ANALYSIS OF FLOODS IN THE COTMEANA CATCHMENT BASED ON STATISTICAL AND GEOGRAPHIC INFORMATION SYSTEMS METHODS

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ABSTRACT-Analysis of floods in the Cotmeana catchment based on statistical and geographic information systems (G.I.S.) methods.
Knowing the characteristics of floods, as well as the risk areas where they can occur, is nowadays of a major importance for the management of watersheds most affected by water-related hazards. This study aims, on the one hand, to analyze the floods produced in the last 5 decades on the Cotmeana river, and on the other hand, to map the zones where the flash floods can occur in the Cotmeana catchment. The Cotmeana River is located in the central-southern part of Romania, being a tributary of the Vedea River. It has a length of 93 km and a basin area of 495 km². The study is based on statistical processing of the hydrological data series from Ciobani hydrometric station on Cotmeana river from 1964 to 2014. The data was provided by the Argeș-Vedea Water Basin Administration (WBA), which includes annual and monthly data of the maximum discharge, as well as hourly discharge series of selected flood events. The floods were analyzed based on their hydrographs and with the help of statistical processing, the return periods of the maximum flows corresponding to the annual floods were calculated. In ArcGisPro environment, the areas susceptible to flash floods were identified and spatialized with the help of a slightly modified version of the Flash Flood Potential Index (FFPI). This index integrates a series of physical-geographic parameters such as slope, lithology, land use, soil texture, density of the hydrographic network, LS factor, etc., thus allowing the determination of the areas with the greatest susceptibility in terms of the production of flash floods. Apart from the morphographic parameters, frequently used in previous studies, in this study, two important factors in the genesis of floods were included in the calculation of the FFPI: rainfall and snow depth, resulting in a higher susceptibility in the north of the basin.

Keywords: *Cotmeana river basin, Flash Flood Potential Index, floods, statistical analysis*

1. INTRODUCTION

Floods are hydrological risk phenomena, characterized in the first phase by the increase, and then the decrease of the water level of a river (Mustățea, 2005).

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Depending on the favorable factors, such as the climate conditions or the terrain orography, these phenomena can quickly turn into flash floods. Flash floods usually occur in small watersheds, being characterized by the velocity of the rising levels of water in response to high-intensity rainfall or to melting snow in the spring seasons (Liu et al., 2022).

The most common flood analysis method is implies a statistical treatment of the data series, being used to calculate water flow probabilities and temporal variability of hydrological values, in this way increasing the safety of the population (Chaibandit and Konyai, 2012). By means of statistical analysis, daily discharge served as a basis for the monthly and annual hydrographs, whereas the hourly time series were used to calculate the flood events parameters (Drobot, 2020). However, in order to know even better the frequency of floods, it is also necessary to calculate the return periods, with the help of theoretical probabilities, a common method used in hydrology being Log Pearson III (Singh, 1998), showing the discharge corresponding to several return periods.

In recent years, the GIS method has become the most popular in the analysis of geospatial data, especially in the flood risk management. Flash Flood Potential Index (FFPI) represents an index that allows us to identify the areas with high susceptibility to flash floods (Zaharia et al., 2017). This index sums up the values of several geographic parameters, which favour the flash floods occurrence, being calculated differently from one author to another. For example, Zaharia et al, (2012), analyzed the FFPI considering the slope, land use, soil texture, profile curvature and lithology, while Costache (2019), added other parameters such as LS factor, Topographic Wetness Index (TWI) or plan curvature. However, the most important factor that contributes to the formation of flash floods is the climate factor, especially the rainfall and snow depth, the purpose of this study being that one to use these factors as a new method to calculate FFPI over a catchment.

The results of this article are structured in two parts, the first one being focused on the statistical analysis of the floods in the Cotmeana catchment between 1964 and 2014, and the second one being focused on the FFPI computation and distribution.

2. STUDY AREA

The Cotmeana hydrographic basin is located in the central-southern part of Romania, being a part of the Vedea Catchment, (Figure 1.A.). From a physical-geographic point of view the Cotmeana basin is extended on two large relief units: the Getic Plateau and the Romanian Plain.

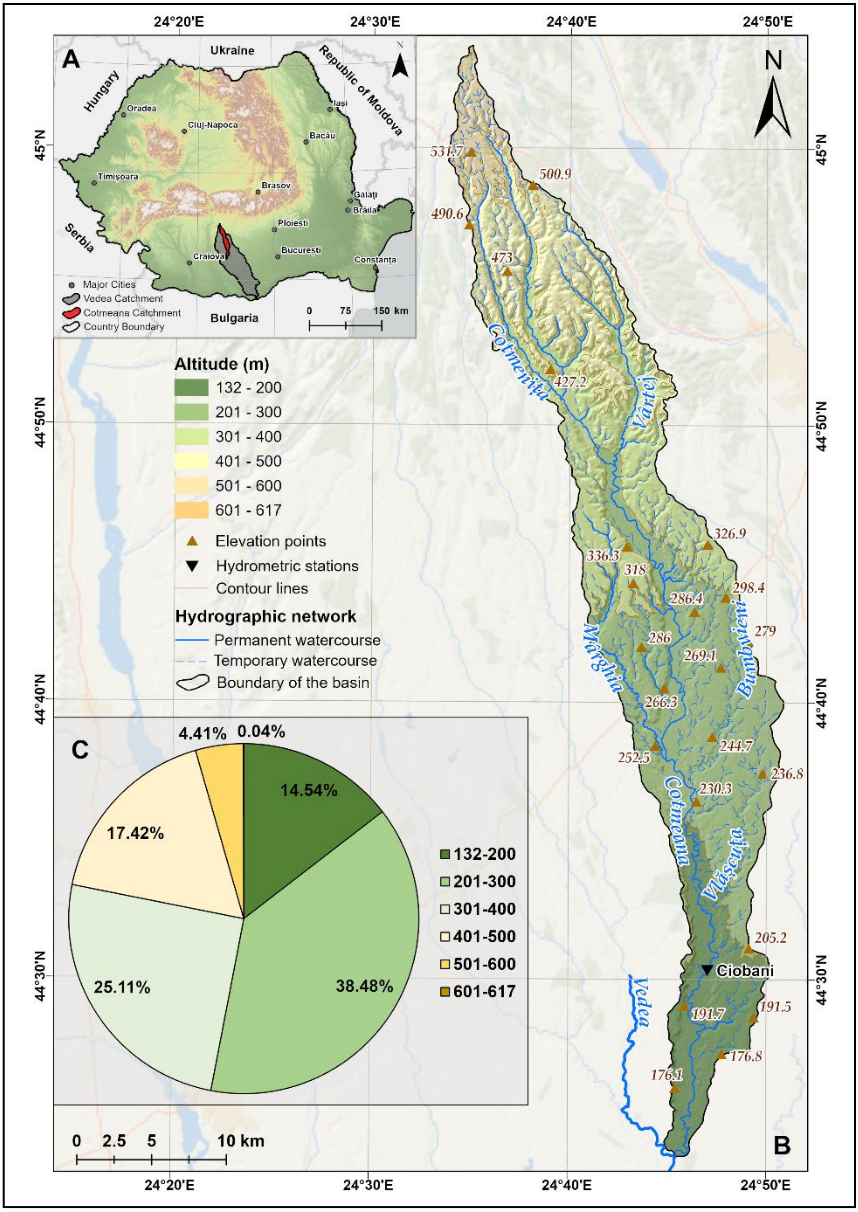

Fig. 1. The Cotmeana catchment. A) Location map; B) Hypshometric map; C) Altitude ranges
Data source: EU-DEM 25 meters

According to Parichi (2001), the general feature of the area is that of a piedmont plain. This implies that the landform rises more and more towards the north, being formed from large valleys and incipient ridges (Posea, 2006). The highest altitude is located in the north of the basin (over 600 m), where the main hydrographic network of the catchment springs (Figure 1.B). The Cotmeana rivers form its torrential system of springs, considered to be the real top of the Vedea system (Ujvari, 1972), on the border with the Subcarpathians, in the Pilești village (Parichi, 2001).

Most of the altitudes (53% of the river basin area) are between 132-300 m, about of the basin area (Figure 3.C), which means that the tributaries of the Cotmeana watercourse are plain rivers with temporary drain regime. The main tributaries that the Cotmeana river receives along its 93 km length are Cotmenița and Mârghia on the right bank and Vârtej, Bumbuieni and Vlășcuța on the left (Atlas of the water cadastre in Romania, 1992) .

The Cotmeana river flows into Vedea, with its river mouth in the Bădești-Băi, at an altitude of 132 m. After the confluence, the Vedea changes its hydrological order, from order VI becoming order VII, as a result of the large contribution that the Cotmeana river basin brings directly into the river bed (Cîrciumaru, 2010).

The Cotmeana river (Figure 2.A.) is monitored by only a functional gauging station, located at Ciobani (Figure 2.B.) in the lower sector of the analyzed river, the other gauging stations being disables in 1990. According to one of the Romanian hydrological regimes classifications (Pișota and Zaharia, 2002), Cotmeana river and its tributaries fall under the Moldavian-Wallachian type, characterising, in these Southern part of Romania, all the autochthonous rivers originating from the Getic Piedmont and the Romanian Plain. This is characterized by high waters and floods during the spring season and by minimum discharge in autumn. In Figure 3.C. the hydrograph of monthly mean discharge at Ciobani station (from 1964-2014) highlights February as the month with the highest flows, with an average of 2,93 m^3/s, while the lowest values are recorded in the months of August, September and November (0,5 m^3/s).

Floods can occur in any season, but most frequently, they have been reported during the summer in the months of June and July. The main causes of the floods in the Cotmeana catchment are precipitations, which varies between 550 and 650 mm, high slope values (over 25º), soil texture, land cover and lithology composed of rocks with high permeability (sands, gravels, loess deposits), which allow the infiltration and the underground circulation of water (Ielenicz and Săndulache, 2008).

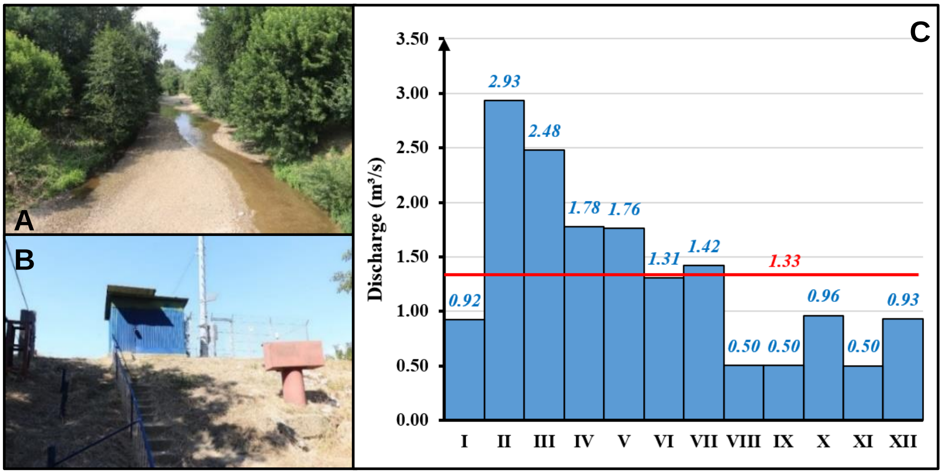

Fig. 2. The Cotmeana river characteristics. A) Cotmeana river; B) Ciobani gauging station; C) Monthly mean discharges (1964-2014) Data source: Argeș-Vedea WBA

2. DATA AND METHODOLOGY

For this study, several methods were used, among them the method of observation, comparison, analysis, statistics and geographic information systems. Excel software was used to create the hydrographs, such as the wave floods and theoretical insurance curve. For the maps of various physical and geographical factors that influence the formation of flash floods, the ArcGis Pro software was used.

The hydrological data of annually and monthly discharge values (1964-2014), and the hourly data for floods (2005, 2014) was provided by Argeș-Vedea Water Basin Administration, being then subjected to several statistical analyses in Excel. They consisted in hydrographs of the annually maximum discharge, monthly frequency of floods and seasonal frequency of floods. In addition to flood waves, the parameters of these floods were also calculated by applying their formula in Excel to the hourly data series of discharge available at Ciobani gauging station. These include the maximum discharge (QMAX); basic discharge at the start of the flood (BQS); base discharge at the end of the flood (BQE); base discharge (BQ); growing time of limb of the hydrograph (GT); decrease time of limb of the hydrograph (DT); total time of the flood (TT); base volume (BW) and drained volume (DW).

The flood frequency was calculated with the help of the Log Person III method, from the site http://ponce.sdsu.edu/onlinepearson.php, that used the methodology elaborated by Ponce (1989). This analysis is more accurate in flood frequencies, because by using the maximum flow values over a certain time interval, it automatically calculates the return periods (T), the probability (P%), frequency factor (K) and their related flood discharge (Q).

Regarding the mapping of the areas susceptible to flash floods, the Flash Flood Potential Index (FFPI) is one of the most common index which was used in several previous studies in Romania (Zaharia et al., 2015; Costache and Zaharia, 2017; Zaharia et al., 2017). To calculate such an index, it is necessary to use several physical-geographical factors that influence the formation of flash floods. As such, in Table 1 are represented the factors used in the mapping of FFPI, and their data source.

Table 1. The parameters and data used for FFPI computation

Nr.	Parameter	Type	Data source
1	Slope (degrees)	Raster	EU-DEM 25 meters (2014)
2	Rainfall (mm)	Raster	WorldClim (1970-2000) Resampled
3	Snow depth	Raster	ERA5 Land (1970-2000) Resampled
4	Drainage Density	Raster	Topographical map of Romania (1981)
5	LS Factor	Raster	Slope Length and Steepness factor for the EU (2015)
6	Land Cover (2018)	Vector	Corine Land Cover (2018)
7	Lithology	Vector	The geological map of Romania (1984)
8	Soil Texture	Vector	Pedological map of Romania (1978)

For each of these parameters, thematic maps were made, as it can be seen in Figure 3 and Figure 4. The slope is relevant for the formation of flash floods, because large slopes also determine high water velocities in channels and on the slopes, for example in the Cotmeana catchment, the highest slopes are located in the northern half. Rainfall is the most important parameter in the formation of these water phenomena, the higher the precipitation, the chances of flooding increase. In the Cotmeana watershed, the rainfall decreases from north (660 mm) to south (550 mm). The snow is equally important, because at the end of winter and especially in spring, it melts, contributing to an additional supply of water to the river. Drainage density is also important because it shows where the most of the water volume is likely to come from (Rai et al., 2017). The LS Factor describes the effect of topography on water and soil erosion, the formula of its calculation being different from an author to another. For this study, has been used the LS Factor values for the entire Europe, published by Panagos et al. (2015).

The land cover is equally important for favouring or impeding the runoff, because some areas that absorb the excess water such as the vegetated ones, while there are other, with no vegetation which favours the flash floods. The lithology, through the rocks' permeability influence the water infiltration rate, the loess deposits from our study basin being characterized by the highest infiltration capacity. Also, the soil texture has the same role as the rock, depending on the hydrological group, presenting different properties. For example, the group A has the lowest drainage capacity, while the group B and C has a moderate one. The group D has the highest drainage capacity, but the lowest infiltration rate (Moroșanu, 2020).

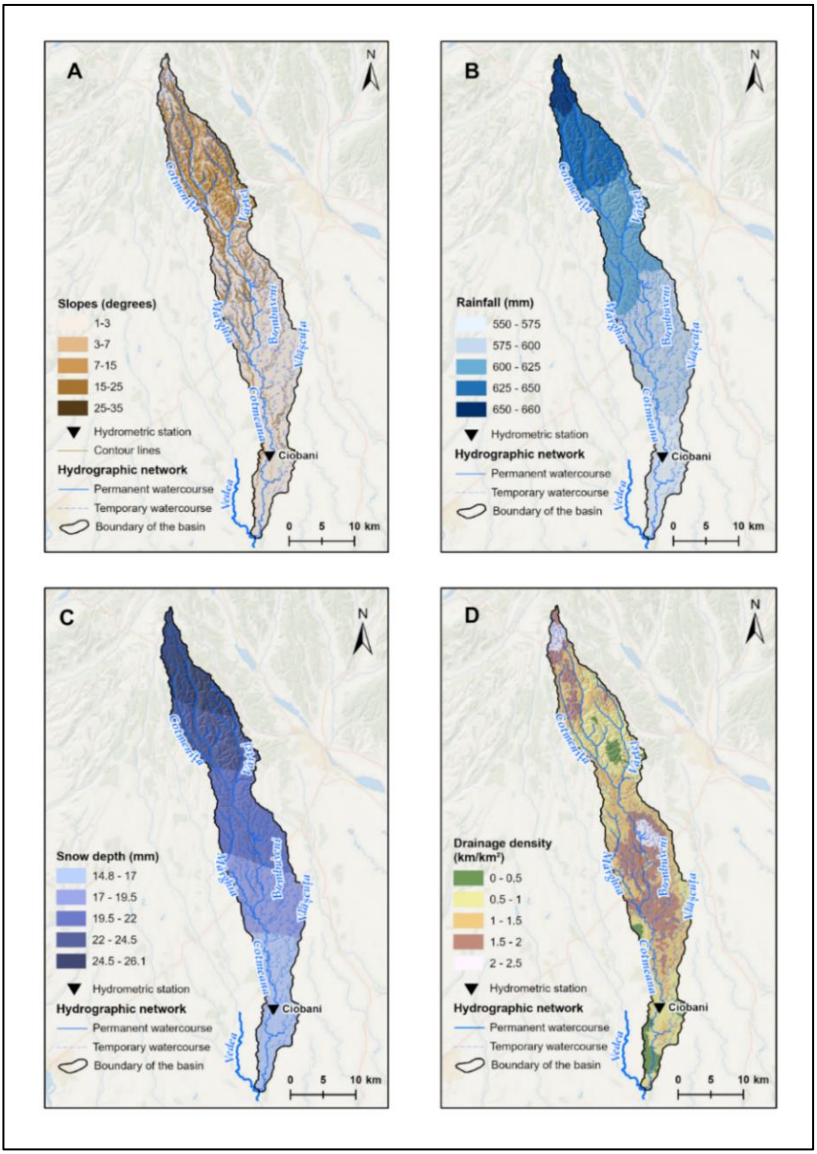

Fig. 3. The maps of used parameters of FPPI (Part I). A) The slope map; B) The rainfall map; C)The snow depth map; D) The drainage map

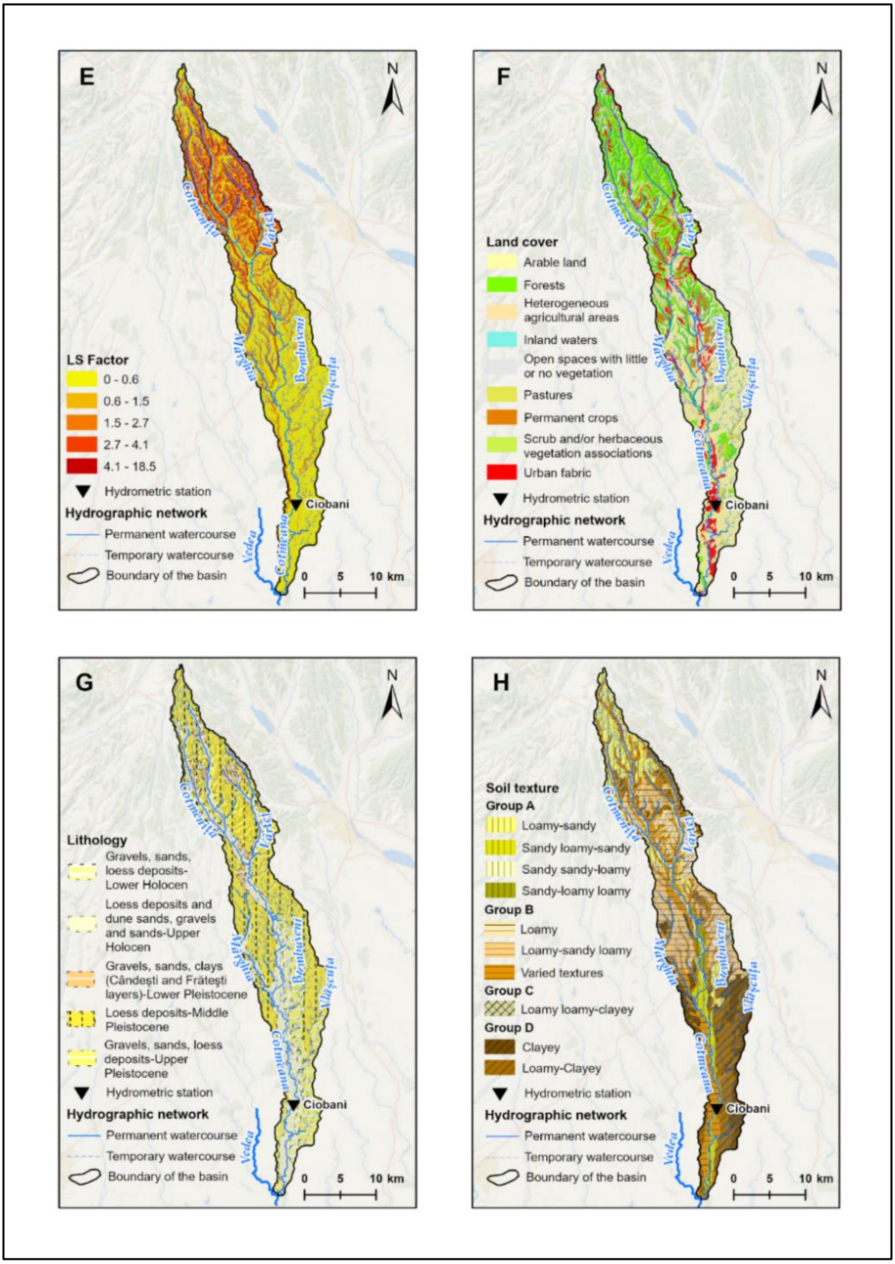

Fig. 4. The maps of used parameters of FPPI (Part II). E) The LS factor map; F) The land cover map; G)The lithology map; H) The soil texture map

Table 3 shows the classification of the physico-geographical factors for the computation of the FFPI, based on their score and the influence. The score has been given according to each parameter classes from 1, which represent the lowest susceptibility to formation of flash floods, to 5 - for the highest susceptibility. Each layer was classified in a raster with the resolution of 25 meters.

Table 2. Classification of the physico-geographical factors for the computation of the FFPI

Parameter			**FFPI Classes**			**Influence**
Slope (degrees)	0-3	3-7	7-15	15-25	25-35	**22.1%**
Rainfall (mm)	550-575	575-600	600-625	625-650	650-660	**25.4%**
Snow depth (mm)	14.8-17	17-19.5	19.5-22	22-24.5	24.5-26.1	**17.9%**
Drainage density (km/kmp)	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	**5%**
LS Factor	0-0.6	0.6-1.5	1.5-2.7	2.7-4.1	4.1-18.5	**10.9%**
Land cover	Forests	Scrub or herbaceous vegetation associations; Permanent crops	Urban fabric; Heterogeneous agricultural areas	Arable land;Pastures	Open spaces with little or no vegetation; Inland waters	**2.2%**
Lithology	Loess deposits - Middle Pleistocene	Loess deposits and dune sands, gravels and sands- Upper Holocene	Gravels, sands, loess deposits- Lower Holocene	Gravels, sands, loess deposits- Upper Pleistocene	Gravels, sands, clays (Cândești and Frățești layers)- Lower Pleistoce	**4.7%**
Soil texture	Sandy sandy-loamy; Sandy loamy-sandy;	Sandy-loamy loamy; Loamy-sandy	Varied textures; Loamy; Loamy-sandy loamy	Loamy loamy-clayey	Loamy-clayey; Clayey	**11.7%**
Score	**1**	**2**	**3**	**4**	**5**	**100%**

As for the influence of each parameter it was calculated based on the AHP method (analytical hierarchy process). This is a decision making method to assist various types of multi-criteria analysis, based on their importance in the process (Vilasan and Kapse, 2022), thus creating a hierarchy of factors. For example, in this study, the slopes exert a higher influence over the runoff formation than the vegetation, but lower than the rainfall; in this case the rainfall being superior to the slope and vegetation. On the base of this prior knowledge, a matrix is created (Table 3), where each factor was assigned a specific weight of intensity based on the Expert's judgement (Choudhury et al., 2022).

Table 3. The decision matrix

Parameter	**Slope**	**Rainfall**	**Snow depth**	**Drainage density**	**LS Factor**	**Land cover**	**Lithology**	**Soil texture**
Slope	**1**	1/3	5	9	1	7	3	1
Rainfall	3	**1**	3	5	3	5	3	1
Snow depth	1/5	1/3	**1**	3	3	7	5	3
Drainage density	1/9	1/5	1/3	**1**	1/3	3	1	1
LS Factor	1	1/3	1/3	3	**1**	5	3	1
Land cover	1/7	1/5	1/7	1/3	1/5	**1**	1/3	1/5
Lithology	1/3	1/3	1/5	1	1/3	3	**1**	1/3
Soil texture	1	1	1/3	1	1	5	3	**1**

The FFPI map resulted from the calculation of all parameters in ArcGisPro (*Raster Calculator* tool) relied upon the next formula:

$$FFPI = (S * 0.221) + (R * 0.254) + (Sd * 0.179) + (Dd * 0{,}05) + (LS * 0.109) + (Lc * 0.022) + (L * 0.047) + (St * 0.117)$$

where:

S=Slope; *R*=Rainfall; *Sd*=Snow depth; *Dd*=Drainage density; *LS*=LS factor; *Lc*=Land cover; *L*=Lithology; *St*=Soil texture

3. RESULTS AND DISCUSSIONS

3.1. Flood analysis

In Figure 5.A. the variation of the annual maximum discharge values of the Cotmeana river at the Ciobani hydrometric station between 1964 and 2014 is showed. These values correspond to the highest flood produced in the study years (annual flood), the general trend being one of decrease. From the analysis of the graph, it can be seen that the year 1970 is distinguished by the highest flow recorded during the analysis period, 526 m^3/s, related to the flood produced on July 8. Also, years with important maximum flows were 1972 (310 m^3/s), 1975 (351 m^3/s), 1995 (328 m^3/s) and 2014 (344 m^3/s). The lowest values were recorded in 1992 (0.52 m^3/s) and 1994 (0.67 m^3/s), these years being the driest of the entire analyzed period.

Figure 5.B. and Figure 5.C. illustrate the monthly frequency of the annual floods and seasonally frequency of these floods of the Cotmeana river, at the

Ciobani g.s. between 1964 and 2014. Most floods occurred during May, thus favoured by abundant precipitation, exceeding 70 mm in this month, in some years. May is followed by June and July, with 6 floods each, but in addition to precipitation, higher temperatures favour evaporation, leading to a their lower peak values and so, a lower frequency of occurrence. Floods also show a high frequency in the months of February (7) and March (8), snowmelt and spring rains being the basis of their formation. September is the month in which the frequency of floods is lower, as a result of the dry period, which continued from August. The highest seasonal frequency was recorded in the spring (41%), the causes being of a climatic nature (rainfall and snow melting). The frequency during the summer is 26%, as a result of the abundant precipitation, while the frequency during the winter is determined by the early melting of the snow in the highlands. In autumn, floods have the lowest frequency, 8% more precisely, being a period of thermal comfort, over which the river dries up.

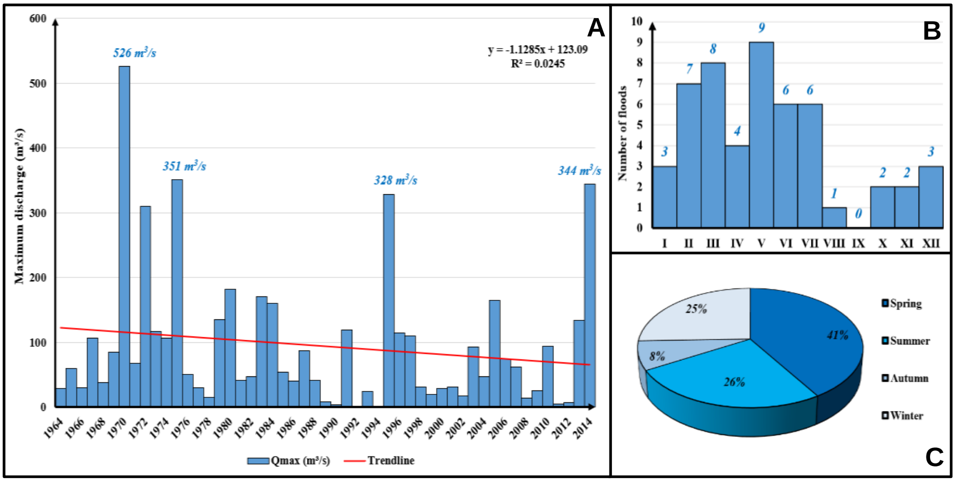

Fig. 5. Characteristics of the floods on Cotmeana river at Ciobani gauging station (1964-2014). A) Annually maximum discharges; B)Monthly frequency of floods; C) Seasonally frequency of floods
Data source: Argeș-Vedea WBA

In Figure 6, two of the highest flood waves recorded at Ciobani gauging station, in June 2005 and July 2014 are represented. The flood from June 2005 was a singular one, with a unique maximum of 165 m^3/s reached on June 9, 11:00 a.m., as it can be seen in Figure 6.A. The initial flow of the flood was 5.6 m^3/s on June 9 at 3:00 a.m. and the final flow was 19 m^3/s reached on June 10 at 10:00 a.m. This was a flash flood lasting 31 hours, with a rise time of 10 hours and a decrease time of 21 hours. The total drained volume is 9,597 million m^3, with a base volume of 1,373 million m^3 and a drained volume of 8,224 mil. m^3.

In Figure 6.B. is represented the July 2014 flood on Cotmeana river. It had a singular peak with a maximum of 344 m^3/s reached on July 30, 5:00 a.m. The initial flow of the flood was 24.4 m^3/s on June 29 at 20:00, and the final flow was 38.8 m^3/s reached on June 30 at 15:00. This was a flash flood with a duration of 19 hours, with a rise time of 9 hours and a decrease period of 10 hours. The total drained volume is 10.805 mil. m^3, with a base volume of 2.16 mil. m^3 and a drained volume of 8.643 mil. m^3. Both floods are have unique peaks and a shape of a triangle. These phenomena were caused by the heavy rainfall in the summer months, then generating damages at the level of the settlements located along the main hydrographic network of the basin.

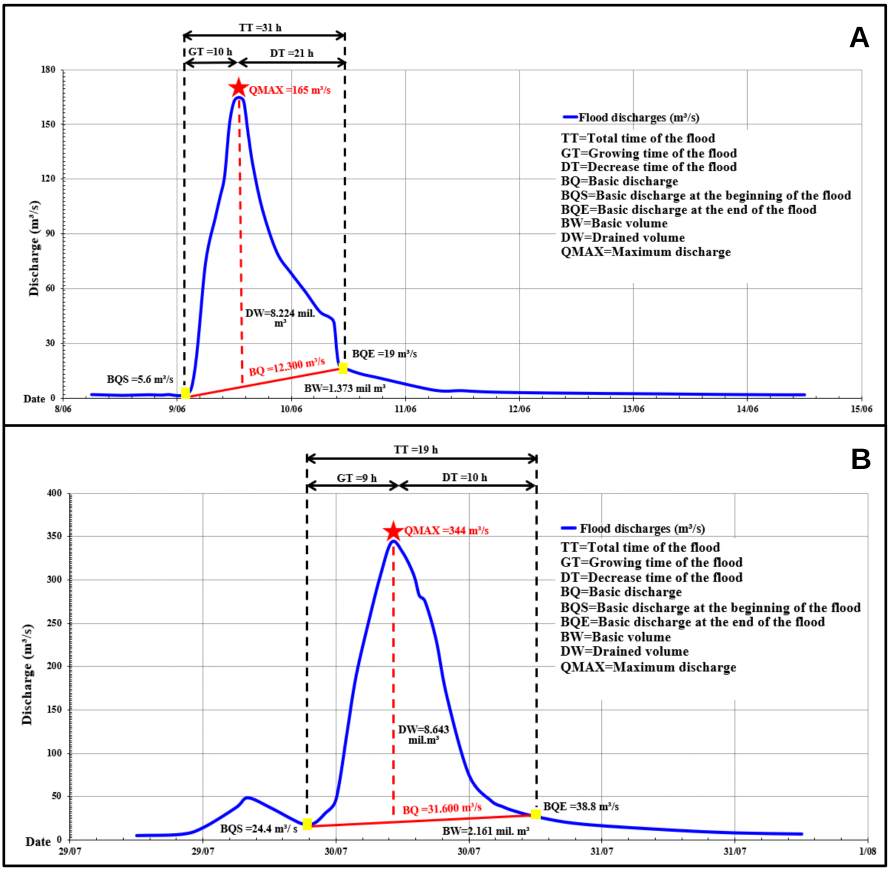

Fig. 6. Flood waves on the Cotmeana river. A) Flood wave from June 2005; B) Flood wave from July 2014
Data source: Argeș-Vedea WBA

In Table 4, the frequency of the annual floods according to Log Person III method is calculated. As it can be seen, the lowest flood discharge has a shorter return period, for example the floods discharge of 3 m^3/s has a return period of 1.05 years, with a probability of 95,2%. Instead, the higher flood discharges a bigger return period, for example the flood discharge of 413 m^3/s has a return period of 200 years with a probability of 0,5% or the flood discharge of 382 m^3/s has a return period of 100 years with a probability of 1%. Also, the maximum discharge recorded in 1970 at the Ciobani gauging station cannot fit into any of the calculated probabilities, meaning that its return period is greater than 200 years. Figure 7 displays the theoretical insurance curve of Log Pearson III method, which has a correlation coefficient (R^2) of 98% between maximum discharges and probability to occur.

Table 4. The frequency of floods results according to Log Person III method based on the annual maximum dicharges between 1964 and 2014)

Nr.	Return period T (years)	Probability P (percent)	Frequency factor K	y = log (Q)	Flood discharge Q (m^3/s)
1	1.05	95.2	-2	1	3
2	1.11	90.1	-1	1	7
3	1.25	80	-0.735	1	17
4	2	50	0.191	2	62
5	5	20	0.845	2	158
6	10	10	1	2	224
7	25	4	1	2	298
8	50	2	1	3	344
9	100	1	1	3	382
10	200	0.5	2	3	413

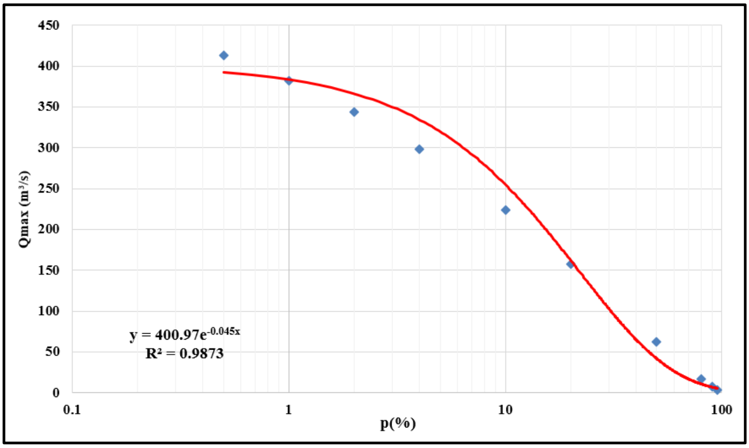

Fig. 7. The theoretical distribution curve Log Pearson III of the maximum annual discharges of Cotmeana River at Ciobani (1964-2014)

3.2. Flash Flood Potential Index mapping

The flash flood mapping represents an effective way to elaborate land use planning and mitigation strategies, in the case of occurrence of such a hazard (Alarifi et al., 2022). In the Cotmeana catchment, the flash floods are likely to have the highest susceptibility of occurrence in the northern part of the basin, as it can be seen in Figure 8.

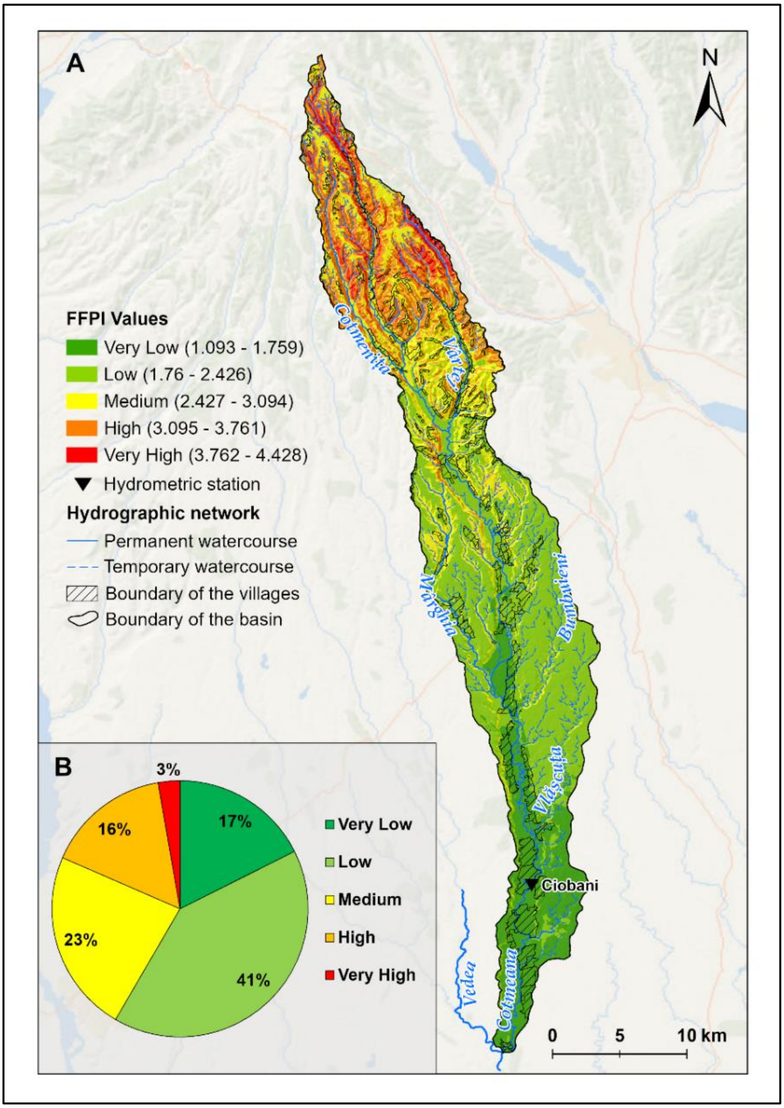

Fig. 8. Flash flood potential index map A) Cotmeana catchment FPPI distribution; B) FFPI values ranges

Areas of high and very high values of FFPI occupy nearly 20% (140 km^2) of its total basin surface, being determined by the high values of the climatic factors from the north of the basin and by the high slope values of the Cotmeana Piedmont. The medium values occupy 23% (78 km^2). The FFPI values decrease in the southern part of the catchment where the low and very low values occupy an area of 41% (164 km^2) and 17% (107 km^2), respectively.

Regarding the settlements distribution in relation to FFPI values, just 6% (3,7 km^2) of them are located in areas with high and very high values of FFPI. 23% (13,8 km^2) of villages in areas with medium values of FFPI, while more than 70% (34,5 km^2) are located in areas with low and very low values.

Even if more than 50% of basin has a low susceptibility to flash floods, and more than 70% of settlements are in areas with low values of FFPI, this does not necessarily imply that floods in the upper sector of the basin do not influence its lower sector. Therefore, the highest floods that caused damages, were recorded in the southern half of Cotmeana catchment, where numerous settlements are located. Among them, the flood of 2014 has been the most recent.

4. CONCLUSIONS

In conclusion, in this study, based on statistical methods, the floods produced in the period 1964-2014 in Cotmeana catchment were analyzed and the areas susceptible to flash floods were mapped.

In the Cotmeana catchment, annual floods have the highest frequency in spring, as a result of melting snow, but they can also occur in other seasons (summer and winter), being conditioned by precipitation. The years with important floods were 1970 (525 m^3/s), 1975 (351 m^3/s) and 2014 (344 m^3/s).

Statistical methods represent a benchmark for causing flood return periods, within the study area, floods with a flow rate of approximately 400 m^3/s having a return period of 200 years, while floods with a flow rate of 60 m^3/s having a return period of only 2 years. The FFPI shows that the highest susceptibility of the flash flood occurs in the norther sector of the Cotmeana basin, the climate factors and the slope being the most important parameters in their genesis.

Therefore, the higher susceptibility in the northern sector of the basin, field validation of the areas with high FFPI values is envisaged, more precisely the mapping of the torrential mechanisms which determine flash floods.

Finally, the importance of such a study is given by the need to adopt new flood risk reduction measures to protect population and settlements.

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