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Land Vulnerability to Geomorphological Hazard Induced by Pluviometric Criteria (Romanian Plain)

Florina GRECU [(*)], Cristina GHIŢĂ[(*)], Emil CÎRCIUMARU[(*)]

Land vulnerability to geomorphological hazard induced by pluviometric criteria (Romanian Plain). This study tries to bring a contribution to the motivation of the current geomorphological processes in terms of their genetic link with the climatic factor in general and the rainfall one in particular. One of the most esed climatic index to determine the susceptibility of land to rainfall, with real and concrete applications in dynamic geomorphology, is the Angot index. The general objective of this study is to identify first the months, seasons or years with very high or very low susceptibility to erosion phenomena production of the banks and also the values of this index during the year, in order to identify the cumulation of the pluvial conditions which could induce, in general, the modeling processes. Aplied to amounts of rainfall from Stolnici and Alexandria meteorological station for the period 1961-2000, Angot Index reveals that geomorphological processes along Vedea valley and its tributaries are largely generated by the fallen precipitation amou8nts, plus other factors (petrographic, hydrogeological, morphometric, the use of the land, etc.).

Key Words: Angot Index, Romanian Plain, Vedea basin, precipitation susceptibility.

Vulnerabilitatea terenurilor la hazarde geomorfologice după criteriul pluviometric (Câmpia Română). Prezentul studiu încearcă să aducă o contribuţie la motivarea proceselor geomorfologice actuale prin prisma legăturii lor genetice cu factorul climatic, în general şi cel pluviometric, în special. Unul dintre cei mai folosiţi indici climatici pentru determinarea susceptibilităţii terenului la precipitaţiile atmosferice, cu reale şi concrete aplicaţii în geomorfologia dinamică, este indicele Angot. Obiectivul general al studiului îl constituie identificarea, pe de o parte a lunilor, sezoanelor sau anilor cu o susceptibilitate foarte ridicată sau foarte coborâtă de producere a fenomenelor de dinamică a albiilor şi torenţialitate ca şi variaţia valorilor acestui indice în cursul anului în vederea identificării cumului de condiţii pluviometrice care ar putea induce, în general, procesele de modelare. Aplicat la cantităţile de precipitaţii de la staţiile meteorologice Stolnici şi Alexandria, pentru perioada 1961-2000, Indicele Angot evidentiază faptul că procesele geomorfologice din lungul văii Vedea şi a afluenţilor acesteia (sunt generate într-o mare măsură de cantităţile de precipitaţii căzute, la care se adaugă şi alţi factori (petrografici, hidrogeologici, morfometricei, modul de utilizare al terenurilor etc).

Cuvinte cheie: Indicele Angot, Câmpia Română, Bazinul Vedea, susceptibilitate la precipitaţii.

1. Introduction and objective

In the plain area, the appearance and intensity of the contemporary geomorphological processes are controlled by geology (type of deposits, thickness, granulometry), hydrogeology (depth of water table, water-level regime, flow direction, mineralization), human interventions (dams, dykes, irrigations), and especially by the climatic factor in general and the precipitation regime in particular (Grecu et. all, 2006; 2009)

One of the most widely used climatic index for determining the land susceptibility to atmospheric precipitation, with real and concrete applications in dynamic geomorphology, is the Angot index.

The precipitation is a major meteorological element that triggers, maintains and reactivates some geomorphological processes, thus acting as a shaping agent in the plain areas. This influence can be highlighted by quantifying the values of selected characteristic variables (duration, frequency and intensity), as well as by delimiting in time the individual and successive snapshots that present a certain degree of susceptibility (Dragota, 2006).

The general objective of this study is to identify first the months, seasons or years with very high or very low susceptibility to erosion phenomena production of the banks and also the values of this index during the year, in order to identify the cumulation of the pluvial conditions which could induce, in general, the modeling processes.

2. General Features about the Study Area

The Vedea catchment lies in the central part of the Romanian Plain, where the climatic features, together with the geological and hydrogeological ones, may turn into vulnerability factors for the land (Fig. 1). In addition, the trunk river is allochthonous and it flows directly into the Danube.

From the hydrogeological point of view, the northern section of the catchment is represented by the piedmontane deposits, which have a flow regime imposed by the thickness and lithological characteristics of the Candesti Strata (Grecu et. all 2006, 2009). In the southern section, the presence of the Fratesti Strata (of Balcanic origin) at high depths and the specific features of the overlying loessoid deposits have imposed different underground and superficial flowing regimes (Liteanu, 1953,1969). Under the circumstances, precipitation becomes a major shaping agent for the triggering, maintaining and reactivation of the channel and slope processes.

Pluviometric regime. The mean multiannual amount of precipitation specific for the Vedea catchment drops on the north-south direction, from 569.3 mm at Stolnici, in the piedmont area, to 520.3 mm at Alexandria (acording NMA). The maximum is recorded in August in the north (78.6.mm) and in July in the south (65.9 mm), whereas the minimum values are specific for January and February in the north (32.6 mm) and October in the south (28.2 mm).

Table no. 1 **Vedea drainage basin - morphometric parameters**

Morphometric parameters		Vedea basin/river
Altitude (m)	max	559
	min	20
Lenght of the river (km)		251 (200 in the plain)
Width of the basin (km)		54
Drainage area (km^2)		5266
Horton-Strahler hierarcy (*Horton*, 1945, *Strahler*, 1952).		7

The multiannual regime emphasizes considerable departures from the mean. Thus, the highest annual amounts may reach in the rainy years more than 700 mm, both at Stolnici (1966, 1971, 1972, 1979, 1980) and at Alexandria (1964, 1966, 1969, 1972), whereas the lowest amounts, below 400 mm, are specific for the dry years: at Stolnici in 1990 and 2000 and at Alexandria in 1965, 1985, 1990, 1996 and 2000.

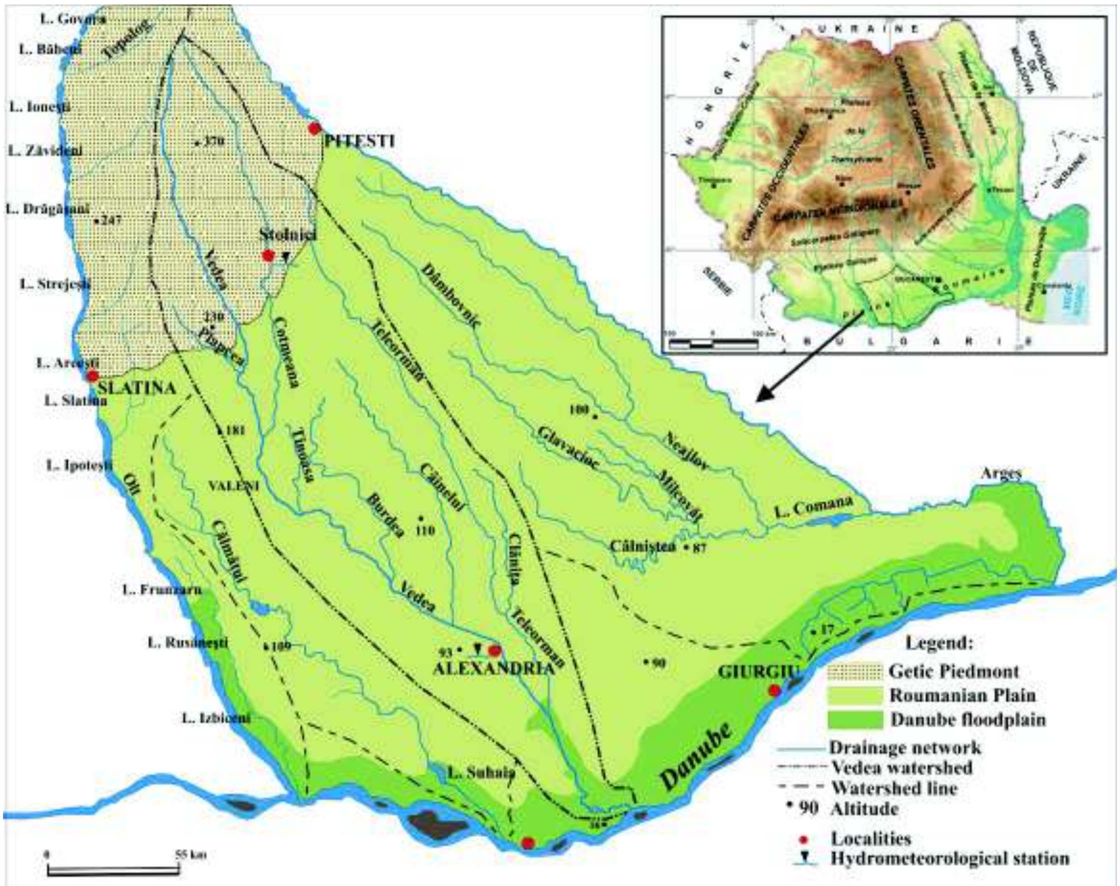


Fig. 1. **Location of the Vedea drainage basin and the weather station used in the study**

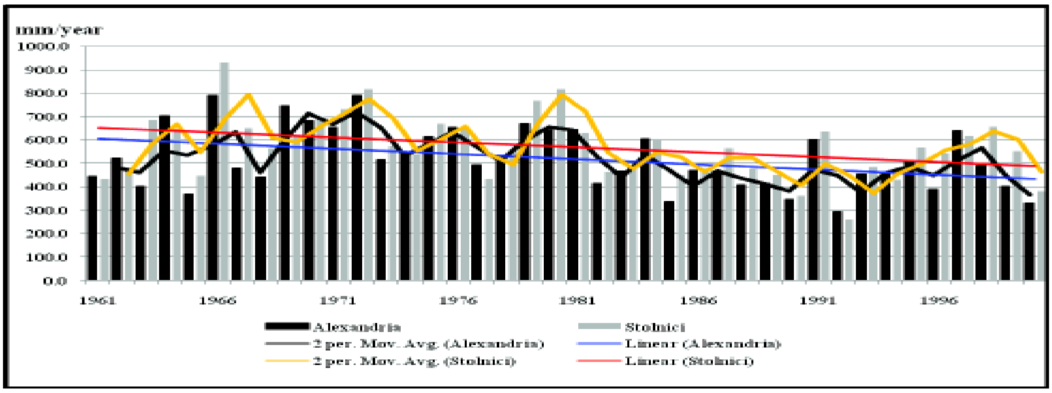


Fig. 2. **Variability of annual quantities of precipitation and their trends**
(Stolnici and Alexandria weather station) (1961-2000)

The precipitation shows a slight decreasing linear tendency both in the north and in the south. The polynomial trend line of degree six shows the following aspects: in the north the annual amounts of precipitation increased sharply from 1961 to 1966 and then dropped by 200-250 mm during the periods 1966-1967 and 1979-1980; between 1970 and 1972 and between 1976-1979 precipitation decreased; after 1979 until the year 2000 there was again a decrease, with a significant departure from the multiannual mean for the interval 1990-1995 and for the year 2000 (Fig. 2). The highest amount of precipitation was recorded in 1966, a year when floods were frequent and water table rose.

In the multi-annual regime, in 18.91% of the cases July was the wettest month of the year, while January and February were in 64.85% of the cases the driest months. Except for February, which is the driest month, all the other months of the year experienced during the investigated period maximum annual amounts, too. Thus, January was the wettest month of the year in 2.3% of the cases (a percent that is also specific for April and November), March, September and October in 4.7% of the cases, May and August in 9.3%, July in 16.3% and December in 11.5% of the cases. These monthly shares of the pluviometric regime determine the maximum range of temporal variability of this meteorological parameter, which influences the occurrence rate of geomorphological processes.

3. Data and Methods

The analysis of the pluviometric regime in the Vedea catchment is based on the data recorded at the two weather stations in the area, namely Stolnici, in the north of the catchment, and Alexandria, in the south. The stations are representative for the entire catchment both from the point of view of the territorial covering and from the point of view of the possibility to extend the datasets by calculation. The first station is representative for the upper section of the catchment and for most of its central part, that is for the piedmontane area and for the north of the plain. The second station is representative for the downstream part of the catchment lying entirely in the plain and drained by the Vedea and its tributaries. The Angot index values have been computed for the interval 1961 – 2000.

1. The specific features of the pluviometric regimes of the Vedea catchment influence the susceptibility to the contemporary geomorphological processes. In order to highlight this, the Angot index has been used, which is computed as follows:

$$I_{\text{Angot}} = (q/n)/Q/365$$

where q is the mean daily amount of precipitation for a given month; n is the number of days of the respective month (except for February, which is considered to have 28 days even in the leap years); Q is the mean multiannual amount of precipitation; and 365 is the number of days in a year (*Indici şi metode cantitative utilizate în climatologie,* 2003).

This index shows the annual variability of precipitation and highlights the rainy ($I_{Angot} > 1$) and the dry ($I_{Angot} < 1$) intervals. Depending on the results, the susceptibility classes to the contemporary geomorphological processes are determined based on the amount of precipitation fallen to the ground (Table 2).

Tabel no. 2 - **Susceptibility classes of precipitations to reactivating geomprphological processes based on Angot Pluvial Index attributes**

Pluviometric attributes	Very dry	Dry	Normal	Rainy	Very rainy
Susceptibility classes	Very low	Low	Moderate	High	Very high
Angot Index value	<0.99	1.00 – 1.49	1.50 – 1.99	2.00 - 2.49	> 2.50

The computing formula of the Angot index has the advantage of characterizing the months of the year from the pluviometric point of view.

2. Cartographic data extracted from topographical maps (scales of 1:25.000 and 1:50000), ortophotos (scales 1:5000) and thematic maps (geologica, hydrogeological, climatic)

3.Climate data (precipitation) taken from different sources, mainy the Meteorological National Administration (MNA), Clima Romaniei (2008), for the weather stations in the investigation area (Alexandria, Stolnici). The analyzed periods are variable, between 1961-2006.

4.Data from field observation and measurements (topographic surveys).

4. Results

4.1. Angot Index analysis

For the Vedea catchment, the Angot index values for the northern section of the catchment (Stolnici) are more than one all year round, with a maximum in July (2.5). In the lower section, at Alexandria, the maximum is reached in July (2.19), while in October the value is less than one (0.88) (Fig. 3). This index shows that in this area of the Romanian Plain the amount of precipitation is higher than in its eastern part, where the values more than one are specific only for the interval April – September. For instance, in the Mostistea catchment the maximum value of the Angot index is 1.47 in July (Ghita & Dragota, 2010). The index also emphasizes that the driest months belong to the cold season.

From the standpoint of the *multiannual regime*, in 83% of the cases July was the wettest month of the year, the maximum value of the Angot index reaching 6.32 in 1980. At Stolnici weather station, January, February, March and October experienced in more than 60% of the cases the lowest mean amounts of precipitation. With the exception of October, which displayed drastic water deficits in 1965, 1969 and 2000, when the values dropped to zero, all the other months of the year recorded maximum annual amounts during the period 1960 – 2000.

At Alexandria weather station, the situation was as follows: the wettest month (June) showed values more than one in 95% of the cases, but values above 2 in only 20% of the cases. The driest month of the year (October) exhibited values less than one in 75% of the cases.

At both weather stations, January was the wettest month of the year in 6% of the cases, a percent specific also for February and October. March, April, November and December were the wettest in 7% of the cases, and May, June, July and August in more than 10% of the cases (July 13.5% and June 12.5%). These monthly percentages determine for the study area the maximum range of temporal variability of precipitation, which in its turn influences the occurrence of geomorphological processes all year round. It is worth mentioning that despite the fact that on a multiannual scale October is the driest month, in 1972, under exceptional conditions, it displayed the highest values of the Angot index (9.2 at Stolnici and 5.61 at Alexandria).

The determination of the annual pluviometric features based on the annual values (K) of the Angot index.

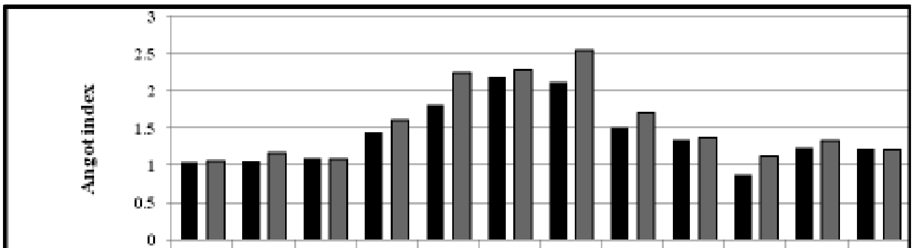
During the interval 1961 – 2000, there was only one year (2000) when the pluvial regime did not offer favorable conditions for the triggering of the contemporary geomorphological processes. This situation was emphasized by the Angot index value, which was lower than 0.99.

The driest years do not create favorable conditions for the triggering of geomorphological processes, because of the weak pluvial impact. At Stolnici station, there are 14 years when the Angot index values did not exceed 1.5. Of the previously mentioned interval, the driest year was 1992, when the Angot Pluvial Index was less than one.

At Alexandria weather station, 12 years with values less than 1.2 are considered dry. These years are: 1961, 1963, 1965, 1982, 1985, 1988, 1989, 1990, 1992, 1996, 1999 şi 2000. In the southern part of the catchment, the year 1985 showed Angot index values less than 1.2 for each month, while the values for 1990, 1992 and 2000 were less than one. Every year has a certain prevalence of the months with moisture deficit.

Table no 3. **The driest 2 years (*K*<1) over 1961-2000** (Vedea catchment)

Weather station	The driest year K< 0,99							
	Year	Pp. annual (mm)	No. of mounth	Dry months	% of months	Rainy months	No. of months	% of months
Stolnici	1992	261.9	10	**I, II, III, V, VII, VIII, IX, X, XI, XII**	83	IV, V	2	
Alexandria	2000	330.2	8	**II, III, V, VII, VIII, X, XI, XII**	66.6	I, IV, VI, IX	4	33.3



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
■Alexandria station	1.04675	1.06525	1.1055	1.45	1.82	2.192	2.12575	1.519	1.3425	0.88425	1.234	1.23025
■Stolnici station	1.1	1.2	1.1	1.6	2.2	2.3	2.5	1.7	1.4	1.1	1.3	1.2

Fig. 3. **Variation of monthly rainfall index Angot - Vedea catchment** (1961-2000)

At Stolnici station, the situation is the following: in the 14 years considered dry, the months with pluviometric deficit vary between 7 and 10 cases (a frequency of 58% and 83% respectively). For Alexandria weather station, the number of dry months ranges from 8 to 12, that is from 67% to 100%. The prevailing dry months with Angot index values less than 1.5 occur frequently during the periods January – April and September – December. In the case of the dry years, the rainy months differ in the north in comparison with the south of the catchment. At Stolnici station, the frequency of the months with pluviometric surplus varies between 2 and 5 (25% and 42% respectively) and the occurrence intervals are May – August and, rarely, December. At Alexandria, the number of rainy months of the dry years is between 0 and 4, that is a frequency of 0 and 33%.

By contrast, the Angot index values have allowed the separation of some rainy years, when *K* was greater than 2, which means the respective years had a high susceptibility of the landscape to the pluvial factor (table 4). The Stolnici station lying in the north of the catchment has a long series of years when the land was exposed to the pluvial factor, as follows: 1966, 1971, 1972, 1979 and 1980. As far as Alexandria station is concerned, the datasets include only three rainy years, namely 1966 (July – 128.8 mm), 1969 (June – 165.8 mm) and 1972 (July – 114.5 mm) (according to Dragota, 2006 and *Clima Romaniei*, 2008). One should note that for both weather stations 1966 and 1972 were very wet years (table 4), which demonstrates that precipitation regime was the same over the entire Vedea catchment.

In the north, at Stolnici weather station, only four months in 1972 (May, August, September and October) exceeded the index value of 2 units, whereas in the south, at Alexandria, only five months were wet (May, July, August, September and October). For both weather stations, the highest Angot index values were recorded in October 1972 (9.2 at Stolnici and 5.61 at Alexandria), which explains the high floods that plagued that year. At Stolnici station, in the five years designated as having a maximum susceptibility to precipitation the rainy months ranged from 4 to 8, that is between 33% and 67% of the year. Generally, the precipitation fell during the warm season, with the exception of 1966 and 1980 when the wettest months occurred in the cold season. At Alexandria, the number of rainy months in the three years considered very susceptible to the pluvial factor was between 5 and 6, that is 42% to 50% of the year. A special situation occurred in 1966, when most of the months having an Angot index greater than 2 belonged to the cold season.

On *a monthly scale*, of the 960 possible cases (the total number of months in the 37 investigated years) the highest frequency (40%) is hold by the very low susceptibility class, followed by the low susceptibility one (18%). In 159 cases (3.15%) the land susceptibility to contemporary geomorphological processes was very high.

In the cold semester, the very low and low susceptibility values are prevalent, while the relative frequencies of the high and very high classes are low.

In the warm semester, the very high and high susceptibility classes prevail, but the medium class has a significant relative frequency.

4.2. Vulnerability

In order to get a comprehensive picture of the degree of influence of the amount of precipitation on the hydromorphological processes the study has also taken into account the monthly frequency of the susceptibility classes for the Mostistea catchment, which lies in the eastern section of the Romanian Plain and experiences different climatic conditions (Ghita, Dragota, 2010).

Table no 4. **The rainiest 2 years (*K*>2) over 1961-2000** (Vedea catchment)

Weather station	The rainiest year *K*>2							
	Year	Pp. annual (mm)	No. of mounth	Dry months	% of months	Rainy months	No. of month	% of months
Stolnici	1972	817.4	4	V, VI, IX, X	33.3	**I, III, IV,VI,VII,VIII,XI, XII**	8	67
Alexandria	1966	787.7	6	II, IV, V, VI, IX, X	50	**I, IV, VI, IX**	6	50

By analyzing the values in Table 5 one can see that 40% of the cumulated precipitation do not have a significant impact on the landscape (*K* < 0.99) in terms of triggering or reactivating the geomorphological processes. With irrelevant exceptions, this situation is specific for the winter months, which in this area are generally dry.

At the same time, 18% of the monthly amounts of precipitation, which lead to Angot index values between 1.00 and 1.49, impose a low susceptibility to the land. These precipitations are distributed all year round, with some differences introduced by the interval of the year when they occur. At Stolnici, only January has 10 cases, whereas at Alexandria there are 15 cases in April and 10 in November.

The occurrence probability below 20% affects the entire catchment all year round, while the values higher than 20% are recorded only in January, April and November. The moderate susceptibility classes (III and IV), which show the considerable impact of precipitation on the landscape through the triggering of geomorphological processes have an annual occurrence probability of 14%. However, the role of precipitation must be weighted by taking into account the properties of loess deposits that cover the south of the catchment, the hydrogeological and morphological properties, as well as the land use in the region. One should note that in the warm season the K values are clustered.

The upper susceptibility classes, with monthly values greater than 2 or 2.5, which encourage the most the dynamics of the channel and slope processes, and especially the floods, are mainly specific for the warmest months of the year (the interval May – July). Higher amounts of precipitation are recorded in June and July, both in the north (with 19 and 18 cases) and in the south (with 11 and 17 cases respectively). The occurrence probability of some intense geomorphological processes is specific for May, June and July, when the frequency exceeds 30%.

High values of the Angot index (*K* = 2.00-2.49), which prove the land is very susceptible to precipitation and floods, have been observed especially in the south during the decade 1961-1970 (in 1966 and 1969 the *K* values being 2.16 and 2.04 respectively). The most important decade from this point of view is 1971-1980, both in the north and in the south. The year 1972 is common for the entire catchment, with K values of 2.20 in the north and 2.16 in the south, whereas 1971, 1979 and 1980 are rainy years only for the southern part of the catchment, with K values varying between 2.00 and 2.20. In this case, the occurrence probability is between 10% and 25%.

The highest annual amounts of precipitation define the very high susceptibility class (*K* > 2.50). In an interval of 40 years, only in 1966 the K value reached 2.60. This happened in the north of the catchment, where the impact of precipitation on the land is obvious, especially on the slopes with higher gradients, which encourage the formation of gullies and torrents.

Table no. 5 **Frequency of susceptibility classes monthly quantities of precipitation**
(Stolnici, Alexandria and Fundulea weather station)

Susceptibility clases	*K* index values (Angot)	Absolute frequency (no. of cases)		Cumulative frequency (no. of cases)		Relative frequency (%)	
		Vedea	Mostistea (Ghita, Dragota, 2010)	Vedea	Mostistea (Ghita, Dragota, 2010)	Vedea	Mostistea (Ghita, Dragota, 2010)
I - very low	< 0.99	386	348	960	444	40	78,3
II - low	1.00 - 1.49	246	74	574	96	18	16,6
III - moderate	1.50 - 1.99	139	16	399	22	14	3,6
IV - high	2.00 -2.49	101	5	260	6	11	1,12
V - Very high	> 2.50	159	1	159	1	17	0,22

If we take into account that for the entire investigated period of time there were 8 cases with moisture surplus (*K* > 2.00), representing a frequency of about 17%, we may contend that at least in the north of the Vedea catchment (where *K* > 2.5) geomorphological processes are to a great extent the result of the high amounts of precipitation. The amplest of these processes are triggered only in the rainy years and especially in the areas with maximum vulnerability.

If we take into account that for the entire investigated period of time there were 8 cases with moisture surplus (*K* > 2.00), representing a frequency of about 17%, we may contend that at least in the north of the Vedea catchment (where K > 2.5) geomorphological processes are to a great extent the result of the high amounts of precipitation. The amplest of these processes are triggered only in the rainy years and especially in the areas with maximum vulnerability.

In comparison with the eastern section of the Romanian Plain (the Mostistea catchment) one can note, however, higher values of the moderate and high susceptibility of the land (17% and 11% respectively, in comparison with 1.12% and 0.22%) (Ghita C., Dragota C-S., 2010). These are mainly encouraged by the amounts of precipitation and the hydrogeological conditions of the territory (the presence of the piedmontane deposits close to the surface – the Candesti Strata in the north and the Fratesti Strata in the south). Under the circumstances, the drainage density has acquired high values, while torrential, channel and slope processes are common (Grecu et al., 2006) (Fig. 4).

A very good example that mirrors the influence of the Angot Pluvial Index and the specific susceptibility classes is the confluence of the Vedea and Teleorman rivers (the Benceni – Smardioasa reach), where the channel dynamics has suffered significant changes over an interval of 36 years (Grecu et. all, 2009, 2010) (Fig. 4). One can see a shortening of the Vedea channel by approximately 2.5 km, on the one hand because of the stream piracy and the migration downstream of some meander loops and on the other hand because of the engineering works accomplished in the last 30 years.

Likewise, the extreme pluviometric events that are mirrored by the land susceptibility to erosion have brought about significant changes in a short period of time. We can mention in this respect the very high values of the monthly Angot index (*K* > 2.5) at Alexandria, when the abundant precipitation made the Vedea River overflow its banks. Such repeated events led to significant changes of the river channels (lateral erosion, stream piracy and accumulation) and to the weakening of the dams built across the Vedea River and its tributaries.

5. Conclusions

The susceptibility of the Vedea catchment to the contemporary geomorphological processes, encouraged by the precipitation amounts (grouped in several susceptibility classes depending on the Angot index values) is predominantly low and moderate. In comparison with the eastern section of the Romanian Plain (the Mostistea catchment), the Angot index values point at a moderate, high and very high susceptibility. The pluviometric events have turned into an important imbalance in the general dynamics of the Vedea morphohydrographic system. The pluvial factor plays an important part in the present dynamics of the topography and together with the local land use and the hydrogeological features, it is responsible for the accelerated dynamics of the landscape.

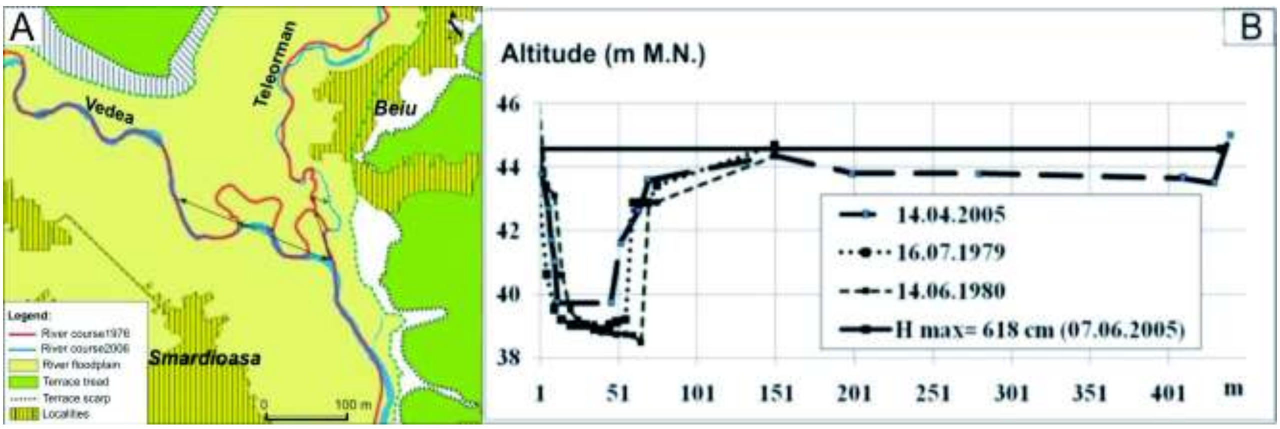


Fig. 4. **The Vedea riverbed dynamics at Teleorman junction** (in plans - A and cross section - B) (downstream Alexandria weather station) (after A.N.A.R. – D.A.A.V, 2008, with modifications)

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