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Frequency of Floodplain Spills in the Tisza River Valley at Vylok (Transcarpathia, Ukraine)

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Abstract: Record-breaking floods occurred in the autumn of 1998 and the spring of 2001 in the lowlands of Transcarpathia, as well as in the areas of Hungary and Romania bordering Ukraine, which caused severe damage. Our research was to determine the frequency of floods. The fluctuation of precipitation values brings about the increased frequency of the rivers' inundation as well. The research is based on the data of the Tisza River's inundation onto the flood plain near Vylok, as well as the precipitation data of the Rakhiv meteorological station. Both data series include the data of the latest 46 years (1970-2015), highlighting the pre-flood period of 1970-2001. To evaluate the data, we used linear trend analysis, which was edited using the Microsoft Excel spreadsheet program. The results of the study showed that no particular changes in precipitation were observed, but the frequency of flood waves and the coverage of the floodplain with water showed a gradually increasing trend. The results of studying the amount of precipitation and the Tisza River's inundation: in recent decades the frequency of flood wave formation and the coverage of the flood plain with water show a gradually increasing tendency.

Key words: Transcarpathia, floods, precipitation, flood plain, inundation.

1. Introduction

Humans can not yet fully control the forces of nature. We also experience the forces of nature, the negative phenomena, processes and situations they cause, thus inflicting significant damages. They include the most common negative phenomenon—floods. High flood waves occur almost every year in Transcarpathia complicating humans' vital functions, destroying buildings, influencing production processes and causing damage to nature.

Floods as watercourse regime phases are repeated in the course of the year and are characterized by intensive increase of the riverwater level due to heavy rainfalls, snow melting or their combination. At the time of floods the water overflowing into the catchment area (flood plain) covers vast territories. Floods have their consequences: vast territories covered with water, wreck of buildings and structures, damage to public roads and railroads, death of game and farm animals, washout of agricultural land, spread of infectious diseases, deterioration of water and food quality, and migration of the population.

Before regulations were introduced (17th and 18th centuries), the correspondence between counties at the time testified the flood prevention work in Ung and Bereg Counties, the embankment breakthroughs, their repairing, and erection [1].

In Ukraine, to investigate the causes of the floods, the Ukrainian Academy of Sciences has set up special committees to study the causes of the floods of November 1998 and March 2001. They examined the procession of the floods and the damages caused. The Final Report of the Ukrainian Academy of Sciences [2] lists the natural (heavy rains, accumulation of flood waves) and anthropogenic (forestry, agriculture, water management, industrial, infrastructure, built-up, organizational, financial and technical) factors that have caused the floods.

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Koval [3] highlights the change of climatic conditions among the main factors leading to the occurrence of significant floods. Temperature and hydrological processes, the moisture content of the soil layers close to the surface changed the ecological conditions of the forests and reduced their water regulatory capability. The other important factor is man's economic activity. The size and frequency of floods are fundamentally affected by the functioning of agriculture, forestry and other components in these sectors.

The water regulatory function of mountain forests and ground cover plays an important role in the development of catastrophic floods. This was pointed out by Kolodko and Tretyak [4] in 2004, who said that significant logging in mountain forests in the 1950s, 1960s and 1990s became a determining factor in the development of floods in the 20th century.

Kuzik [5] noted in an article on the formation of floods that forests are simply not able to cope with the occasional heavy rainfall.

Researchers of the Budapest University of Technology and experts of the Upper Tisza Water Directorate, among others, were involved in the research of outstanding flood waves in the Upper Tisza region in 1970, 1998 and 2001. Many of the flood research experts studied the formation and impact of the catastrophic floods in the Upper Tisza region in 1970, 1998 and 2001. Lászlóffy and Szilágyi [6] dealt with the weather conditions of the 20th century and the water regime of rivers, as well as the factors of the formation of floods. Vágás [7] wrote about the hydrological characterization of the flood waves on the Tisza, the need to create emergency reservoirs, and the improvement of forecasts and flood protection measures. Szlávik and Vágás [8] dealt with the floods of the Tisza Valley, the current state of flood protection and further developments. Illés and Konecsny [9] showed that the impact of human interventions on runoff increased appreciably, the change in the runoff conditions of the catchment was associated with the decrease of the forested area, the changes in agriculture and the effect of urbanization.

We started studying floods in Transcarpathia after the catastrophic floods in 1998 and 2001. The studies of floods focus mainly on the extent of increase or decrease of flood frequency in Transcarpathia, the number of days the water remains on the flood plain, as well as the regularities that can be observed in the nature and course of the floods. We ordered data from the Uzhhorod Office of the Transcarpathian Hydrometeorological Centre.

The research so far has not covered the trend of precipitation intensity in the upper reaches of the river (Rakhiv), which may have an impact on the formation of flood waves, and the frequency and monthly distribution of floods in Vylok, where the Tisza already has lowland features.

2. Location of the Research Territory

2.1 Geographical Location

Transcarpathia is situated in western Ukraine (Fig. 1), to the south-west of the Verkhovyna Dividing Ridge in the north-eastern Carpathians. Its territory is 12.8 thousand km^2 (2.1% of Ukraine's territory), thus occupying the 23rd place among the country's 24 regions [10]. It can be divided into two big geographical units: the highland territory of the Carpathians and the area of the Transcarpathian lowland. The county is the wettest region of the country (600-1,400 mm), where rivers often have more or less water level fluctuations.

Transcarpathia is Ukraine's westernmost region. It is almost equidistant from the North Pole and the Equator. It is almost 2,000 km from the Atlantic Ocean, which has a major impact on its climate. The nearest sea is the Black Sea, at a nearly 500 km distance. The region borders on Poland in the north-west, Slovakia in the west, Hungary in the south-west, and Romania in the south. In the north and north-east, along the Dividing Ridge of the Carpathians, it borders on Ukraine's L'viv and Ivano-Frankivsk regions.

Fig. 1 Location of Transcarpathia on the map of Europe.

Administratively, Transcarpathia (Zakarpattia oblast) from July 2020, is subdivided into 6 raions, the largest being the Khust (3,200 km^2) and the smallest is the Berehove (1,500 km^2) raion [11].

2.2 Relief

Almost 80% of the county's territory is occupied by medium-high and low mountainous terrain, the north-eastern ranges of the Carpathians (Ukrainian Carpathians). The Ukrainian Carpathians are a characteristic medium-altitude mountain range with rounded hilltops and sloping hillsides. The line of bearing of the ridges is northwest-southeast. Its highest point is Hoverla with 2,061 meters. The Transcarpathian lowland, that occupies the southwestern part of the county, has a flat relief.

2.3 Rivers

In Transcarpathia the amount of precipitation and the variability of the relief facilitated the formation of a dense network of rivers. There are nearly 10,000 rivers in the county, among which four rivers (Tisza, Latorca, Ung and Borzsa) exceed 100 km in length. The density of the river network is 1.7 km/km^2 [12].

In the vast majority, the county's river network belongs to the right bank of the Tisza river basin. A significant part of the rivers originates in the mountainous part of the Carpathians and their flow direction is northeast-southwest. They are fed mostly by rainwater (40%), melting snow juice (30%) and groundwater (30%). The long-term average of the specific runoff is 19.8 L/s/km^2. During the flood period (March-May) 55-70% of the annual runoff occurs [12].

The course of the Transcarpathian rivers changes greatly during the year. Frequent water level fluctuations, spring floods and early summer green floods, caused by melting snow and rain, are typical. Floods often occur as a result of the Mediterranean climate, especially during the autumn-winter period. The inequality in relief between the mountains and the hillsides contributes to the rapid rise of water in the rivers and its quick subsidence, i.e. the high water level rarely lasts for more than 4-8 days. Low water levels only occur during prolonged periods without rain or low temperatures at < 0 °C.

The largest river in the county is the Tisza, a left-bank tributary stream of the Danube. It originates at Rakhiv, at the confluence of the Black and the White Tisza source lines. Tisza's length in the county is 201 km. The whole area of Transcarpathia belongs to the Tisza river basin [12]. The fall determined by the Google Earth website (www.googleearth.com) between the source of the Black Tisza (1,260 m) and the Vylok Bridge (115 m) is 1,145 m.

The runoff of the Tisza is very variable. It is only 30 m^3/s at low water level, but can exceed 3,000 m^3/s during floods [6]. The reason for this fluctuation may be that the source region of the Tisza is one of the wettest parts of the catchment area, and the floods of the river's tributaries may accumulate on top of each other.

2.4 Vegetation

Transcarpathia has a diverse flora. The county belongs to the European deciduous zone. There are 2.6 thousand higher plant species, 650 moss and 860 lichen species in its territory. Mountain and lowland plant associations differ from each other. The natural vegetation has undergone significant changes as a result of human economic activity, especially in the lowlands and low mountain areas. Based on the current vegetation, the lowland part can already be classified as belonging to the forest-steppe province [12].

The greatest botanical value of Transcarpathia is the forest, the area of which has been growing steadily since the 1970s, and now covers more than half of the county's area (52%) [10]. The level of forest coverage in the lowlands is below 10%. The most common tree species in the mountains are beech, oak, spruce, fir, in the plains—oak, hornbeam, beech, aspen, alder. Altitudinal zonality of the vegetation can be observed in the mountains.

3. Research Methods and Data Sources

The earliest reliable and continuous data sets were found from the year 1970, which is why we chose this year, among others, as a starting point.

To determine the frequency of floodplain spills (Vylok) and to evaluate and compare the climatic elements on monthly basis, we used the data of the data warehouse of the Transcarpathian County Hydrometeorological Centre [13, 14], which has several measuring stations in Transcarpathia.

The change of precipitation values at the Rakhiv (Fig. 2) meteorological station (531 m above sea level) was determined by statistical processing of monthly meteorological data from 1970-2015, taking into account the period (1970-2001) preceding the catastrophic floods in 1998 and 2001. Rakhiv is situated at the eastern, mountainous part of Transcarpathia, in the source region of the Tisza. Vylok is situated in the western, lowland part of Transcarpathia's Vynohradiv raion, at the Ukrainian-Hungarian state border, thus here the Tisza becomes a boundary river between Ukraine and Hungary.

In the course of the assessment, we placed special emphasis on the linear trend analysis. The calculations and graphs were created and edited in Microsoft Excel.

4. Precipitation Data, Forest Coverage

4.1 Climatic Conditions

Transcarpathia has a humid-continental climate. It is influenced by oceanic and continental air masses of the temperate zone, and to a lesser extent—by tropical and arctic air masses. The Carpathian Mountains are particularly important in the climate formation. Mountain ridges prevent the intrusion of cold, arctic air masses into the Carpathian Basin,

Fig. 2 The location of Vylok and Rakhiv in Transcarpathia.

increase convective air movement, thus bringing about heavy rains, which cause floods and landslides, rock and mud avalanches.

The eastern part of Transcarpathia is one of the wettest parts of the Carpathian Basin. As the relief heightens, the amount and intensity of precipitation increase. Most of the precipitation falls in the form of rain in the lowlands and in the form of snow in the mountains. A coherent snow cover forms in mid-November (mountains) and late December (lowland), which mostly melts by beginning of March (lowland) and early April (mountains). The yearly average rainfall in the south-western, lowland part of the county is 600-700 mm, while in the eastern, mountainous part it reaches 1,400-1,500 mm [12].

The river basin of the Tisza in Transcarpathia is in a special situation in terms of the formation of floods, because in the south-western foreground of the mountain system there is a large Holocene basin. As a result, the Maramureş Mountains represent an average elevation “barrier” of 1,000-1,500 m in front of the high-humidity air masses flowing from the southwest. Thus, the warm fronts of the frequent Mediterranean cyclones (hot conveyor-belt) turn into stagnant (stationary) fronts, so that in one day more than average precipitation falls on the south-western part of the mountain system, i.e. on the Tisza river basin.

4.2 Changes in the Annual Rainfall in Rakhiv

In Rakhiv the highest amount of precipitation was registered in 1998 (1,693 mm), while the lowest amount was in 1991 (883 mm, Fig. 3). In the period under analysis between 1970 and 2015, above-average (1,243 mm) precipitation occurred in 21 years, while below-average precipitation was observed in 25 years.

Based on Fig. 3 and with the help of the trendline one can detect no changes in the average precipitation for many years.

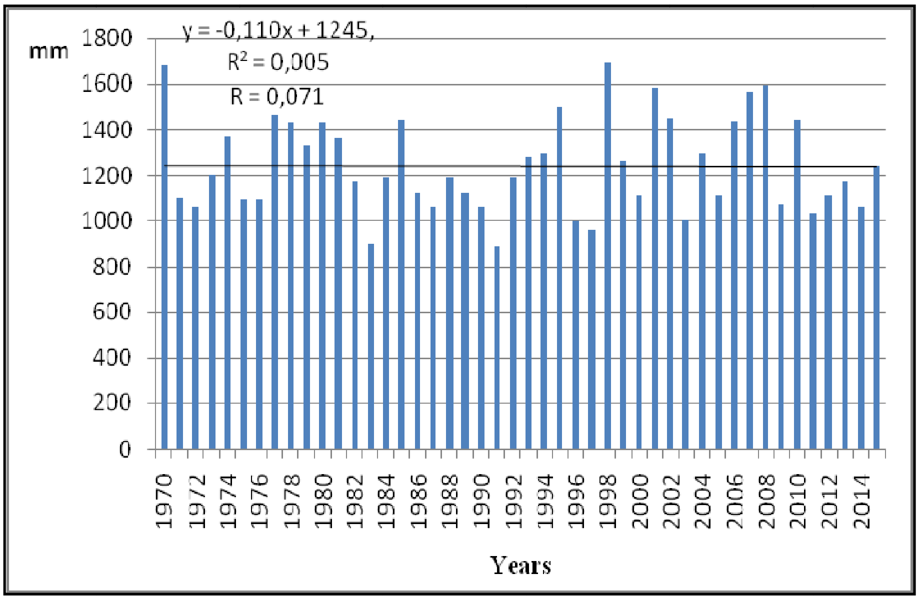

Fig. 3 Formation of the annual average precipitation in Rakhiv between 1970 and 2015 (based on the 2010, 2016 archives of the Transcarpathian Hydrometeorological Centre [13, 14]).

There has been a high amount of monthly precipitation (over 200 mm) in Rakhiv almost every year. It had not occurred before 1998 that in three months of a year the average amount of precipitation exceeded 200 mm, however, since 1998 it was registered thrice (in June, July and October of 1998; in March, June and September of 2001; in March, April and August of 2006). In the period preceding the March 2001 flood in the course of four days (March 2-5) 197.1 mm precipitation (7.5 mm; 25.5 mm; 71.9 mm; 92.2 mm) was registered in Rakhiv, thus causing a significant flood wave. Examining the amount of precipitation during the floods, we concluded that the formation of floods requires a water mass above the average daily precipitation of 40 mm for one or more days [12].

If we select the period preceding the 1998 and 2001 catastrophic floods (Fig. 4), we can observe that the average precipitation values do not show any significant changes; moreover, the trendline presents a slightly decreasing value.

Based on the two data sets, it can be concluded that there were no significant changes in the annual precipitation during the whole study period (1970-2015) as well as in the two pre-flood periods (1970-2001). On the other hand, there was an increase in short-term rainfall over a few days, which in the plains, in most cases, caused the flood wave to exit into the floodplains.

4.3 Changes in the Forest Coverage in Transcarpathia

The main water regulating role in the mountains is played by the forests. The crowns of the trees can absorb 25-35% of the falling rain. That is, increasing the size of forest-covered areas can reduce the amount of water flowing down. The water regulatory role of the forests has not been considered in the past, although there is a complex relationship between the forest coverage and the water management that is affected by climate change over time. In the post-war years the area was affected by intensive logging. In ten years, from 1947 to 1957, 73 million m^3 of trees were felled in the Carpathians which made up 20% of the whole forest coverage. Forested areas were later reforested, but their role as water regulators was significantly reduced [12].

In Transcarpathia, forest coverage (Fig. 5) decreased by 35.8% (from 76.9% to 41.1%) between 1870 and the end of the 1960s, and then increased from the 1970s onwards, currently reaching 52%.

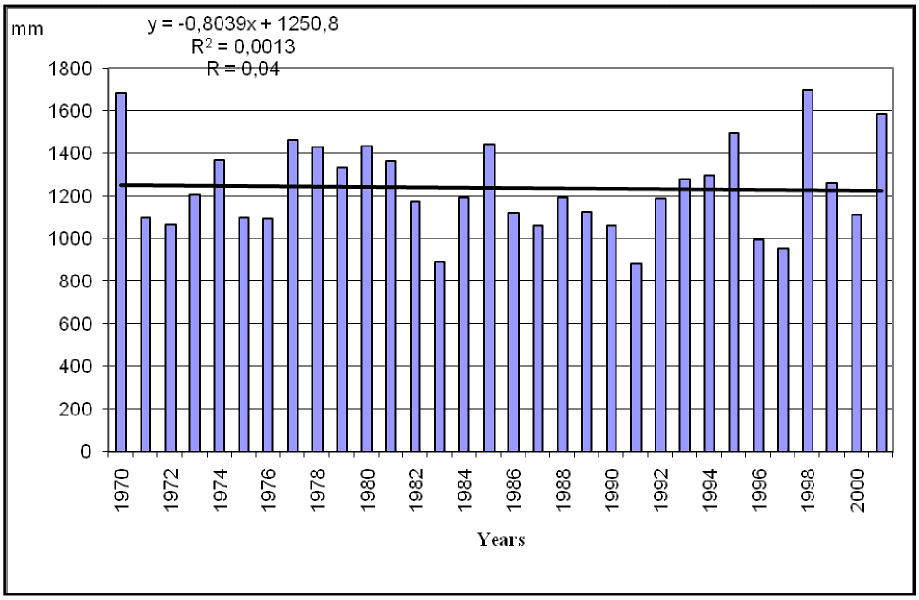

Fig. 4 Formation of the annual average precipitation in Rakhiv between 1970 and 2001 (based on the 2010 archives of the Transcarpathian Hydrometeorological Centre [13]).

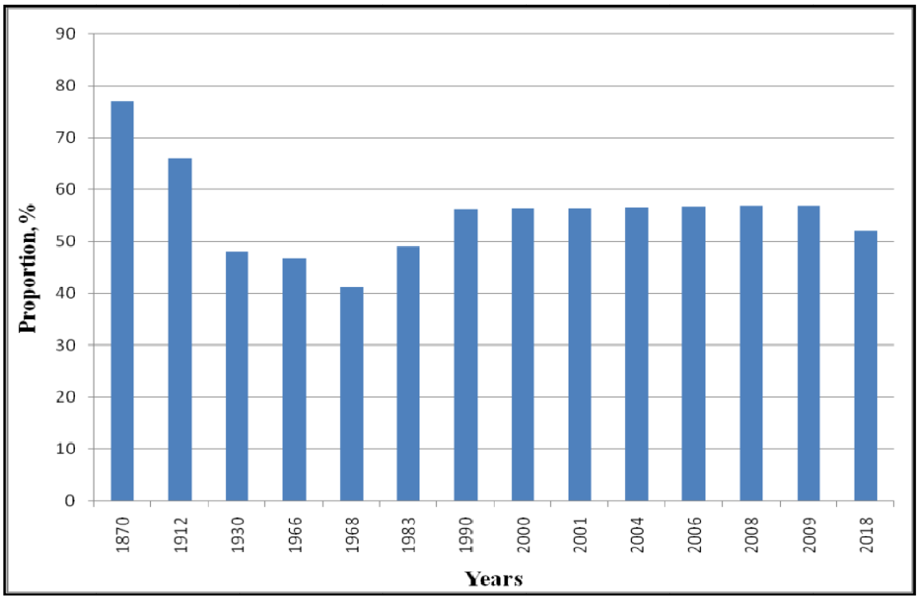

Fig. 5 Changes in the forest coverage of Transcarpathia from 1870 to the present day [8].

The Ukrainian Academy of Forestry [15] conducted a study on the causes of floods, the results of which were summarized in a study. The report highlighted that in recent decades (especially in 1947-1957) there has been an intensive deforestation in the mountainous areas, which led to a significant reduction of forest areas. However, the main cause of the catastrophic floods of recent years has been the heavy rainfalls, the effect of which can not be sufficiently reduced even by the forests that are not affected by human economic activity [15].

5. Flood Frequency Caused by the Tisza River in Vylok and Its Neighbourhood

An increase in precipitation values causes a growth in frequency of the river runoff. The increase in the length of the data series makes it possible to characterize the floods not only by the height of the flood waves, but also by their frequency. Flood protection systems provide protection in a river valley at a certain water level, but floods can cause serious damage if the water exceeds this level. That is, determining the frequency of spills can help with risk liability (establishment, maintenance, improvement of flood protection systems etc.)

The absolute altitude of the Vylok Tisza Bridge water gauge (Fig. 6) is 115.15 metres. At the time of its inundation into the catchment area the Tisza River's water level is equal to or exceeds 380 centimetres above the absolute altitude of the flood meter's 0 point. Big flood wave is achieved in case of the flood exceeding 600 cm water level. In the period under analysis, such situation occurred five times: in May 1970 (696 cm), in December 1978 (603 cm), in November 1998 (660 cm), in March 2001 (686 cm) and in December 2010 (629 cm). In other words, the highest-level flood wave in the period under study was formed in 1970.

In the period from 1970 to 2015 the river flowed over into the catchment area 32 times. In general, the water remained in the catchment area for a day or two and then retreated. However, there were cases when the catchment area was under water for three or even four days.

If we only take into account the occurrence cases, we can see that in the period of 1970-2015 the frequency of the Tisza River's inundation into the catchment area near Vylok shows a decreasing tendency (Fig. 7). On the other hand, taking into account only the period preceding the catastrophic floods (between 1970 and 2001) this frequency was increasing (Fig. 8). Figs. 7 and 8 show an increased frequency of floods in the period between 1977 and 1986, when there were inundations into the catchment area every year except 1982 and 1984. 1979 stands out as the year, when floods occurred 3 times and the water covered the inundation area for 5 days. In addition, 1995 stands out for the flood wave has covered the catchment area 4 times.

At the time of the catastrophic floods the water remained in the catchment area for three days (November 5-7) in November 1998 and for four days (March 4-7) in March 2001.

The inundation frequency of the Tisza River and the correlation coefficient of the years equal to 0.15 and 0.16 respectively (the critical values of r for 46 years are 0.29, for 32 years—0.35), which is not a significant change on a 95% probability level [16].

Comparing the frequency of floods and the formation of the precipitation values we did not find correlation between the two phenomena. The floods did not become more frequent with the growth of precipitation.

Fig. 6 The water gauge at the Tisza River Bridge in Vylok (Izhak, 2012).

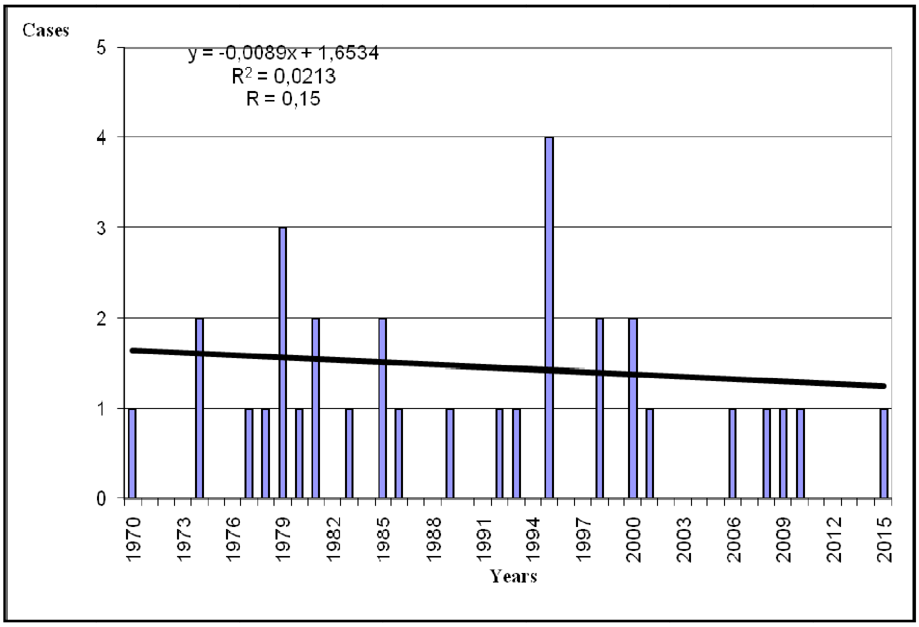

Fig. 7 Frequency (number of cases) of the Tisza River's inundation onto the flood plain in 1970-2015 (based on the 2010, 2016 archives of the Transcarpathian Hydrometeorological Centre [13, 14]).

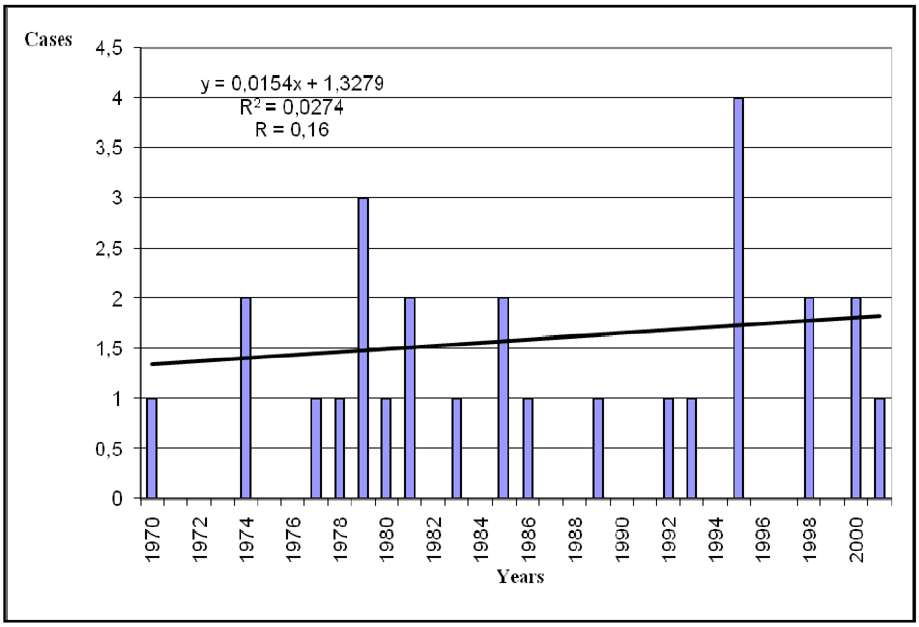

Fig. 8 Frequency (number of cases) of the Tisza River's inundation onto the flood plain in 1970-2001 (based on the 2010 archives of the Transcarpathian Hydrometeorological Centre [13]).

If we analyse the river's inundation into the catchment area on a monthly basis (Fig. 9), we can see that in the course of 46 years there were no floods in August and September, while December stands out in this respect (with 8 cases). The number of inundations in decreasing order: 5 cases in March; 3 cases in January, April, May, and November; 2 cases in June and July; 1 case in February and October.

We reached different results on the frequency of the Tisza River's inundation by analysing the number of days. In both cases, in the period of 1970-2015 (Fig. 10) and 1970-2001 (Fig. 11) the trendlines show an increasing tendency.

Studying the Tisza River floods, the year 1995 stands out for it is the year when the river inundated into the catchment area 4 times (03.29; 04.29;

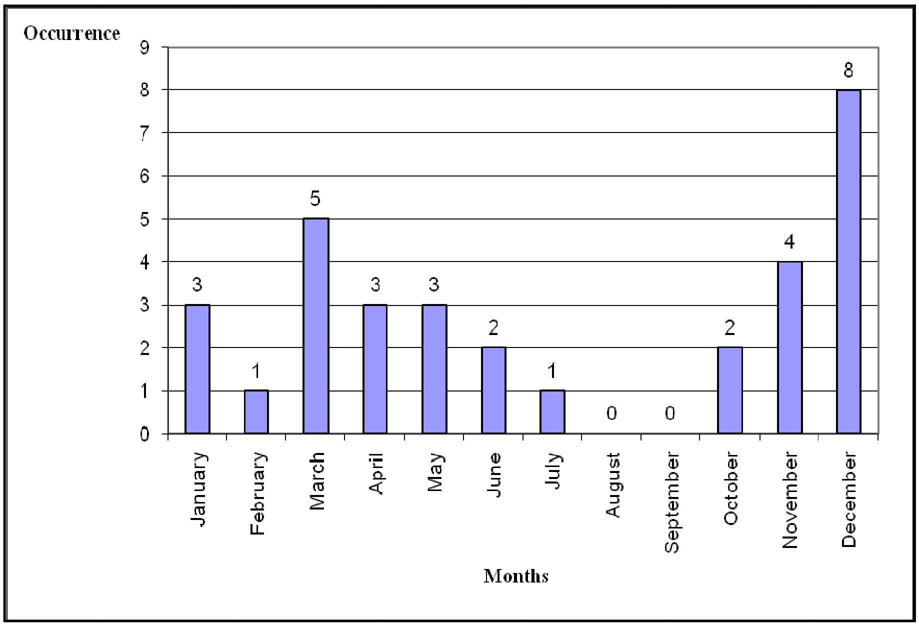

Fig. 9 The occurrence of floods per month between 1970 and 2015 (based on the 2010, 2016 archives of the Transcarpathian Hydrometeorological Centre [13, 14]).

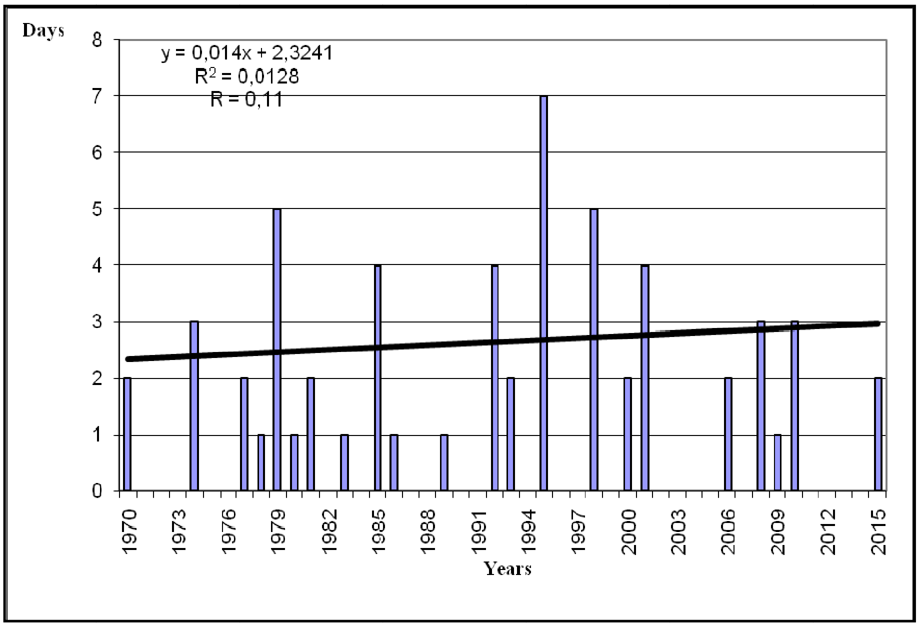

Fig. 10 Frequency (number of days) of the Tisza River's inundation onto the flood plain between 1970 and 2015 (based on the 2010, 2016 archives of the Transcarpathian Hydrometeorological Centre [13, 14]).

11.18-19; 12.25-27) and the water coverage lasted for 7 days. One more interesting characteristic of the data series is that the floods occurred almost regularly, every three years (from 1994 to 2001) and the periods without floods were not longer than two years. Longer periods without floods (3-4 years) occurred in 1971-1973, 2002-2005 and 2011-2014.

During the mentioned catastrophic floods, in 1998 the river covered the catchment area twice for 5 days, while in 2001 it did so once for 4 days.

The inundation frequency of the Tisza River and the correlation coefficient of the years equal to 0.11 and 0.38 respectively (the critical values of r for 46 years are 0.29, for 32 years—0.35), which, on a 95%

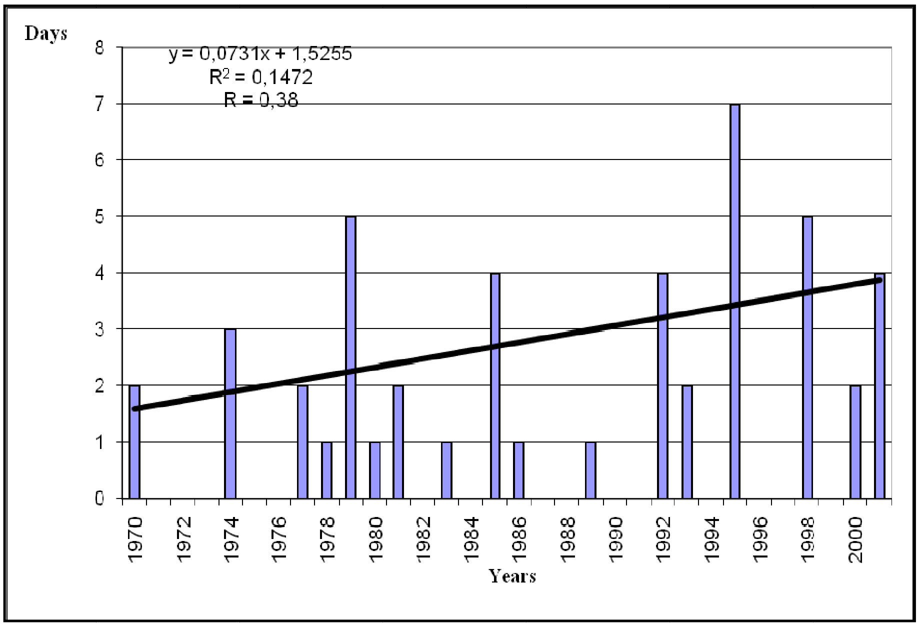

Fig. 11 Frequency (number of days) of the Tisza River's inundation onto the flood plain between 1970 and 2001 (based on the 2010 archives of the Transcarpathian Hydrometeorological Centre [13]).

probability level is not significant for 46 years, but renders significant changes likely in the 32-year period preceding the catastrophic floods (1998 and 2001) [16].

Floods have not become more frequent, however in the course of the 46 years under analysis, the flood plain's coverage with riverwater increased; i.e. the amount of water passing during the floods could become higher.

6. Conclusions

Analysing the Tisza River's inundation into the catchment area we have come to the conclusion that there is no complete correlation between the annual average precipitation and the frequency of occurring inundations. At the meteorological station under analysis the years with the highest amount of precipitation were 1970 and 1998, while the majority of floods occurred in 1975 and 1995. If we take into account the 32 years preceding and including the 1998 and 2001 catastrophic floods in Transcarpathia (1970-2001), we can observe a small decrease in precipitation values.

Though, we can find a connection between the amount of precipitation and the number of inundations in 1995, 1998 and 2001. The amount of precipitation in these years was above average, just like the frequency of inundations. Floods mostly occurred in the years with above-average precipitation. From the viewpoint of flood danger, the most critical months in Transcarpathia are March and (especially) December, while the safest ones (without any major floods) are August and September.

Summarizing the research, we have come to the conclusion that the connection between the change of precipitation values and flood frequency is not significant. Thus, high flood water levels are probable during floods caused by thawing snow (March, December) followed by heavy rainfall. However, the period of flood wave passing increases, water remains in the catchment area and on the flood plain for a longer time. Although no increase was observed in the annual precipitation data series, spills into the floodplain became more frequent. This may be due to the occasional high rainfall in a few days (daily average above 40 mm) in the Upper Tisza River Basin, the decrease in forest coverage in the 20th century (from 78% to 41%), human urbanization activities (asphalt, concrete, roof, sewerage etc.), which speeds up the rate of runoffs.

Nowadays, climate-change tendency is attributed an increasing significance and the accompanying extreme weather affects ever greater territories. At the time of floods in the catchment area unforeseen situations can occur on the Tisza River and its tributaries, high water levels may become more frequent, causing environmental problems and changes.

There always have been and will always be floods in the future. The frequency of discharges and the length of time the water stays in the floodplain are important for the assessment of environmental changes and flood risk, which causes the gradual filling of the floodplain, the accumulation of river sediments (mud, sand), changes in the floodplain's natural life and human economic activity.

Further research is needed to determine the frequency of floods in different sections of the Tisza, to analyze them and to define the causes of the changes.

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