

USING THE FOURNIER INDEXES IN ESTIMATING RAINFALL EROSION. CASE STUDY - THE SECAȘUL MARE BASIN

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ABSTRACT. - **Using the Fournier Index in Estimating Rainfall Erosivity. Case Study - The Secașul Mare Basin.** Climatic aggressiveness is one of the most important factors in relief dynamic. Of all climatic parameters, rainfall is directly involved in versant dynamic, in the loss of soil quality and through pluvial denudation and the processes associated with it, through the erosivity of torrential rain. We analyzed rainfall aggressiveness based on monthly and annual average values through the Fournier's index (1970) and Fournier's index modified by Arnoldus (1980). They have the advantage that they can be used not only for evaluating the land susceptibility to erosion and the calculation of erodibility of land and soil losses, but also in assessing land susceptibility to sliding (Aghiruș, 2010). The literature illustrates the successful use of this index which provides a summary assessment of the probability of rainfall with significant erosive effects. The results obtained allow observation of differences in space and time of the distribution of this index.

Keywords: rainfall erosivity, Fournier indexes, pluvial denudation, Secașul Mare.

1. INTRODUCTION

The processes developing at the earth surface are mainly influenced by rainfall. Either as rain or as water from melting snow, water is a very important morphogenetic agent, which gives versants a strong dynamic and creates specific microshapes. Climatic conditions determine the constant or spasmodic pace, the intensity and the permanent seasonal regime of the influence of external agents, i.e. water from precipitation. Climate aggressiveness is manifested on the one hand by thermal oscillations that prepare the crust through weathering processes, and on the other hand by the erosive action of rain. The regime of rainfall reflects the aggressiveness of pluvial denudation on the geological substrate and soil through the volume, duration and intensity of rain. The more aggressive they are, especially after long periods of drought. The erosive effect is felt immediately through accelerated modeling: the impact of rain drops due to their kinetic energy, the washout of the topsoil, gully erosion, ravination, etc. This is evident in the Secașul Mare Basin, where the brittle substrate composed of sand deposits, gravel, clay and agricultural use (cereals, viticulture, fruit growing and grazing) allow for these processes to occur and reactivate older forms.

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2. MATERIAL AND METHOD

The rainfall analysis was based on data from weather stations in Păltiniș (1450 m), Sibiu (420 m) and Sebeș (240 m) which are representative for the Secaș basin. Sibiu and Păltiniș stations are outside the basin, near its eastern and southern borders, respectively, under bio-climatic conditions which are similar to the basin area. The analyzed period covers a total of 30 years, between 1980 and 2010, with particularizations to the Păltiniș station - 1980-2008. Modeling of significant conditions were analyzed: mean annual precipitation and precipitation surplus, torrential rains, the maximum amounts of rainfall in 24 hours.

Rainfall erosivity can be estimated through several methods, of which one of the most relevant is based on torrential rainfall intensity. This requires however daily data, and in the case of long-lasting torrential precipitation, more complex information: quantities for various time intervals (15', 30'), the core position and intensity. These detailed data are not easily available, they are extracted from pluviograms. Obtaining data which cover a longer period of time is practically impossible, on the one hand because of the restrictions imposed on data circulation, and on the other hand due to the high costs involved.

Under these circumstances, we assessed regional rainfall erosivity based on the Fournier (1960) index and the Fournier modified index (Arnoldus, 1980). The Fournier index was calculated according to the relation (1):

$$(1) F = \frac{P_{\max}^2}{P} \text{ where } P_{\max} \text{ is the monthly average amount of precipitation of}$$

the most rainy month (mm), and P is the average annual quantity of precipitation.

The Fournier index modified by Arnoldus (1980) was calculated by means of the relation (2):

$$(2) F_M = \sum_{i=1}^{12} \frac{P_i^2}{P} \text{ where } P_i \text{ is the monthly average amount of precipitation}$$

for month i (mm), and P is the average annual quantity of precipitation (mm).

The literature shows that the Fournier index and the modified Fournier index are relevant in the studies focused on rainfall aggressiveness and are correlated to other climatic variables, which are contributing factors in the triggering or reactivation of erosive phenomena. These indices enable us to evaluate the probability of intense rainfall phenomena (Scrinzi et al., 2006). The choice of the critical value of 100 mm below which climate aggressiveness is considered low is supported by Rice, Pillsbury (1982), who developed an index of rainfall severity causing land sliding and erosion, which takes into account the amount of precipitation and the duration of the phenomena in hours. The rainfall erosivity classes determined by means of the Fournier index (Oliver, 1980, qtd. in Sfîru et al., 2011) and the modified Fournier index (Scrinzi et al., 2006, Yuksel et al., 2008, qtd. in Aghiruș, 2010) are shown in table 1.

Table 1. The erosivity classes by Fournier index (F) and modified Fournier index (F_M)

Erosivity class	F	Clasa de erozivitate	F _M
Verry low	0 – 20	Verry low	0 - 60
Low	20 – 40	Low	60 – 90
Moderate	40 – 60	Moderate	90 - 120
Severe	60 – 80	High	120 - 160
Very severe	80 - 100	Very high	> 160
Extremely severe	> 100		

3. CIRCUMSTANCES OF RAINFALL AGGRESSIVENESS

The current modeling of the relief and soil erosion is under the direct incidence of precipitation intensity and frequency.

In order to determine the influence upon the versants, **precipitation variation and variability** should be determined. Multi-annual average quantities increase with the altitude (516.6 mm/year in Sebeş, 638.2 mm/year in Sibiu, 943 mm/year in Păltiniş), the average increase gradient being 48.6 mm/100 m. The rainfall vertical gradient is not constant, it is 67.6 mm in the depression and plateau sections of the basin and falls in the foothills and the lower mountain area in the southern part of the basin to around 30mm/100m). Monthly amounts of precipitation change significantly in relation to the general circulation of the atmosphere, the position of the basin and the intensity of local processes which cause precipitation. Multiannual monthly distribution shows a continuous increase in rainfall from January to June when it reaches the maximum value (72.5 mm in Sebeş) and then falls until February to the minimum value (19.7 mm in Sebeş). In the lower basin, the largest average amount of precipitation occurs in June and, over 400 m altitude, in July. We note that the warm season of the year is characterized by increasing precipitation, with the highest values recorded from May to July. Moreover, precipitations are greatly variable and their variability depends on atmospheric dynamic and they are influenced by the existing characteristics of the active surface (Bogdan, Niculescu, 1999; Dragotă, 2006).

In the years with intense cyclonic activity (oceanic and Mediterranean cyclones) there is a surplus of precipitation caused especially by heavy rains, in the warm season of the year. In the period under review, i.e.1980 - 1982, 1989, 1991, 1995, 1995 – 1998, 1999, 2001, 2004 – 2008 and in 2010, there was a remarkable rainfall surplus (fig.1). There were positive deviations between 100 and 200 mm in Sebeş, in 1997, 1998, 2005, 2007, 2008 and 2010, and positive deviations above 200 mm (235 mm) in 2001. The quantity of precipitation increases from west to east and with the altitude, and thus in Sibiu and Păltiniş positive deviations were higher (in Sibiu between 100 and 200 mm in 1981, 1991, 2007; between 200 and 300 mm in 1980 and 2005 and over 300 in 1998, and in Păltiniş between 100 and 200 mm in 1981, 1991, 1997; between 200 and 300 mm in 1980, 1995, 1998 and 2005 and over 300 in 2007). At altitudes below 500 m, excess precipitation is grouped on the interval from May to November, when positive deviations are equal to or greater than monthly multiannual averages (Rusan, Negoescu, 2008).

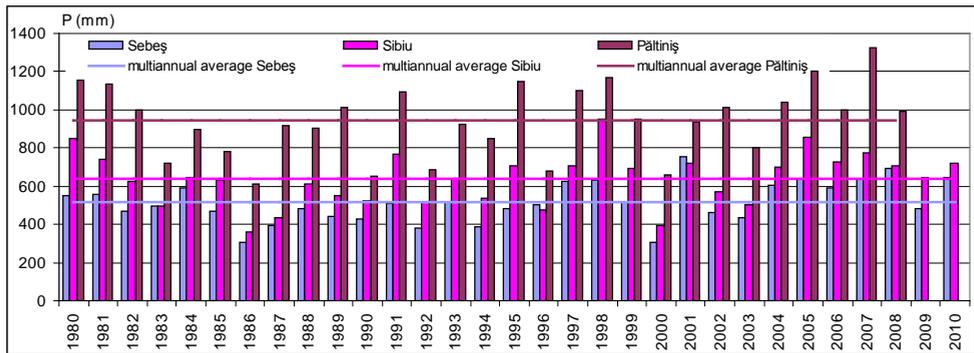


Fig. 1. Precipitations variability during 1980 – 2010 and deviation from station amount

Excess precipitation was recorded for short (1-2 years) or longer (4-7 years) periods of time alternating with periods of drought, which caused a much higher rainfall aggressiveness and a reactivation of slope and channel processes in the Secașul Mare basin.

Torrential rain has the strongest erosive effect on landscape and soil. The efficiency of pluvial erosion or aggressiveness is best measured when the intensity of torrential rain is considered for a period of 15 minutes. Rains whose torrential core has a minimum intensity of 0.6 mm/min for a period of 15 minutes are considered aggressive rain (Bojoi, 1992). Research conducted on experimental lots in Romania (Moțoc, 1963) indicates the fact that the most aggressive are torrential rains with maximum intensity and those with the maximum intensity core located at the end of the rain. The research conducted by the Pedologic and Agrochemical Research Institute shows that pluvial aggressiveness in Romania has the following characteristics: it is lower in the west of the country (0.08), moderate in the south (0.13), east and north-east (0.10) and high in the center of the country, in the sub-Carpathian hills (0.14), in the Transylvania Plateau (0.12) and the Carpathians area (0.15 – 0.16). According to these values, the Secașul Mare Basin located in the south-western part of the Transylvanian Depression is characterized by a moderate to high pluvial aggressiveness, whose values increase from west to east and north to south. We believe, however, that the value of the rainfall erosivity indicator is not relevant due to the small differences between regional values, and to the significant differences in terms of rainfall (e.g. 0.12 for the Transylvania Depression and 0.13 for the Apuseni Mountains and the Bârlad Plateau). That is why we shall calculate the regional values of the Fournier indexes.

Most torrential rains occur in the summer, especially in June and July. Referring to the intensity of torrential rains in the Secașelor Plateau, Raboca (1995) argued that it is between 0.3 to 2.85 mm/min at the Sebeș station and that maximum intensity and the development of the torrential core is in most cases (63-66 %) within 15 minutes of their occurrence. The variation of the amount, duration and intensity of torrential rains in the basin is subject to sub-mountainous position,

the role of orographic barrier of the Carpathians, the opening to the west of the basin to moist air advection and the influence of the active surface.

Although data on torrential rains are most relevant in modeling through pluvial denudation, they are not easily accessible, and in some cases they are actually missing. This shortcoming can be eliminated by taking into account another weather-related parameter, namely the **maximum absolute amount of rainfall in 24 hours**. To the Secaşul Mare Basin, this parameter is particularly relevant in terms of the erosive effect because their value is about 70-90 % of average annual values of the month in which they occur. They have a torrential character, the amount exceeding 20 mm in all cases, and in 65 % of cases exceeding 30 mm. They have an extremely important erosive role on the versants through the impact of raindrops, but especially through the fact that they feed the tributaries of the Secaşul Mare River and they cause flooding.

The yearly distribution of the maximum amount of rainfall in 24 hours is not uniform. The highest values occur in the warm season of the year, the absolute maximum being 61.3 mm in Sebeş, recorded on June 18, 1998. Daytime highs are generated as a result of the association of barometric systems with altitude. On the basin surface, there are changes of the dominant oceanic air masses and cyclonic Mediterranean areas which are in contact with the orographic barrier of the Carpathians (Dragotă, 2006). In the cold season, due to poor thermal convection and prevalence of anticyclone circulation, maximum amounts of precipitation fallen in 24 hours are lower and slightly erosive in comparison with the rainfall in summer. This is due to the resistance of the substrate and soil because of low temperature. There are exceptions in the cold season, when monthly averages are exceeded (in Sebeş, the February daytime maximum was 30.7 mm on February 10, 1984, and the December daytime maximum of 40.0 mm occurred on December 30, 1989). These exceptions from the cold season are due to exceptional synoptic situations, i.e. advection of moisture laden air masses.

4. ESTIMATING EROSIVITY BY THE FOURNIER INDEXES

For the Secaşul Mare basin, the Fournier indexes were determined as shown above, based on the monthly and yearly precipitation average data recorded at the stations which are representative for the basin; the data were provided by CMR Transilvania Sud. Differentiated altitudinal positions of the stations allow for correlation of these indices with altitude, and the position in space allows for analysis of spatial distribution of rainfall aggressiveness index. The analysis covers a period of 30 years, some with precipitation surplus and others deficient in precipitation, which will diversify over time the value of the two indices of rainfall aggressiveness depending precipitation variability (fig. 2, fig.3).

The multiannual average value of the Fournier index is 22.2 mm in Sebeş, 31.6 in Sibiu and 37.04 in Păltiniş. For the modified Fournier index, the multiannual average values for the period under review are: 62.9 mm in Sebeş, 80.0 mm in Sibiu and 111.63 mm in Păltiniş. The values of the Fournier index

shows very low aggressiveness in the lower area of the basin and low to moderate aggressiveness in the higher area of the basin (fig. 2).

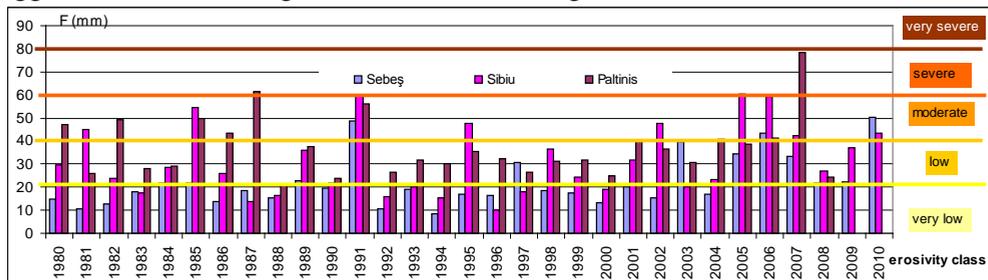


Fig. 2. Fournier index variability during 1980 – 2010

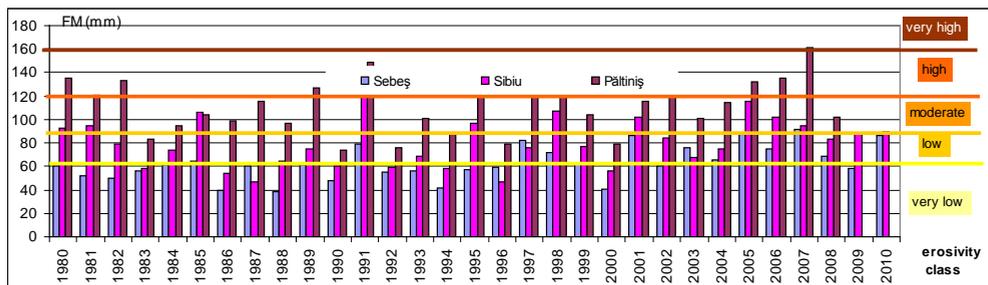


Fig. 3. Fournier modified index variability during 1980 - 2010

The F index showed a very low aggression at all stations (26 - 60 - 65% of cases), low aggression in 28-45% of cases, moderate aggression in 3-23% of cases and only at the station in Sibiu there was high aggression in 6% of cases. The average value of the F index was exceeded at all stations in 1991 (deviation 20-34 mm), in 2005-2007 (with deviations of 12-40 mm) and 2010 (with deviations of 12 to 28 mm). The values of the Fournier index grow from west to east and with the altitude, which is true also for deviations from the average values.

According to the aggressiveness classes of the modified Fournier index, for altitudes below 200m aggression is very low, for altitudes between 200 and 800 aggression is low and for altitudes over 800m aggression is moderate (fig.4 a , b). The values of the F_M index for the lower area of the basin show a very low aggression in 23 – 45 % of cases, low aggression in 44 – 52 % of cases and moderate aggression in 3% of cases. For the higher area of the basin, the F_M index shows a low aggressiveness in 21% of cases, moderate aggressiveness in 38% of cases, high aggressiveness in 38% of cases and very high aggressiveness in 3% of cases. In comparison to the average value of the F_M index, there were positive deviations at all stations in 1991 (deviation of 15 – 46 mm), in 1997 – 1998 (deviation of 9 – 27 mm), in 2001 (deviation of 21 – 23 mm), between 2005 and 2007 (deviation of 15 – 49 mm) and in 2010. Deviations are lower at lower altitudes (< 30mm) and in the western part of the basin and increase with the altitude and towards the east (30 – 49 mm), which causes the rainfall

aggressiveness to increase as well, with high and very high aggressiveness at altitudes of over 800m. The correlation of the F_M index to the altitude indicates a strong and significant connection, with a correlation value of 0.95 (fig.4b).

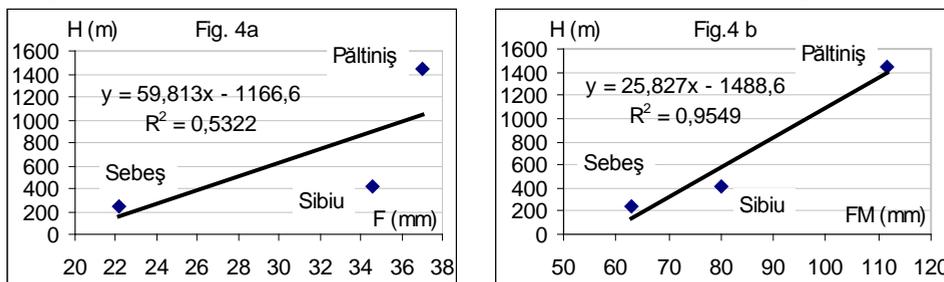


Fig. 4. Correlation with altitude of F(a) and Fm indexes (b)

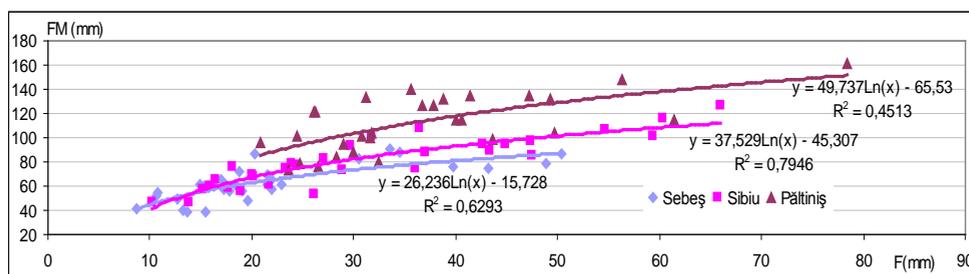


Fig. 5. Correlation between F and FM indexes between 1980 – 2010

Figure 5 illustrates the positive and significant correlation between the two indexes. The correlation value is higher at lower altitudes (0.63 in Sebeş and 0.79 in Sibiu) and decreases towards higher altitudes (0.45 in Păltiniș). This decrease may be due to the vertical pluviometric gradient which undergoes changes when altitude changes.

5. CONCLUSIONS

Considering the results presented above, we came to the following conclusions: 1).- applying the Fournier indexes for the assessment of rainfall aggressiveness is a rather simple, quick and easily available method, because it does not require complex calculations and experimental research; 2).- the two indexes are influenced by the pluviometric characteristics, namely the monthly and annual values recorded at the representative stations for the area under review, which confers them their local or regional character; 3).- both variants of the Fournier indexes indicate the same pluvial aggressiveness classes at low and medium altitudes in the basin, which is also demonstrated by the correlation between the two indicators, with a value of 0.63-0.8; for higher altitudes, the correlation is lower (0.45); 4).- the modified Fournier index is more relevant for the study of rainfall aggressiveness as it takes into account the value of precipitation in different months of the year and the variation during a specific year; 5).- the

obtained indexes fall mostly under the moderate aggressiveness class, but there were also years when rainfall aggressiveness was high and very high, particularly at medium and high altitudes.

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