CLIMATE SEASONALITY AND ITS RELEVANCE FOR SOIL EROSION DURING SUMMER IN EXTRA-CARPATHIAN MOLDOVA

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Keywords: climate seasonality, climatic indices, extra-Carpathian Moldova, ROCADA database, rainfall erosivity

Abstract: Rainfall erosivity is one of the most important topics, linking geomorphological and climatological studies. Rainwater plays an important role in triggering soil erosion. Thus, the impact of raindrops during significant torrential episodes causes the destabilization of soil aggregates and leads to erosion. Romania is a country where dry periods alternate with the rainy ones and studying rainfall erosivity is essential due to its importance for agriculture. The highest intensity of erosion occurs during violent rainfall episodes in the summer months, this being triggered by the energy of the torrential rains, but also by the liquid runoff. The extra-Carpathian Moldova is located in the northeastern and eastern part of Romania. In this study, The Suceava Plateau, The Moldavian Plain, The Moldavian Subcarpathians and The Bârlad Plateau were considered as part of the extra-Carpathian Moldova. Four indices were used to assess the climate seasonality on a general level with focus on the summer climate conditions: De Martonne Aridity Index (IdM), Lang Factor (L), Precipitation Concentration Index (PCI) and Angot Index (K). Our results indicate moderate seasonality in precipitation concentration along the year which underlines that the region cannot be considered climatically prone to massive soil erosion induced by rainfall erosivity.

INTRODUCTION

Rainfall erosivity is the subject of numerous studies due to its importance and topicality (Moțoc, 1963; Bojoi, 1992; Păltineanu et al., 2007; Sfiru et al., 2011; Stângă, 2011; Biali et al., 2014; Panagos et al., 2015a; Dumitrașcu et al., 2017; Rusănescu et al., 2018, Borrelli et al., 2020). One of the main drivers of rainfall erosivity can be considered the climatic seasonality. Firstly, the temperature seasonality induces modification in the soil structure, and secondly,

precipitation seasonality leads to the concentration of precipitation in summer, which can detach and mobilize the small particles of the soil. Therefore, rainfall is one of the main triggers of soil erosion and the reason why it accounts for the greatest loss of soil mass in Europe compared to other erosion processes (Panagos et al., 2015b). The erosive force of rainfall is expressed as rainfall erosivity (Panagos et al., 2015a).

During the last few decades, among other climate extremes, those focused on precipitation caught international attention and became some of the most important topics in climatic literature (Croitoru et al., 2018).

The temperate region is subject to the most pronounced seasonality of air temperature. Also, the precipitation seasonality increases towards the inner parts of the continent leading to the concentration of most of the precipitation amount during the summer season. These are the reasons why rainfall erosivity is related mostly to this time of the year.

As a consequence, a significant part of the Romanian territory is affected by water modeling as a result of the peridiocity of the meteoric waters' action. The highest erosion intensity occurs during violent storms episodes which are specific for the warm season (Dobri et al., 2017). Erosion is triggered by the energy shock caused by torrential rains, but also by the rapid organization of the liquid runoff. A primary evaluation of climate seasonality can be determined through a number of indices. Two indices were used in order to underline this aspect in the current paper: De Martonne Aridity Index (IdM), Lang Factor (L). Also, the concentration of the precipitation was assessed using other two indices: Precipitation Concentration Index (PCI) and Angot Index (K). The main goal of this study is to obtain a general image of the climate seasonality and precipitation concentration over the analyzed region as a background for a better understanding of the climate's role in rainfall erosivity.

1. STUDY AREA

The extra-Carpathian Moldova is located in the northeastern and eastern part of Romania (Posea, 2006). In this study, we considered as part of it the Suceava Plateau, the Moldavian Plain, the Moldavian Subcarpathians and the Bârlad Plateau. The altitudes vary between 32 m in the Prut valley and 911 m on the Pleșu Peak in the northern part of the Subcarpathians, the precipitation amount being determined by the cyclonic activity over the entire year (Niță et al., 2020) and mainly by the atmospheric instability during summer (Dobri et al., 2017). The annual precipitation amount decreases to less than 550 mm in the lower regions (the Prut valley and the Moldavian Plain) and overpasses 650 mm on the highest altitude from the Subcarpathians and the Moldavian Plateau

(Clima României, 2008). More than 65% of this precipitation amount is recorded during the warm season (April to September). Also, the annual variation of air temperature reaches regularly 40°C, between mean maximum temperature in July (35°C) and minimum mean air temperature in January (-15°C). This variation exposes the upper levels of the soil profile to intensive disaggregation that mobilizes soil particles, making them susceptible for soil erosion during the intervals with high amounts of precipitation.

Figure 1. Geographical location of the extra-Carpathian Moldova

Moreover, the region is known for its highest values of precipitation amount in 24h at country scale (Clima României, 2008; Dobri et al., 2017) which is considered as an indicator of the increased rainfall erosivity. As well, from a geomorphological perspective the same region is known for the high extension and intensity of erosional processes that are generally linked to these meteorological conditions (Moțoc et al., 1998; Ioniță, 2000a, 2000b, 2006; Niacșu et al., 2019).

2. DATA AND METHODS

For this study we used the ROCADA database (Dumitrescu & Bîrsan, 2014), which includes the daily records of 9 meteorological parameters during the period between 1961 and 2013. From these parameters we have used the precipitation and air temperature datasets.

The Windows PowerShell command program was used to extract the data from the ROCADA database, using climate data operators (CDO). The analyzed indices were calculated in this program and the resulting files (NetCDF) were added into ArcMap 10.4 software so that the extracted data could be interpolated and, finally, to obtain the cartographic products.

One of the most widely used interpolation method is the kriging. This is based on the idea that there is an autocorrelation among the values of the spatial variables that are nearer to the center point. In this paper we used the ordinary kriging method. While the simple kriging is applied on the raw data, the ordinary one uses the residues obtained from the subtraction of the arithmetic mean (Patriche, 2009).

3. RESULTS AND DISCUSSIONS

3.1 De Martonne Aridity Index (*IdM*)

Droughts are caused essentially by the climatic conditions, being the most known recurring meteorological phenomena and one of the most frequent natural disasters in many regions of the world (Stângă & Minea, 2013). Aridity can be expressed through many indices, some of them using precipitation and temperature data, as De Martonne Aridity Index. Basically, it was calculated to separate more clearly the humid areas from those affected by aridity. Even if this index does not represent a direct tool to assess soil erosivity, we considered that it could give an image on the overall precipitation seasonality. The formula uses precipitation and temperature data:

$$IdM = P / T_a + 10^*$$

*P = annual amount of precipitation; T_a = average annual temperature.

De Martonne Aridity Index allows the separation of areas with a humid or semi-humid climate from those with an arid or semi-arid climate. During the analyzed period (1961-2013), in June (Fig. 2a), the index had values between 25.83 (semi-humid climate) and 63.03 (humid climate). This is a normal distribution and because of the latitudinal zoning the values increase from south to north. Also, the role of altitude in the area of the Moldavian

Subcarpathians and the Suceava Plateau in enhancing the values of this index is very well individualized. June is generally rich in precipitation and, consequently, the potential risk of soil erosion through rainfall erosivity is higher.

Table 1. Climate types according to the De Martonne Aridity Index

Type of climate	De Martonne Aridity Index
Very dry	0 – 5
Dry	5 – 10
Semi-dry	10 – 20
Semi-humid	20 – 30
Humid	>30

In July, the values of De Martonne Aridity Index begin to decline: the minimum obtained value was 18.72 (semi-dry climate) and could be found in the southeastern part of the analyzed region. The maximum value was 53.71, spatially distributed in the area of the Moldavian Subcarpathians and the northwestern part of the extra-Carpathian Moldova.

Figure 2. The spatial distribution of the climatic indices: a) De Martonne Aridity Index (June); b) Lang Factor (June)

August brings with it quite significant changes in the values of this index, as a result of the decrease in precipitation. The minimum value is 14.34 (semi-dry climate) and is found in the southeastern part of the extra-Carpathian Moldova. The maximum values (39.28 – humid climate) are distributed in the northwestern part and in the southwestern extremity of the Moldavian Subcarpathians.

Overall, for the summer months, humid and semi-humid conditions prevail over the region which indicates the occurrence of moist intervals inducing erosional processes through precipitation.

3.2 Lang's Rain Factor (L)

Lang's Rain Factor is a climatic index that separates the areas with different climate types. It has some restrictions as well, for example, it can only be calculated for the months with positive temperature values because the negative ones can bring a series of errors.

$$L = P / T_a^*$$

* P = annual amount of precipitation, T_a = average annual temperature.

Table 2. Climate types according to the Lang Factor

Type of climate	Lang Factor
Very dry	0 – 20
Dry/Arid	20 – 40
Semi-dry	40 – 70
Humid	>70

For the extra-Carpathian Moldova, In June (Fig. 2b), the Lang's Rain Factor has values between 39.94 (dry climate) and 119.46 (humid climate). Thus, the lowest values are found in the southeastern part of the region, and the maximums are concentrated in the western and northern parts.

In July, the minimum value is 28.04 and is located in the southeastern part of the extra-Carpathian Moldova. This time, the maximum value reaches 93.03 units (humid climate) and we find it in the Suceava Plateau and in the Moldavian Subcarpathians.

In August, as a result of the decrease in rainfall, Lang's Rain Factor also had significant lower values. The obtained values were between 20.72 (dry climate – southeastern part) and 62.75 (semi-dry climate – in the Suceava Plateau and the northern part of the Moldavian Subcarpathians).

We should underline that the prevailing semi-dry class is equivalent with semi-humid class in De Martonne Aridity Index.

3.3 Precipitation Concentration Index (PCI)

The Precipitation Concentration Index is used for assessing the type of distribution of the precipitation amount over a year or a longer period (Zhang et al., 2019). Depending on their distribution, the seasonality of precipitation can be assessed. Its calculation formula uses average monthly amount of precipitation data:

$$PCI = 100 * \sum_{i=1}^{12} P_i^2 / (\sum_{i=1}^{12} P_i)^2 *$$

* P_i = monthly amount of precipitation data.

Table 3. Distribution types according to the Precipitation Concentration Index

Type of distribution	Precipitation Concentration Index
Uniform	<10
Moderate	11 – 15
Irregular	16 – 20
Strong irregular	>20

A uniform distribution of precipitation is the ideal scenario to avoid or to minimize the effects of soil erosion through rainfall (Bojoi, 1992). Instead, the precipitation seasonality increases the erosional capacity. For example, a seasonal distribution affects multiple soil properties. In the season when there is a large amount of precipitation, the probability of erosion is higher. As we have observed, from De Martonne and Lang indices, the summer season, over the entire extra-Carpathian region, represents such a season with an important amount of precipitation. The greatest risk of erosion occurs when the soil contains a large amount of water and the surface runoff detaches soil particles more easily. Also, at the beginning of the rainy season there is an increased risk of soil erosion by rain denudation. This refers to the dislocation of soil particles by spraying, depending mostly on rain aggressiveness (Ioniță, 2000b). The seasonal distribution is also dangerous in the dry season because excessive drying of the soil's surface layer can lead to other types of erosion such as wind erosion (Niacșu et al., 2019).

The Precipitation Concentration Index has often been calculated for different areas from Europe and Romania (Strat & Nistor, 2012; Gogic et al., 2016; Mohammed et al., 2020). Relating to these studies, they range from 10.43 to 12.49 in Serbia, 11.8 in Hungary and between 11 and 15 in Romania, in the Târgu Jiu Depression.

In the extra-Carpathian Moldova, the Precipitation Concentration Index indicates a moderate seasonal distribution, with values ranging between 12.05 and 13.75 (Fig. 3a), which indicates small differences in the seasonal distribution of the precipitation amount. The minimum values are concentrated in the southeastern part and the maximum ones in the Suceava Plateau, the northern part of the Moldavian Plain and in the Moldavian Subcarpathians. The moderate seasonality of the rainfall distribution was an important argument in restricting this study for the summer months.

Figure 3. The spatial distribution of the climatic indices: a) Precipitation Concentration Index; b) Angot Index (June)

3.4 Angot Index (K)

The Angot Index is used to define the annual variation of the precipitation amount, more clearly in highlighting the rainy and dry intervals (Rusu, 2014).

$$K = p / P^*$$

$$*p = q/n \text{ and } P = Q/365,$$

where q = average amount of precipitation in a month, n = number of days/months, Q = annual amount of precipitation.

Table 4 Favorability classes based on Angot Index values (Dumitrașcu et al., 2017)

Pluviometric attributes	Very dry	Dry	Normal	Rainy	Very rainy
Erodability classes	Very low	Low	Moderate	High	Very high
Angot Index values	<0.99	1 – 1.49	1.5 – 1.99	2 – 2.49	>2.50

An advantage of this index is that it uses only precipitation data, which makes it easier to use, and classifying erosivity is simpler because it uses value classes that are already established (Dragotă et al., 2008).

In June (Fig. 3b), the values range between 1.64 (in the southern part of the Moldavian Plateau) and 2.12 (in the Moldavian Subcarpathians and southwestern part of the Suceava Plateau).

One of the causes that led to this kind of distribution of the Angot Index is the altitudinal variation. The increase in altitude is directly related to the amount of precipitation. This is noticeable in the Moldavian Subcarpathians and the Fălticeni Hills, where the maximum values of the Angot Index are recorded in June. This index can highlight the predisposition to trigger the processes of the linear erosion. The values over 2 – 2.5 of the Angot Index show very favorable conditions for triggering the erosion (Dinu, 2015). In the extra-Carpathian Moldova, in the entire analyzed period, values over 2 are found in June in the Suceava Plateau, the Moldavian Subcarpathians and the Tutova Hills. Given the negative effects of exceeding this threshold, in areas threatened by erosion it is recommended to apply anti-erosional systems.

In July, the values of the Angot Index decline due to the decrease in the precipitation amount. The minimum value is 1.21 (the southern and southeastern part of the Moldavian Plateau) and the maximum value is 1.99 (the Suceava Plateau and the northern part of the Moldavian Plain).

As the rainfall regime of the study area shows us, August is characterized by a lower amount of precipitation than the previously analyzed months. The minimum registered value is 1.01 (the southeastern part of the Moldavian Plateau) and the maximum one is only 1.56 (the eastern and northeastern part of the Suceava Plateau). In August, over 90% of the analyzed territory falls into the low erosivity class.

The resulting values of the indices highlighted the fact that rainfall erosivity was directly dependent on the latitudinal and altitudinal zoning; the

biggest values were located in the highest areas of the extra-Carpathian Moldova.

Overall, soil erosion through water has an increasing trend, but we found that rainfall erosivity has a rather secondary role in this process, in the studied region.

If land degradation increases this is not due to meteorological reasons, such as high rainfall intensity, but due to the complex and accelerating changes in land use during the last 30 years (Rusu et al., 2020).

4. CONCLUSIONS

Each index that was used in this study contributed to the representation of the overall conditions for the rainfall erosivity in the extra-Carpathian Moldova and represent a basis for further studies in the field. In brief, from our results, although there are areas affected by erosion, this processes can't be fully justified by the meteorological factors.

Also, the period 1961-2013 was marked by numerous changes in the land use of the analyzed territory. We believe that significant changes in erosivity occur due to the constant change of the interface of vegetation and due to some changes in the geomorphological and pedological parameters. The high level of erosivity in some areas of the extra-Carpathian Moldova can be rather attributed to the improper land use, deforestation and, not necessarily, to climatic conditions. For instance, soil erosion in the Bârlad Plateau is significant, but it is not generated only by rainfall. Temperature variations during winter seem to play a very important role in some types of erosional processes (gully erosion, creeping). Also, a couple of other factors as land use or agro-technical practices combined with the overall moderate rainfall erosivity can lead to intense erosional processes.

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