SCIENTIFIC CONTRIBUTIONS IN ORDER TO CALCULATE RAINFALL EROSIVITY FACTOR (R) FROM REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE) FOR VALEA TATA WATERSHED, DAMBOVITA COUNTY, ROMANIA

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Abstract

The research studies on the occurrence of complex soil erosion phenomena in the hydrographic basin of the Valea Tata stream, a right bank tributary of the Ialomita river, were carried out in the period 2017-2021 and aimed to quantify the amount of soil that is lost annually from the surface of the analyzed watershed. The main objective of this study was to calculate the rainfall erosivity factor (R) included in the Revised Universal Soil Erosion Equation (RUSLE) based on the records made in the period 2017-2021 on the experimental field as well as the data recorded at the climate monitoring stations in the proximity of the watershed for a period of 30 years for the calculation of soil loss from the Valea Tata watershed depending on the rain aggressiveness. The average value obtained for the Moroeni climate monitoring station was 289.54 MJ mm ha^{-1} h^{-1} $year^{-1}$ with a minimum value of 83.20 MJ mm ha^{-1} h^{-1} $year^{-1}$ and a maximum value of 964.06 MJ mm ha^{-1} h^{-1} $year^{-1}$ while for Fieni climate monitoring station the values obtained were between 60.99 MJ mm ha^{-1} h^{-1} $year^{-1}$ and 537.22 MJ mm ha^{-1} h^{-1} $year^{-1}$ with an average value of 193.38 MJ mm ha^{-1} h^{-1} $year^{-1}$. For the experimental field, where the rainfall data, rain intensity and duration of the erosive events were more complex, the results obtained for the erosivity factor (R) has values between 149.50 MJ mm ha^{-1} h^{-1} $year^{-1}$ and 800.80 MJ mm ha^{-1} h^{-1} $year^{-1}$ with an average value of 284.91 MJ mm ha^{-1} h^{-1} $year^{-1}$.

Key words: R-factor, experimental parcels, RUSLE, ROMSEM, GIS

On a planetary scale, large areas of land are affected by the phenomenon of soil erosion and phenomena related to the processes of siltation of dams located downstream of torrential watersheds. A recent report issued by IPCC (Intergovernmental Panel on Climate Change) highlights the increasingly pronounced degradation of soils worldwide as a result of the acceleration of soil erosion phenomena and the loss of organic carbon from the topsoil layer (Shukla P.R. *et al*, 2019).

Rising temperatures combined with the change in precipitation characteristics (duration, intensity, frequency, quantity) but also their intensification will probably be the triggering factors of this complex soil degradation process (Prein D. *et al*, 2017). Despite the fact that in the last decade the erosion phenomena experienced a progressive acceleration due to climate changes, in Romania there are very few studies carried out to quantify the erosion rates and highlight the spatial dynamics of the erosion-sedimentation processes at the scale of a hydrographic sub-basin. Therefore, in this work we propose to analyze the runoff and dynamics of erosion processes with the help of experimental plots located in a hydrographic basin strongly affected by surface and depth erosion phenomena considering the intensification of the phenomenon due to the increase in intensity of the triggering factors.

Currently, there are a multitude of models that can be applied to estimate the potential or effective soil erosion both at the local and regional or continental level. In order to choose a certain mathematical model, we must know with certainty the purpose of the study, the availability of the data to be entered, but also the precision of the results to be obtained. Due to lack or insufficient experimental data, the calibration and validation of models applied to a study area becomes a difficult step to achieve. The factors included in the calculation equation for estimating the amount of eroded soil have different names depending on the model adopted, they have undergone changes and revisions starting from the universal soil loss

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equation (USLE) and numerous studies and research have been carried out to calibrate these factors but also to be adapted to environmental conditions in different areas of the world.

The R factor or the rainfall erosivity factor included in the universal soil erosion equation represents a variable that measures the erosive force of the amount of precipitation, which depends on the intensity and duration of the rain and which can be determined (estimated) starting from the average annual precipitation, monthly maxima, daily maxima or hourly maxima based on statistical relationships, for a study area only if there are hydro-meteorological records.

Determining this factor is quite difficult because it is not usually recorded by weather stations and therefore it can be calculated with maximum accuracy only experimentally by setting up standard plots to control runoff. There is also the possibility, where the density of climate observations is relatively low, to apply linear interpolation equations (which generate isoerodent maps whose lines join points with similar erosive intensity) or regression equations. In Romania, the R factor from the universal soil loss equation (USLE) is called K factor when the ROMSEM equation is applied to calculate the amount of soil loss. It is expressed differently and represents the annual soil losses depending on the rainfall intensity (ICPA 1987). The objective of this study is to calculate with as high a precision as possible the erosivity factor R for each month/year/rainfall event for the entire period taken into account at the two monitoring stations (Moroeni and Fieni) but also to apply a regression equation for the monitoring station located within the experimental plots where we have a relatively low monitoring period *(2017-2021-figure 3)*.

MATERIAL AND METHOD

The studied area is located in Dambovita County, Romania, being bounded to the North by Magura Mountain (1439.43 m), to the West by Plaiul Stubeiu with Stubeiu Peak (1168.06 m), to the South by the Ialomita River near the village of Dealu Mare and to the East by the village of Pietrosita. The area of the Valea Tata watershed (Dealu Frumos) is 1615 Ha. *(figure 1)*.

From a hydrographic point of view, the Valea Tata river is part of the Ialomita hydrographic basin, which is 417 km long, with an area of 10.350 km^2 (4.4% of the country's surface) and is a component of the Buzau-Ialomita hydrographic area, which has a reception area of 23874 km^2.

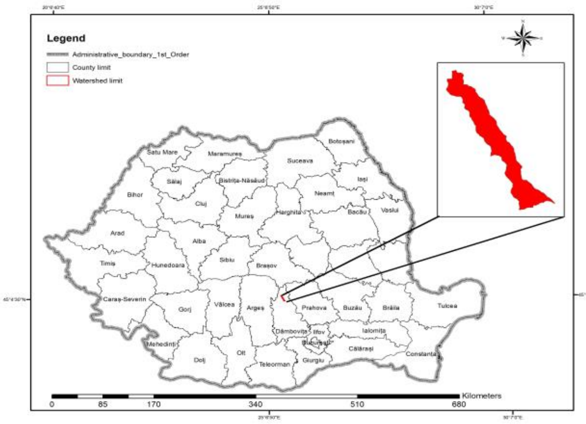

Figure1 **Study area map**

The average annual precipitation value for the studied watershed is 800.1 mm and the average minimum and maximum values recorded annually are 434.8 mm and 1459.7 mm, respectively. The highest amount of precipitation is usually recorded in June (eg. 272.5 mm - 2010). The number of days in which precipitation over 25 mm is recorded is over 30 days/year.

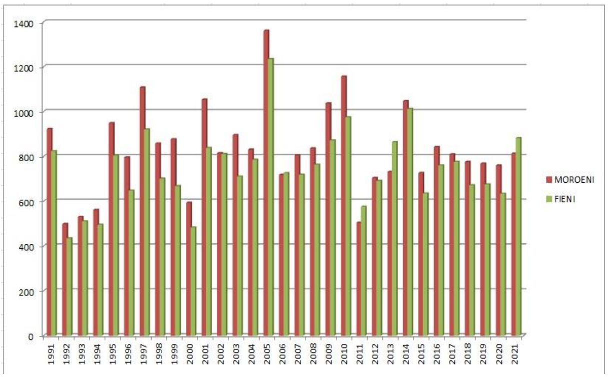

Figure 2 **Annual precipitation 1991-2021 Moroeni, Fieni**

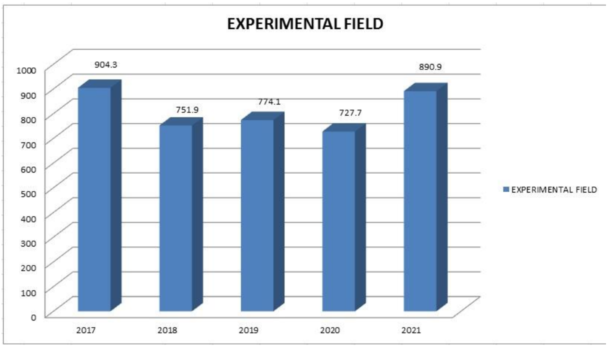

Figure 3 **Annual precipitation 2017-2021 Experimental field**

Precipitation data were collected in the period 2017-2021 together with the records from two climate monitoring stations located in the vicinity of the study area, namely Fieni monitoring station and the Moroeni monitoring station *(figure 4).*

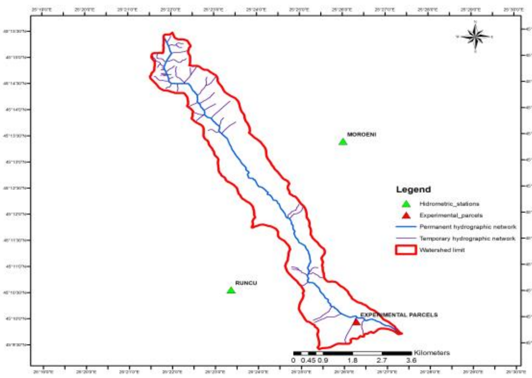

Figure 4 **Distribution of precipitation monitoring stations**

For the Moroeni and Fieni stations the data sets are between 1991 and 2021, while for the experimental field the data set is between 2017 and 2021 *(figure 2 and 3)*. In the mentioned periods, the average annual number of erosive events at the Moroeni station is 19.3, at the Fieni station it is 17.3, and at the experimental field site it is 20.4 *(table 1).* A slight increase in the number of erosive events can be observed at the Moroeni monitoring station compared to the monitoring stations in the southern part generated by the higher amounts of recorded precipitation and the increase in altitude.

The first step in order to calculate the rainfall erosivity factor (R) included in the Revised Universal Soil Erosion Equation (RUSLE) for the study area was to separate the precipitation events from the long series of records from the 3 monitoring points according to certain well-defined criteria and certain:

(i) Solid precipitation in the form of snow from November to March and those below 12.7 mm (0.5 in.) were omitted;

(ii) Also for the calculation of the erosivity factor, a time interval of 6 hours or more, with less than 1.3 mm (0.0 in.) amount of precipitation is considered a break between events;

(iii) The latter were taken into account for the calculation of the erosivity factor only if the intensity exceeded the value of 24 mm h^{-1} or 6.25 mm (0.25 in.) in 15 minutes (Wischmeier and Smith, 1978; Renard et al, 1997; Panagos et al, 2015)-only for the monitoring station located within the experimental field.

After the data were selected according to the previously defined criteria, the following stages were completed:

- The R factor was calculated for each monitoring station;
- For the monitoring station located within the experimental field, a regression equation was applied to estimate the distribution of precipitation erosivity for the years where there are no records (1991-2016);
- The average values of the R factor at the 3 monitoring stations were interpolated using the IDW (Inverse Distance Weighted) method in the ArcMap program to obtain the values for the studied watershed.

After applying a linear power function (R^2=0.619), we performed the correlation between the amount of precipitation during the warm season (April-October) and the annual amount of precipitation for each monitoring station *(Figure 5, 6 and 7)*.

Following the analysis of the precipitation data at the 3 monitoring stations, we can make the following statements:

- at the Moroeni monitoring station, the precipitation in the warm season (April-October) represents between 61.15% and 94% of the amount of annual precipitation;

- at the Fieni monitoring station, the precipitation in the warm season (April-October) represents between 53.7% and 91.4% of the amount of annual precipitation;

- at the monitoring station located within the experimental field, the precipitation in the warm season (April-October), during the 5 years of monitoring, represents between 65.4% and 77.4% of the amount of annual precipitation.

Tabel 1

Characteristics of the monitoring stations

No.	**Name**	**Years**	**X**	**Y**	**Z**	**Total of erosive events**	**Average annual erosive events**
1	Moroeni	30	45°13'19.78"N	25°25'51.50"E	578.10	579	19.3
2	Fieni	30	45°8'15.16"N	25°26'2.10"E	477.42	518	17.3
3	Experimental field	5	45°10'3"N	25°26'19"E	560.00	102	20.4

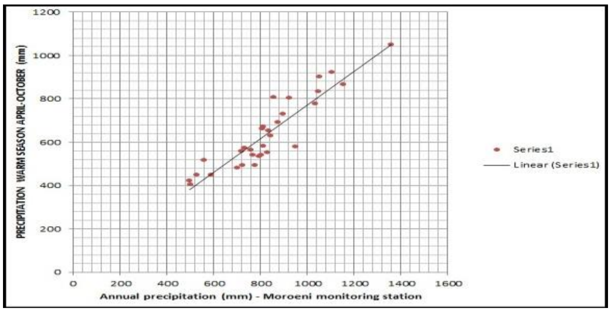

Figure 5 **Spatial correlation of the amount of precipitation during the warm season (April-October) at the Moroeni monitoring station**

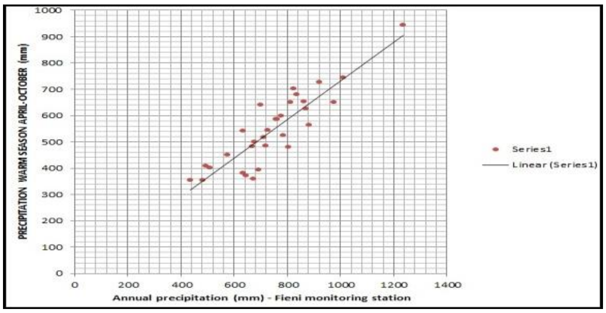

Figure 6 **Spatial correlation of the amount of precipitation during the warm season (April-October) at the Fieni monitoring station**

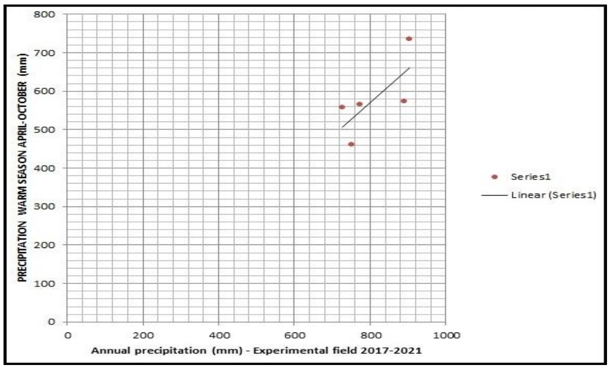

Figure 7 **Spatial correlation of the amount of precipitation during the warm season (April-October) at the monitoring station within the experimental field**

In order to estimate the R factor, depending on the applied model (USLE/RUSLE/ROMSEM) and the area for which it is applied, indirect methods have been developed based on a series of statistical relationships between this factor and other factors such as (the average amount of precipitation for the warm season, the average of annual precipitation, the maximum amount of daily or hourly precipitation, coefficients applied to meteorological stations, etc. - *Table 2*). For Romania, the rainfall erosivity is expressed differently and represents the product between the total amount of precipitation that fell during a rain (mm) and the intensity of the torrential core with a duration of 15 minutes (mm/min) -H*I15 (Sevastel M., 2008).

In most of the studies carried out in Romania, the value of this factor varies from 0.064 for the Western Plain, 0.144 for the Curvature Subcarpathians to 0.207 for the Southern Carpathians and is extracted from the rainfall erosivity zoning map made by Mircea Motoc *et al* in 1975 *(figure 8)*.

Considering the current climate changes and pessimistic predictions regarding the increase in intensity, frequency and magnitude of climate phenomena in the next 30-50 years for Europe (Panagos G *et al*, 2017a), Central Asia (Dulatov *et al*, 2019), Turkey (Kilic and Gunal, 2021) but also for other areas of the world, it is absolutely necessary to update the existing data on the erosivity generated by precipitation in order to have a clear picture of the risk generated by these changes.

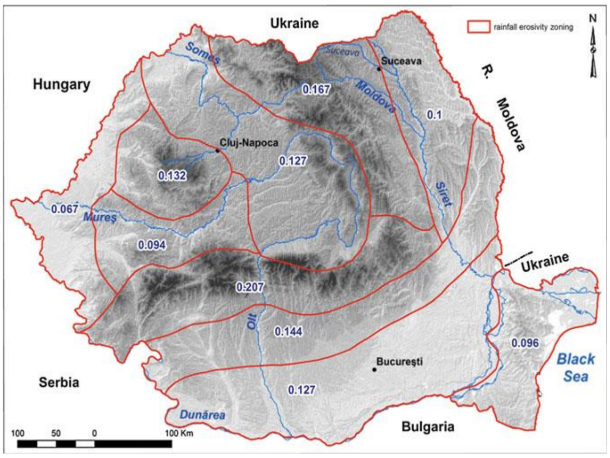

Figure 8 **Rainfall erosivity zoning for Romania (reproduced by C.V Patriche 2017 from ICPA 1987)**

Within the RUSLE model (Revised Universal Soil Loss Equation), the average annual erosivity factor (R) is mathematically calculated according to the following formula (Brown and Foster, 1987; Renard et al, 1997):

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m_j}(EI_{30})\,k\right]j$$

Table 2

Methods for estimating the erosivity factor depending on the applied model (USLE/RUSLE/ROMSEM) - according to M. Radoane & A.V Stroe, 2017

No.	Autor\Region	Formula
1	Rogler and Schwertmann (1981)\Bavaria(Germany)	$R = 10 (-1.48 + 1.48 N_s)$ N_s—mean precipitation amount (mm) of warm season (May–October)

2	Zanchi (cited by Van der Knijff et al 2000)\ Toscana (Italy)	R = a P_{year} P_{year}—mean annual precipitations (mm) a—coefficient ranging from 1.1 to 1.5
3	Diodato (2004)\Italy (Mediterranean area)	$EI_{30} = 12.142\ (abc)^{0.6446}$ a, b and c—mean annual precipitations, annual maximum daily precipitation and annual maximum hourly precipitation
4	Rousseva and Stefanova (2006)\Bulgaria	$EI30 = a\ (nP)^{1.81}$ P—mean erosive rainfall for a certain meteorological station a—meteorological station specific coefficient n—mean annual number of erosive rainfalls
5	Renard and Freimund (1994)\SUA	$R = (0.07397\ F^{1.847})/17.2$, for F < 55 mm $R = (95.77 - 6.081\ F + 0.477\ F^2)/17.2$, for F≥ 55 mm F—Fournier coefficient (Arnoldus 1980), derived from mean monthly precipitations (pi): $Fi = pi^2/\sum pi/12)$

where, E is the total storm kinetic energy (MJ ha^{-1}), I30 represents the maximum intensity of an erosive event measured for 30 minutes (mm h^{-1}), n is the number of years taken into account, m the number of erosive events in each year, j is an index of the number of years used to calculate the average value, k is an index of the number of erosive events in a year. EI30 (MJ mm ha^{-1} h^{-1}), the erosivity index for an event is calculated according to the formula:

$$EI_{30} = \left(\sum_{r=1}^{0} e_r v_r\right) I_{30}$$

where, er and vr represent the energy of precipitation units (MJ ha^{-1} mm^{-1}) and the volume of precipitation (mm) for a time period r, I30 represents the maximum intensity of precipitation measured over a period of 30 min within an event (mm h^{-1}). Rainfall energy per unit depth of rainfall *(e_r)*, is calculated using the relation (Brown and Foster, 1987):

$$e_r = 0{,}29[1 - 0{,}72exp(-0{,}051 i_r)]$$

where, er represents the kinetic energy expressed in megajoules per hectare per millimeter of rain (MJ ha^{-1} mm^{-1}) and ir represents the intensity expressed in mm h^{-1}.

The intensity for each rainfall event and the amount of precipitation that fell at that intensity can be calculated from the existing records at the monitoring stations. The intensity of precipitation is expressed in millimeters per hour (mm h^{-1}) and is calculated according to the formula:

$$i_r = \frac{\Delta v_r}{\Delta t_r}$$

where, Δt_r is the duration of the increase in which the rain intensity is considered to be constant in hours (h) and is the depth of the rain (mm) during the respective increase şi Δv_r is the depth of the rain (mm) during the respective increase. For the monitoring station located within the experimental field, it was possible to calculate the erosivity factor using the relationships in the RUSLE equation because data on the intensity and duration of precipitation were recorded.

Considering the fact that for the 2 monitoring stations Moroeni and Fieni there is daily data on the amount of precipitation over a period of 30 years, but there is no data on the intensity and duration of precipitation, the erosivity factor could not be calculated using the formula of calculation suggested within the RUSLE model, but a formula based on the Fourier index was used (Arnoulds, 1960). The Fourier index is calculated according to the formula:

$$FI = \frac{p^2 max}{p}$$

where p_{max} is the average monthly rainfall for the month with the highest rainfall and *P* the average annual precipitation (mm).

Arnoulds (1977) modified the Fourier index *(MFI)* as follows:

$$MFI = \sum_{i=1}^{12} \frac{p_i^2}{P}$$

where p_i represents the average monthly rainfall and *P* the annual rainfall.

RESULTS AND DISCUSSIONS

The change in climate conditions for the area under study led to obtaining results that vary within quite wide limits, especially depending on the altitude. Thus, at the Moroeni and Fieni monitoring stations, after applying the Modified Fourier Index *(MFI)* values between 51.1 and 192.39 were obtained with an average value of 94.45 and a standard deviation of 27.47 and for the monitoring station located within the experimental field values between 78.70 and 175.83 were recorded with an average value of 104.51 and a standard deviation of 21.95.

The average values of the *MFI* index and R factor at the 3 monitoring stations were interpolated using the IDW (Inverse Distance Weighted) method in the ArcMap program to obtain the average values for the studied watershed *(figure 9 and 10).*

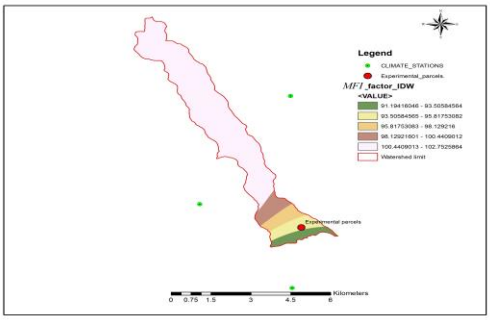

Figure 9 MFI index

The average value of the erosivity factor for the hydrographic basin studied calculated at the Moroeni monitoring station was 289.54 MJ mm ha^{-1} h^{-1} year^{-1} with a minimum value of 83.20 MJ mm ha^{-1} h^{-1} year^{-1} and a maximum value of 964.06 MJ mm ha^{-1} h^{-1} year^{-1} while for Fieni climate monitoring station the values obtained were between 60.99 MJ mm ha^{-1} h^{-1} year^{-1} and 537.22 MJ mm ha^{-1} h^{-1} year^{-1} with an average value of 193.38 MJ mm ha^{-1} h^{-1} year^{-1}.

For the experimental field, where the data related to the amount of precipitation, intensity, duration of erosive events were more complex, the results obtained for the erosivity factor had values between 149.50 MJ mm ha^{-1} h^{-1} year^{-1} and 800.80 MJ mm ha^{-1} h^{-1} year^{-1}.

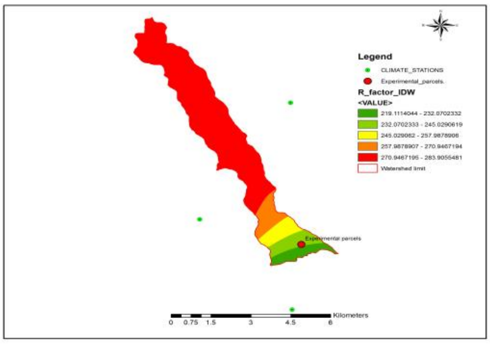

Figure 10 **R factor**

CONCLUSIONS

Due to the low temporal resolution but also the lack of continuous records in many areas on the territory of Romania, especially in small watersheds, the equations for estimating the erosivity factor R can generate satisfactory results but with a certain degree of uncertainty which can the influence of the final result when applying the model chosen for the calculation of annual soil losses in a certain area.

The results obtained after processing the data from the 3 monitoring stations were satisfactory because recent studies carried out at the European level (Paganos et al, 2015) showed values of the R factor between 462.2 MJ mm ha^{-1} h^{-1} year^{-1} and 1150.10 MJ mm ha^{-1} h^{-1} year^{-1} with an average of 785 MJ mm ha^{-1} h^{-1} year^{-1}.

The results obtained for Modified Fourier Index *(MFI)* during the research period vary from one monitoring station to another, having higher values for the Moroeni monitoring station (max. 192.39 -1997) compared to the other 2 stations (Experimental field and Fieni). The minimum value of *MFI* was recorded at the Fieni monitoring station (51.10 – in 1992).

Analyzing the spatial distribution of the data by decade, we can state that in the period 1991-2001 the values of the Modified Fourier Index *(MFI)* were lower by 4.37% compared to the period 2001-2011 and 1.82% higher compared to the period 2011-2021, values that are reflected in the erosivity factor R for the studied watershed.

REFERENCES

Arnoldus HM, 1980 - *An approximation of the rainfall factor in the universal soil loss equation*. In: De Boodt M, Gabriels D (eds) Assessment of erosion. Wiley, Chichester, pp 127–132.

Duulatov E, Chen X, Amanambu A, Ochege FU, Orozbaev R, Issanova G, Omurakunova, 2019 - *Projected rainfall erosivity over Central Asia based on CMIP5 climate models.* Water 11, 897.

Kilic OM, Gunal H, 2021 - *Spatial-temporal changes in rainfall erosivity in Turkey using CMIP5 global climate change scenario*. Ar. J Geosci 14:1-13.

M. Rădoane and A. Vespremeanu-Stroe (eds.), 2017- *Landform Dynamics and Evolution in Romania*, Springer Geography.

Morgan RPC, 1996 - *Soil Erosion and Conservation*. Addison Wesley Longman Limited, Essex, U.K.

Moţoc M, Munteanu S, Băloiu V, Stănescu P, Mihai G.,1975 - *Eroziunea solului şi metodele de combatere*. Ceres Publishing House, Bucharest.

Panagos P, Ballabio C, Borrelli P, Meusburger K, Klik A, Roussev S, Tadić MP, Michaelides S, Hrabalíková M, Olsen P., 2015. *Rainfall erosivity in Europe*. Sci. Total Environ., 511:801–814.

Panos P, Ballabio C, Meusburger K, Spinoni J, Alewell C, Borrelli P, 2017 - *Towards estimates of future rainfall erosivity in Europe based on REDES and WorldClim datasets*, Journal of Hydrology, 548:251-262.

Prein AF, Rasmussen RM, Ikeda K, Liu C, Clark P, Holland G, 2017 - *The future intensification of hourly precipitation extremes*. Nat. Clim. Change 7(1):48–52.

Renard KG, Foster G ,Weesies G, Mccool D, Yoder D, 1997 - *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE).* United States Department of Agriculture.

Renard KG, Freimund JR, 1994 - *Using monthly precipitation data to estimate the R factor in the revised USLE*, J. Hydrology, 157:287-306.

Stănescu P, Drăgan L, 1970 - *Zonarea agresivității pluviale*. The I.C.I.F.P. Yearbook on Pedology. Bucharest; III (XXXVII).