mean annual rainfall and the 3 indices i.e. Arnoldus (formula 1), MFI and Rango-Arnoldus (formula 2). For the case of rainfall above 200 mm, the coefficients of determinations (R2) are 0.8625, 0.9604 and 0.8765 respectively (Figure 2). The correlations between rainfall of more than 300 mm with the MFI and Rango-Arnoldus indices represent the coefficients of determinations (R2), of 0.9379 for MFI, and 0.9584 for the Rango-Arnoldus index (Figure 3). We note that the values of the coefficients of determination are higher for this category of rainfall, and they are lower for rainfall of more than 400 mm. The results we consider inconclusive represent the correlations between the mean annual rainfall and the erosivity indices described by Leprun (1981) and Val et al. (1986), represented by formulas (4) and (5), respectively. The coefficients of determination (R2) are 0.6432 and 0.5767, respectively (Figure 2).

This suggests that the choice of erosivity index depends not just on the annual rainfall but also on the intra-annual rainfall regime. Some authors estimate that the Rango-Arnoldus index (1987) remains very punctual, and that the Arnoldus index (1980) is better adapted to the Mediterranean climate (MAAMAR-KOUADRI et al., 2016; APAYDIN et al, 2006; EL GAROUANI et al., 2008). Our results show that the ratio: MFI index/Rango-Arnoldus index R, will be closer to unity when rainfall increases (Figure 4). The lower the rainfall level, the more the ratio increases in favour of MFI index. The same indices are very close when the annual rainfall reaches and exceeds 500 mm. Then, its efficiency cannot be generalized over the Mediterranean region.

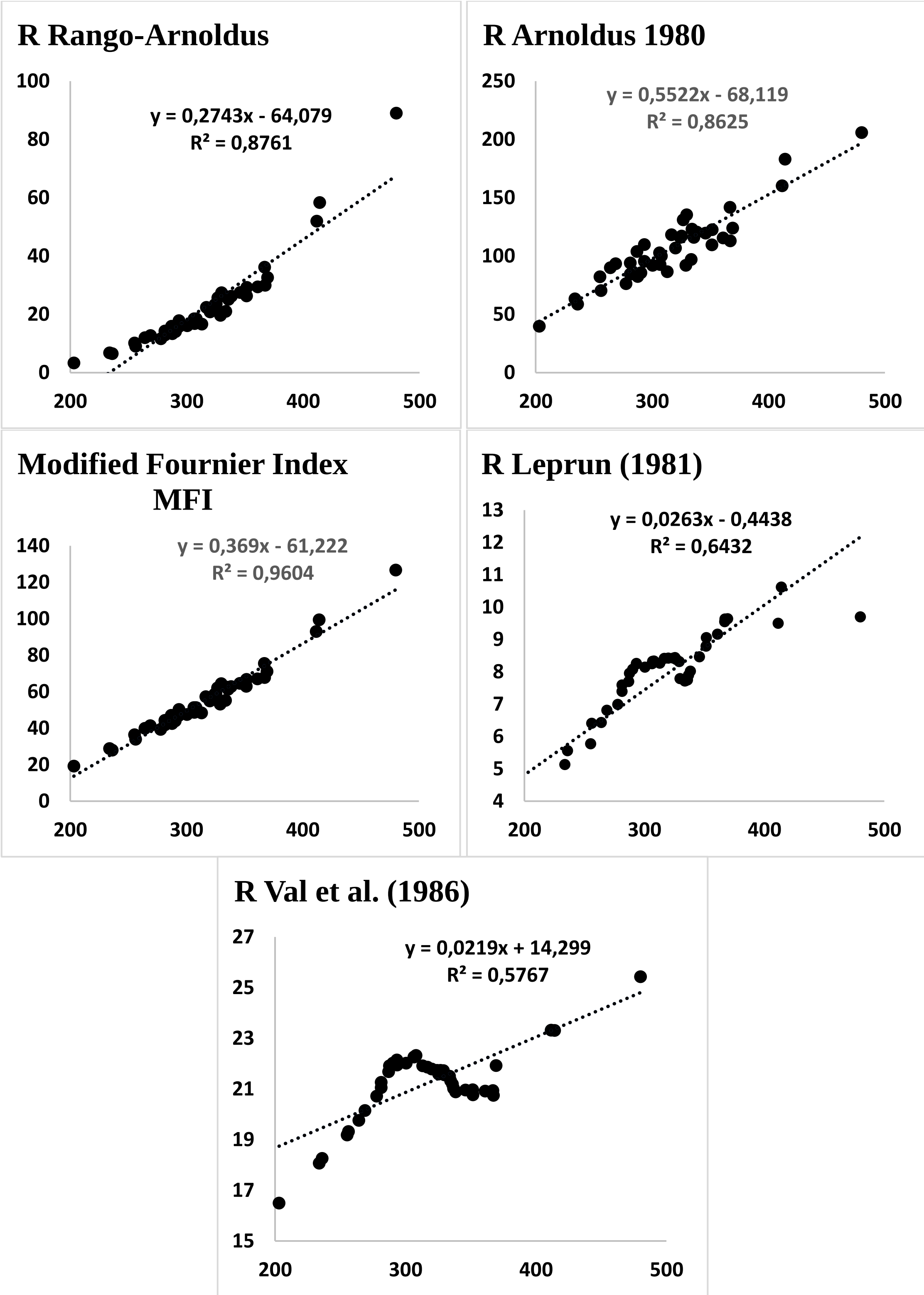
The study by Mazour (1992) reported an MFI index of 39.5 for rainfall of 386 mm, while the results obtained by Maaliou (2010) show the MFI index reaching 113.40 for rainfall ranging from 525.74 to 1061 mm. Our result is quite different, with an MFI index of 126.78 for an average monthly rainfall of 480 mm. This value is the lowest of the results obtained relative to those of other studies. The difference is due to the inter-annual rainfall variability. This index (MFI) would be lower if the inter-annual rainfall were more regular.

Table 1– Erosivity of the rainfall of the 3 indices

Station number	Station Name	Rain (mm) 1970-2011	R Arnoldus 1980	MFI	R Rango-Arnoldus
1	RAS EL MA	203.08	39.78	19.22	3.34
28	TROIS RIVIERES	233.79	63.3	28.81	6.76
11	DAOUD YOUB	235.99	58.56	28.06	6.45
35	BOU HENNI	255.2	82.11	36.49	10.19
33	SAHOUET OUIZERT	256.12	70.3	34.04	9.03
34	OGGAZ	264.17	89.88	39.97	11.94
36	FORNAKA	268.8	93.35	41.47	12.73
14	HAMMAM RABI	277.74	76.18	39.38	11.63
29	BOU HANIFIA BGE	281.29	84.38	41.83	12.92
37	SAMOURIA	281.32	94.04	44.32	14.29
38	MOCTA DOUZ	286.91	103.95	47.05	15.86
15	OUED TARIA	287.61	82.47	42.59	13.34
12	MEFTAH S.B.	290.33	85.53	43.98	14.1
20	FROHA	293.39	95.3	46.91	15.77
41	MARAIS DE SIRAT	293.41	109.73	50.27	17.8
21	MATEMORE	300.45	92.08	47.47	16.11
39	FERME BLANCHE	306.41	102.73	51.29	18.43
26	GHRIS	306.84	92.76	48.64	16.8
23	MAOUSSA	308.05	100	51.26	18.41
3	EL HACAIBA	312.98	86.54	48.37	16.64
32	MOHAMMADIA GRHA	316.74	118.29	57.37	22.39
18	BENIANE	320.04	106.91	55	20.81
31	HACINE	324.12	115.89	58.66	23.27
9	CHEURFAS BGE	325.4	117.07	59.12	23.6
40	BLED TAOUHRIA	326.67	131	62.1	25.7
10	MERINE	329.06	91.95	53.22	19.65
19	FERME ASSORAIN	329.8	135.27	64.45	27.42
17	TAMESNA	333.61	97.04	55.23	20.96
7	MOSTEFA BEN BRAHIM	334.39	123.06	62.6	26.06
6	HASSI DAHO	335.91	116.04	61.33	25.15
5	SIDI BEL ABBES	336.8	119.8	62.43	25.94
30	SFISSEF	338.38	120.48	62.78	26.2
27	MASCARA	345.89	119.53	64.59	27.52
13	AIN EL HADJAR	351.39	109.54	62.96	26.33
22	TIZI	351.62	122.59	66.82	29.19
2	SID ALI BEN YOUB	361	115.59	67.04	29.36
4	SARNO BGE	366.94	141.65	75.53	36.13
16	AIN TIFRIT	367.23	113.07	67.86	29.99
25	SIDI KADA	369.33	123.93	71.21	32.61
24	AIN FARES	411.64	160.22	93.06	51.96
8	AIN TRID	414.21	182.96	99.49	58.36
42	NESMOTH MF	480	205.74	126.8	88.98

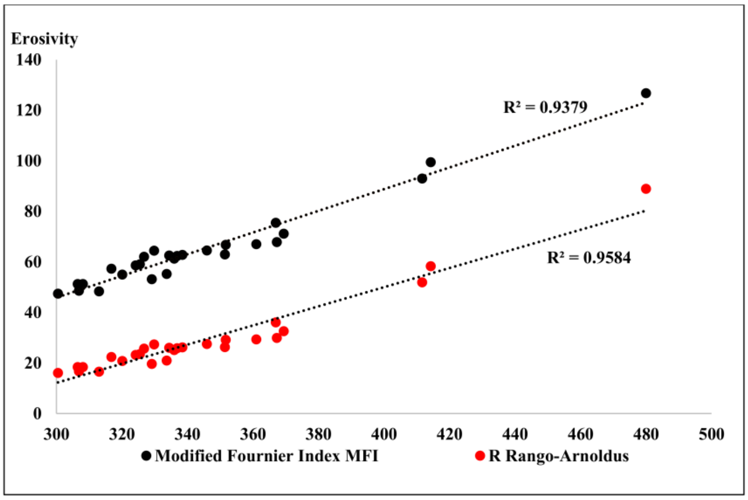
Source: prepared by the authors

Figure 2 – Coefficient of determination between rainfall erosivity indices for annual rainfall of more than 200 mm.



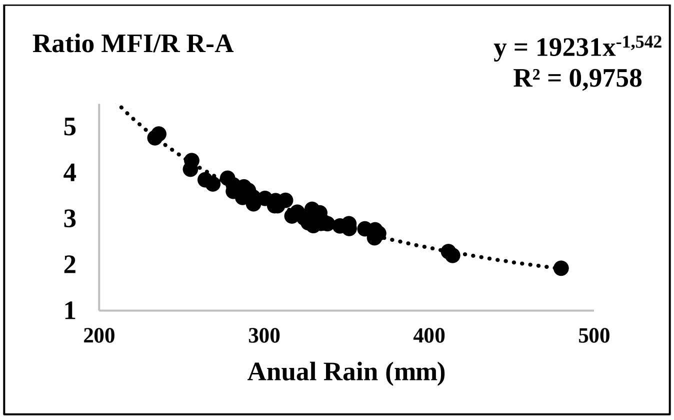
Source: prepared by the authors

Figure 3 – Coefficient of determination between rainfall erosivity indices for annual rainfall of more than 300 mm: example of formula (3) Modified Fournier Index MFI (in black), and example of formula (2) Rango Arnoldus (in red)



Source: prepared by the authors

Figure 4 – Ratio: Modified Fournier Index (MFI)/Rango-Arnoldus Erosivity Index



Source: prepared by the authors

2.2 Mapping of the results: rainfall and erosivity indices

No The maps of mean annual rainfall and rainfall erosion indices shown in Figures (5, 6, 7 and 8) were drawn according to Arnoldus (1980), Arnoldus Modified Fournier (1980) (MFI), and Rango-Arnoldus index (1987) were interpolated using a deterministic method (inverse square distance) and the geostatistical method ordinary kriging (HUBERT and TOMA, 1996). This last accounts for local variations of the mean by limiting its domain of stationarity to a local neighbourhood (TEWOLDE et al., 2010). Here, we considered an isotropic linear model, with the range parameter equal to 0.57 km and the sill parameter equal to 24.21 for the case of average annual rainfall. Similarly, we have interpolated the rainfall erosivity parameters (R Arnoldus 1980 ; MFI and Rango Arnoldus 1987). The rainfall map in Figure 5 shows two increasing gradients, from the centre eastward and from the centre to the southwest. The central part (Hacine rain gauge) is the lowest and the furthest point from the Mediterranean Sea of the watershed (145 m above sea level).

The rainfall within the watershed ranges from 203 mm to 480 mm but does not exceed 367.1 mm for the major part of the watershed area. The highest values are recorded for the east and the southwest of the watershed at the rain gauges of Nesmouth and Ain Trid, with 480 mm and 414 mm respectively.

The interpolated maps of the erosivity indices show similar results for a geographical consideration, the classes with the highest values of erosivity according to MFI and Rango-Arnoldus ranging from 73.38 and 39.15 to 101.69 to 60.13; these are recorded in the east and the southwest of the watershed, at the rain gauges of Ain Fares and Nesmouth on the eastern side, at altitudes of 806 m and 930 m, respectively. And the rain gauges at Sid Ali Ben Youb and Ain on the southwest, at altitudes of 635 m and 530 m, respectively. Similar results were obtained by Elbouqdaoui et al. (2005) for the watershed of Oued Srou in Morocco, where the average rainfall is close to our study case and the values of erosivity are relatively low.

According to the classification of Giordano (1992) (Table 2), based on the Modified Fournier Index MFI (ARNOLDUS 1980), the spatial distribution of erosivity is considered low, with respect to the surface of the watershed, which confirms the result reported by Maamar (2016), distributed as follows:

- 7% of the surface is subject to medium to high erosivity;

- 93% of the surface is subject to very low to low erosivity.

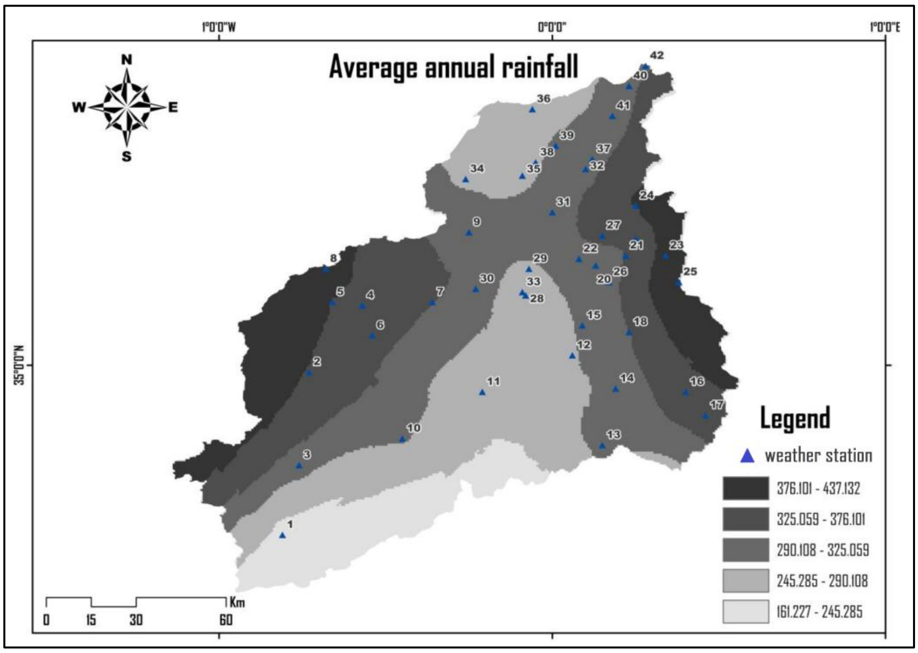
The phenomenon of land erosion at the watershed is confirmed in the study by Gliz (2015), the weak erosivity of the rainfall at the watershed confirms that the causes of erosion are related to the lithological texture, soil occupation and topographic factors (GLIZ, 2015).

Table 2 – Classification of erosivity (giordano, 1992)

Classe description	MFI
Very weak	Below60
Low	60-90
Average	90-120
High	120-160
Very high	Above160

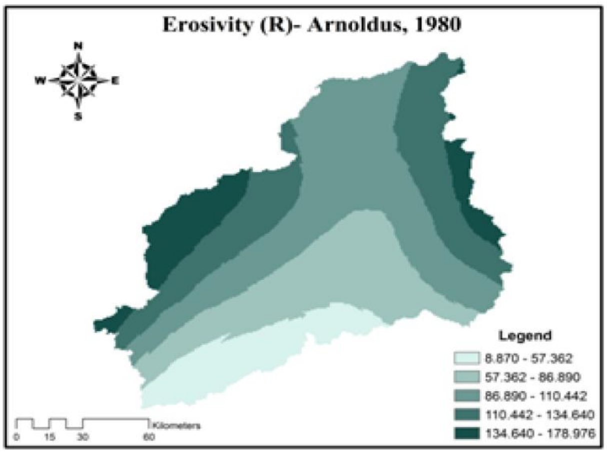
Source: prepared by the authors

Figure 5 – Average annual rainfall 1970-2011



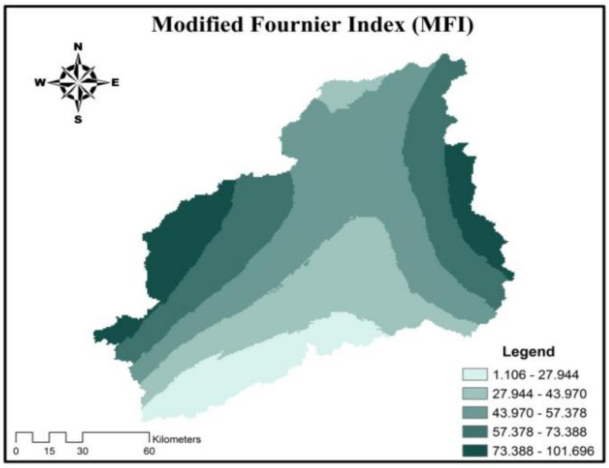
Source: prepared by the authors

Figure 6 – Erosivity R-Arnoldus



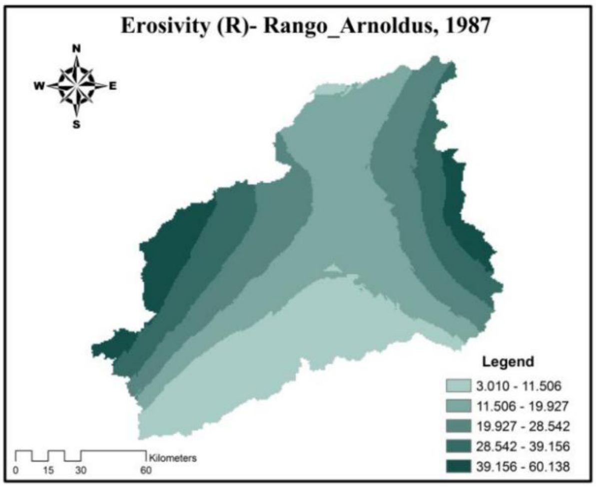
Source: prepared by the authors

Figure 7 – Modified Fournier Index (MFI)



Source: prepared by the authors

Figure 8 – Erosivity (R)-Rango_Arnoldus



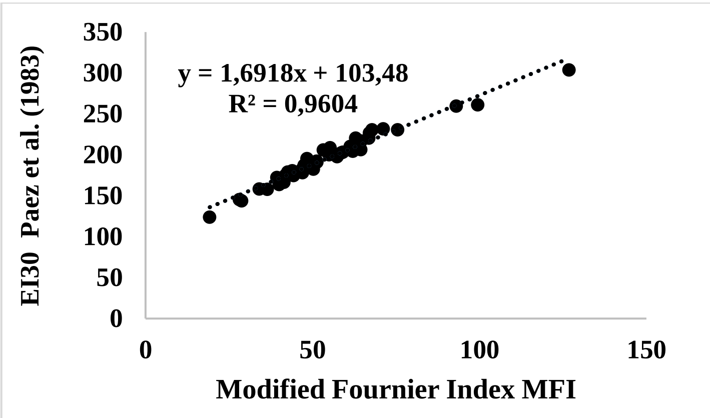
Source: prepared by the authors

Paez et al., (1983) found a linear relationship between the MFI and R=E130 for estimating rainfall erosivity in the study area, using rainfall characteristics that are easier to determine than those required for the USLE R-factor. This relationship was tested efficiently in our study area, as shown in figure 9.

According to Paez et al. (1983), the regression between the MFI and the rainfall intensity EI30 gives a significant linear correlation coefficient (R2 = 0.9604). The regression equation is then written as follows: EI30 = 1.6918 MFI + 103.48.

All the points plotted in figure 9 are very close to the regression line (linear relationship). This means that there is a strong link between the two indices, implying an increasing linear functional relationship. The higher the values of the MFI, the more the rainfall intensity values rise linearly.

Figure 9 – Coefficient of determination between EI30 and the MFI



Source: prepared by the authors

3 Conclusion

A comparison of the three indices of rainfall erosivity, i.e. Arnoldus, Fournier modified by Arnoldus and Rango-Arnoldus, were found to have a positive tendency according to the amount of annual rainfall pouring into the Macta watershed. The highest values are recorded for the rain gauges at Ain

Fares, Nesmouth, Sid Ali Ben Youb and Ain Trid, with rainfall values between 414 and 480 mm, and MFI values ranging from 19.22 to 126.78. Nevertheless, our results have shown the importance of inter-annual variability and its influence on rainfall erosivity. The same index of erosivity can have different values for the same annual rainfall amount, and it is the inter-annual variability of rainfall which induces a high erosivity index.

Areas with high rainfall erosivity at the watershed may be subject to specific planning. The present study could serve as a strategic support for socio-environmental decisions and may also serve as an extra support for any study taking the different factors of hydric erosion into consideration.

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