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RAINFALL EROSIVITY AS AN INDICATOR OF SLIDING OCCURRENCE ALONG THE SOUTHERN SLOPES OF THE BAČKA LOESS PLATEAU: A CASE STUDY OF THE KULA SETTLEMENT, VOJVODINA (NORTH SERBIA)

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Abstract: The risk of soil erosion and landslides is one of the main environmental concerns in Southeast Europe. Although predictions are uncertain, changes in precipitation due to climate variability are expected in the south eastern parts of the Pannonian Basin in the Vojvodina region, North Serbia. To gain a clearer understanding of the dynamics involved in the main climatological agent of erosion, more insight concerning changes in the amount, concentration and variability of precipitation is needed. The Kula settlement on the southern slopes of the Bačka loess plateau in the Vojvodina region, North Serbia was selected for this study. This settlement is endangered by the landslides along the pronounced loess cliff. Various statistical approaches were used to calculate and analyse trends in total annual precipitation and selected rainfall erosivity indices. Results show that annual rainfall displays a relatively uniform distribution for the investigated area, while precipitation concentration indicates a presence of moderate values for the period 1991–2012. Trend analysis of the supra-seasonal scales for wet and dry seasons only indicates the presence of a trend in the time series for the wet season. Calculated values of the Fournier Indices generally display low aggressiveness for the study area with several extremes based on monthly mean values with a pronounced severe erosivity class. These values strongly correspond with the registered occurrence of the landslides in the settlement area. Proposed geomorphological model was applied in order to describe the nature of the dynamic erosional processes on the steep loess cliffs and landslide morphogenesis related to the sedimentological characteristics of the loess-paleosol sequences and influence of the rainfall aggressiveness. Potential solutions for preventative actions are given in order to introduce and conduct qualitative mitigation strategies.

Keywords: rainfall erosivity indices, loess, landslide, hazard, mitigation, Bačka loess plateau, Kula, Vojvodina, North Serbia.

1. INTRODUCTION

The study of natural disasters strives to include all causalities in the natural environment, such as the geosphere, astrosphere and humans. Although natural disasters present various threats to the human environment, it is not always the result of natural environmental processes, but also resulting from interaction between natural and anthropogenic systems. It is difficult to give a generally acceptable definition of what is a natural disaster, even in cases where natural disasters are clearly identifiable (e.g. Lukić et al., 2013; Porfiriev, 2001). According to definitions presented by Lukić et al., (2013), landslides in the Kula settlement can be classified by cause as joint natural and anthropogenic; by spatial distribution as local; by type of cause as accidental; by speed of occurrence as sudden; by character of accident as preventable and by class of belonging as housing-communal.

Landslides cause great damage and may occur due to natural factors or human activities. The main causes of landslides activation include underground water level fluctuation, variation of vegetation and its reduction due to deforestation, high rainfall, prolonged drought periods, snow melting, poor drainage system and uncontrolled surface water drainage, earthquakes, etc. (Alimohammadlou et al., 2013). Among natural factors, rainfall erosivity is of paramount importance because the results thereof are responsible for the largest part of the soil erosion (De Luis et al., 2009). Rainfall erosivity is the potential ability for rainfall to cause soil loss (Silva, 2004) and one of the determining parameters in the universal soil loss equation (Operta & Golijanin, 2013). In this context, rainfall has been recognised as one of the main landslides triggering factors decreasing slope stability. The mechanism is that water infiltration causes a reduction in soil suction (or negative pore pressure) in the unsaturated soil. Soil suction will be lost upon full saturation resulting in a decrease in the effective stress on the potential failure surface, which is reflected in a decrease in the soil strength. Slope failure occurs under constant total stress and increasing pore pressure (Abramson et al., 2002). Factors generally controlling landslide initiation from rainfall are seepage (intensity, duration and infiltration of rainfall), moisture content, excessive pore water pressure and antecedent rainfall (Crosta, 1998; Abramson et al., 2002). Furthermore, technological development, economic and population growth, and social changes led to an evident and serious degradation of the natural environment in most parts of the world (Alimohammadlou et al., 2013). Hence, research regarding this topic is of utmost importance to understand and mitigate landslide risk.

The boundary between natural and anthropogenic landslide triggers (e.g. water run-off modified by new land-uses), and instances where changes and reactions are considered as direct consequences of human activities, should be considered (Michoud et al., 2012). Reduced slope stability influenced by human actions significantly contributes to the risk level because by definition, these sites are located where elements at risk (e.g. people) are present. Landslides are usually considered as typical examples of natural hazards, but can be influenced by human activities. Many examples can be found in the literature about slope instabilities induced by anthropogenic activities, ranging from small superficial landslides to rock avalanches (e.g. Michoud et al., 2012). However, only a few studies could relate actual impact of anthropogenic changes with trends in landslide activity.

Loess is windblown dust deposited over extensive areas in mid-latitudes. Chronologically, the formation of loess deposits is related to the glacial cycles in the Pleistocene (e.g. Vasiljević et al., 2011a). Loess dusts are transported and deposited by wind during glacial periods. During warmer (interglacial) periods, loess deposition is affected by various climatic conditions associated with higher temperature, higher precipitation, and increase of chemical and biological activity. Formerly mentioned processes resulted in the formation of soils. Loess deposits are interlayered with soil bodies, representing the shift from cold and dry to warm and wet climatic conditions (e.g. Kukla, 1977, Pecsi, 1990). Sediments of typical loess in Vojvodina (North Serbia) are preserved in six separate loess plateaus: Bačka, Srem, Tamiš, Banat, south-east Banat, and Titel Loess Plateau (Vasiljević et al., 2011b) (Fig. 1). Several typical features of loess control the way in which different erosive processes affect it. The high porosity (30-50%) and significant carbonate content explains the great permeability and moisture absorption capacity (Leger, 1990; Lukić et al., 2009). Typical loess sediments in the Vojvodina region contain between 10 and 35% carbonate content (Marković et al., 2004, 2005, 2006, 2007, 2008; Bokhorst et al., 2009; Lukić et al., 2009). Under low moisture content, loess generally has sufficient shear strength to resist slope failure, but shows a sharp decrease in strength once wetted (Derbyshire et al., 1994; Gao, 1988; Lin & Wang, 1988; Xu et al., 2013). Heavy and intense precipitation events occasionally affect loess stability, causing it to disaggregate instantaneously under its own weight. The changes in the loess fabric are distinctive (Derbyshire et al., 1995): finer particles are washed out, packing density rises rapidly, and mass flow and landslide may result. This process of hydrocompaction is an important cause of slope failure (Derbyshire, 2000; 2001).

The rainfall regime reflects the aggressiveness of erosion on the geological substrate and soil through the volume, duration and intensity of rain. Different indices of rainfall erosivity have been proposed for analysing soil erosion, and the most appropriate ones seem to be those relating to soil erosion with kinetic energy of rainfall, such as the well-known EI_{30} (Wischmeier & Smith, 1978). However, there is scarce availability of high quality datasets on a regional scale, because EI_{30} requires rainfall data at intervals of one minute (Loureiro & Coutinho, 2001). To avoid this problem, indices based on monthly data averages have been proposed, such as Fourier Index (*FI*) and Modified Fourier Index (*MFI*) (Arnoldus, 1980; Melo et al., 2013).

In this study, indices based on mean monthly data averages such as Fourier Index (*FI*) and its modification by Arnoldus (1980) (*MFI*), were used. Agreement between *FI* or *MFI* with the USLE *R* factor (rainfall aggressivity factor) has been described in several studies (e.g. Renard & Freimund, 1994; Gabriels, 2001; Loureiro & Coutinho, 2001; Diodato & Bellocchi, 2007; De Luis et al., 2010; Mello et al., 2013). The objective of this study is to analyse the relationship between trends of total annual precipitation (*Pt*), Precipitation Concentration Index **(***PCI*) and Fournier indices (*FI*/*MFI*) in order to describe the evolution of rainfall aggressivity during 1991 - 2012 in environments subject to a landslide hazard due to the specific sedimentological characteristics of loess-paleosol sequences, case study Kula settlement in Vojvodina. This approach is essential for the development of prevention activities and for the promotion of mitigation measures.

2. STUDY AREA

Vojvodina, a region in North Serbia located in the south eastern part of Carpathian (Pannonian) Basin, encompasses the confluence area of the Danube, Sava, and Tisza rivers (Basarin et al., 2014) (Fig. 1). Loess and loess-like sediments of eolian origin cover more than 60% of this lowland area (Vasiljević et al., 2011a).

The area presented in this study stretches along the southern part of the Bačka loess plateau and loess cliff of the Kula settlement (between 45^{o} 36′ 60″ N/ 19^{o} 31′ 29″ E and 45^{o} 36′ 27″ N/ 19^{o} 32′ 41″ E, with elevation of 95 m) in Vojvodina, North Serbia (Fig. 1). The loess cliff is approximately 2.2 km long and represents the geomorphological transition from higher Bačka loess plateau to the lower alluvial plain.

Morphogeneticly, this cliff is of natural and anthropogenic origin. Rain induced erosion along the cliff occurred naturally during the last two centuries. However, the problem of major landslides occurrence started during the last 60 years and culminated the past 20 years. Until the 18th century, the water flow from Crna bara slowly eroded the gentile slops of the Bačka loess plateau, creating a steep loess cliff. After the Veliki Bački Canal was constructed (in 1802) the water flow erosion stopped (Stojanović et al., 2014).

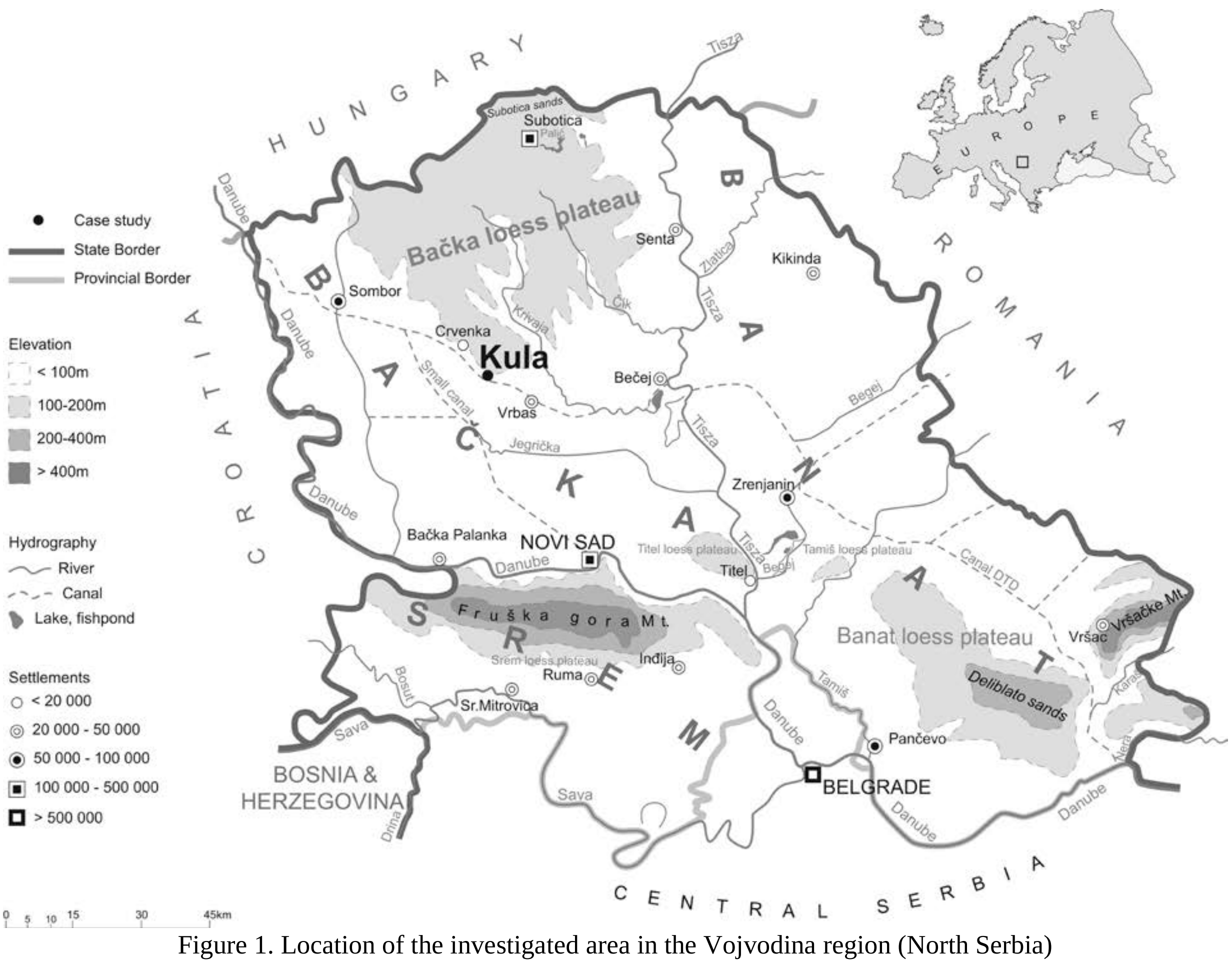

Figure 1. Location of the investigated area in the Vojvodina region (North Serbia)

As the Kula settlement expanded, people extracted the loess sediments near the cliff exploiting this lithological substrate as a construction material for houses. The loess cliff became higher and steeper due to these activities.

During periods of high seasonal rainfall distribution, these partially man-made slopes are highly susceptible to landslides. House, road and pipeline construction changed the structures of the loess plateau near the steep cliffs, causing this problem. The natural path of water circulation and drainage of the terrain is also influenced, creating increased pressure on the plateau surface and threatening its natural stability. Although land use undoubtedly has a significant effect on the probability of landslide frequency (Glade, 2003; Tasser et al., 2003; Petley et al., 2007), its influence with respect to the various regions is still discussed controversially in literature (Douglas et al., 1996; Tasser & Tappeiner, 2002; Krohmer & Deil, 2003).

The climate of Vojvodina is moderate continental, with cold winters and hot, humid summers. The maximum precipitation occurs in June, while minimum is in February. The minimum annual precipitation totals is registered over northern Vojvodina (around 540 mm/year), where southern parts of the Bačka loess plateau receives around 590 mm/year. The maximum of 660 mm is measured in SW Vojvodina. The winter, spring, and autumn precipitations are between 120 and 160 mm (125 and 140 mm respectively for the case study area), while summer precipitation totals varies from 180 mm (196 mm respectively for the case study area) in northern Vojvodina to 220 mm in SE and SW Vojvodina (Tošić et al., 2014).

3. DATA AND METHODS

A database of the Republic Hydrometeorological Service of Serbia for the period 1991 – 2012 for the Kula meteorological station (45°60′ N, 19°53′ E and elevation of 85 m) was used to present the precipitation amount and seasonal distribution in the study area (Meteorological Yearbook of Serbia, 1991-2012). The homogeneity of the precipitation series was examined according to the Alexandersson (1986) test, showing that the time series of the data for the Kula meteorological station are homogeneous.

Precipitation trend and trend in values of the rainfall erosivity indices was assessed by two statistical approaches. The first step was to calculate the tendency (trend) equation of precipitation using linear interpolation of the annual precipitation for Kula meteorological station during the observed period. In a second statistical approach, Mann-Kendall tests were used (Gilbert, 1987) to analyse the precipitation trend. These tests are widely used in environmental science (e.g. Gavrilov et al., 2011; Hrnjak et al., 2014), because they are simple, robust, and can cope with missing values and values below the detection limit. First, Kendall's tau (τ) was calculated (Kendall, 1938; 1975) to estimate a trend in the time series. Thereafter two hypotheses were tested: (I) the null hypothesis, that there is no trend in the series; and (II) the alternative hypothesis, that there is a trend in the series, for a given significance level (α=0.05). Probability was calculated to determine the level of confidence in the hypothesis. The same procedure was applied to the calculated values of the rainfall erosivity indices. This procedure was applied in order to investigate the relationship between amount and distribution of the precipitation and the calculated values of the rainfall erosivity indices. *R* statistical analysis software (Package "Kendall") was used for the precipitation and erosivity indices trend data processing.

The influence of precipitation on landslide occurrence was analysed by applying the rainfall erosivity index. Regional rainfall erosivity was assessed based on the Precipitation Concentration Index (*PCI*) (Oliver, 1980), proposed as an indicator of rainfall concentration and rainfall erosivity (Michiels et al., 1992). This index was calculated on an annual basis according to Eq. (1):

$$PCI\ annual = \frac{\sum_{i=1}^{12} p_i^2}{\left(\sum_{i=1}^{12} p_i\right)^2} \times 100 \quad (1)$$

where p_i is the monthly mean precipitation in month i.

The *PCI* was also calculated on a seasonal scale for winter (December-January-February), spring (March-April-May) summer (June-July-August), autumn (September-October-November), and on supra-seasonal scales for wet (October to March) and dry (April to September) seasons according to Eqs. (2) and (3) (De Luis et al., 2011):

$$PCI\ seasonal = \frac{\sum_{i=1}^{3} p_i^2}{\left(\sum_{i=1}^{3} p_i\right)^2} \times 25 \quad (2)$$

$$PCI\ supra\ seasonal = \frac{\sum_{i=1}^{6} p_i^2}{\left(\sum_{i=1}^{6} p_i\right)^2} \times 50 \quad (3)$$

According to the presented equations, the lowest theoretical value on the annual, seasonal and supra-seasonal scale of *PCI* is 8.3, indicating the perfect uniformity in precipitation distribution (i.e., that same amount of precipitation occurs in each month). Also, on all scales, a *PCI* value of 16.7 will indicate that the total precipitation was concentrated in half of the period and a *PCI* value of 25 will indicate that the total precipitation occurred in one third of the period (i.e. total annual precipitation occurred in 4 months; total supra-seasonal precipitation occurred in 2 months and total seasonal precipitation occurred in 1 month). According to this classification, Oliver (1980) suggested that *PCI* values of less than 10 represent a uniform precipitation distribution (i.e. low precipitation concentration); values from 11 to 15 denote a moderate precipitation concentration; values from 16 to 20 denote irregular distribution and values above 20 represent a strong irregularity (i.e. high precipitation concentration) of precipitation distribution (Lujan & Gabriels, 2005; De Luis et al., 2011; Mello et al., 2013).

Numerous authors showed that the Fournier Index (*FI*)- Eq. (4) and the Modified Fournier Index (*MFI*)- Eq. (5) are useful in studies focused on rainfall aggressiveness and are subjected to the correlation of other climatic variables that are contributing factors in the triggering/or reactivation of erosion phenomena (e.g. De Luis et al., 2010; De Luis et al., 2011; Khorsandi et al., 2010; Mello et al., 2013). Fournier Index (*FI*) is calculated as follows:

$$FI = \frac{p^2 max}{P} \qquad (4)$$

with p_{max} reflecting the maximum monthly precipitation amount of the wettest month of the year and *P* the mean annual rainfall amount.

This (*FI*)-index has shortcomings as estimator of the rain erosivity index within the USLE – as low amounts of monthly mean rainfall can have substantial erosive power, an increase in total rainfall amount should result in an increase of erosivity. It is also illogic that if the maximum monthly rainfall p_{max} remains the same with the mean annual rainfall increasing, the (*FI*) is decreasing. Therefore, Arnoldus (1980) modified the (*FI*) index into a Modified Fournier Index (*MFI*) Eq. (5) considering the rainfall amounts of all months in the year:

$$MFI = \sum_{i=1}^{12} \frac{p^2}{P} \qquad (5)$$

where *p* represents the mean monthly rainfall amount and *P* the annual rainfall amount.

The rainfall erosivity classes determined by means of the Fournier Indices (Oliver, 1980; Sfîru et al., 2011; Costea, 2012) are shown in table 1.

Data obtained from the Planning institute Kula-Odžaci of the municipality of Kula, was used to compare the obtained results and documented field registrations of the landslides for the case study area (Building Inspection of Kula municipality, 2012). Also, the authors used pedostratigraphic and sedimentologic data for the reference profile of the Bačka loess plateau (Crvenka exposure) to aid interpretation of the morphological evolution of landslides in the investigated area (Marković et al., 2008; Zech et al., 2009; Stevens et al., 2011).

Table 1. The erosivity classes by Fournier Index (*FI*) and Modified Fournier Index (*MFI*)

Erosivity class	***FI***	**Erosivity class**	***MFI***
Very low	0 - 20	Very 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		

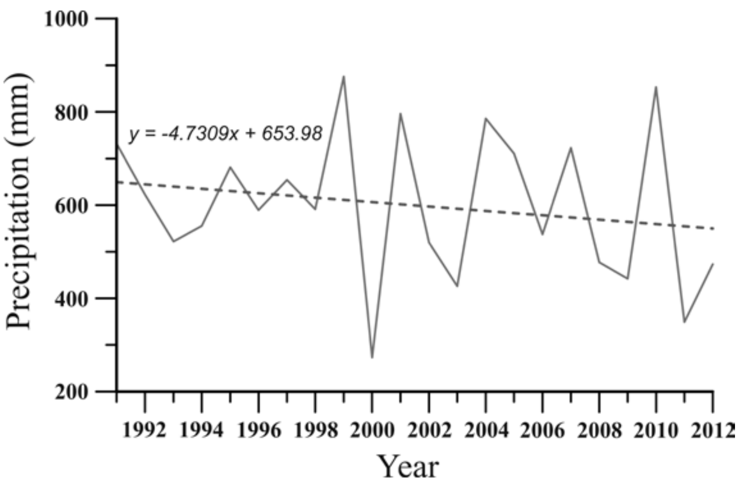

Figure 2. Total amount of precipitation (*Pt*) for the period 1991 – 2012

Proposed geomorphological model (modified after Lukić et al., 2009; Wang et al., 2011; Derbyshire et al., 2000; 2001) was applied in order to describe the nature of the dynamic erosional processes on the steep loess cliffs and landslide morphogenesis related to the sedimentological characteristics of the Late Pleistocene loess-paleosol sequences.

4. RESULTS

The mean annual precipitation for the study area is 639 mm. Data on mean annual precipitation values for the period 1991 – 2012 are shown in figure 2. The amount of precipitation during the research period reflects constant or approximately uniform ranging values (549-649 mm).

Precipitation starts to increase monthly from February (30.5 mm), and reaches the highest value in June (82.0 mm), after which it starts to decline. The precipitation trend is presented in figure 2. This trend, as well as equation ($y = -4.7309x + 653.98$), show a noticeably negative trend. As the computed *p-value* is greater (p=0.456) than the significance level (α=0.05), the null hypothesis cannot be rejected. The risk to reject the null hypothesis while it is true, is 45.63 %, therefore, it can be considered that there is no trend for the observed time series thus making the precipitation distribution relatively uniform for the investigated area.

4.1. Precipitation Concentration Index (*PCI*)

The Precipitation Concentration Index (*PCI*) calculated on an annual basis, varies from values lower than 10 for 1997 to 19.4 in 1992 and 15.3 in 2001, (Fig. 3). Trend analysis showed that according to the computed *p-value* (p=0.325) and the significance level (α=0.05), it can be considered that there is no trend for the observed time series in the *PCI* values, indicating a moderate precipitation concentration in the investigated area.

4.2. Seasonal and Wet-Dry season Precipitation Concentration Index

The Precipitation Concentration Index calculated on a seasonal scale shows that during the winter, *PCI* values are approximately 10.6. Spring's precipitation is generally more regularly distributed within months, with slightly higher *PCI* values (10.7) than during the winter. An interesting observation is that during summer, a higher *PCI* (11.2) value can be observed despite the fact that this period has less precipitation than spring. The *PCI* value for autumn in the investigated area is 10.6. Generally, the seasonal values of *PCI* vary around 10, which according to Lujan & Gabriels (2005) suggest a uniform distribution of rainfall concentration. During the wet season (October to March) a decrease in the *PCI* values is pronounced (Fig. 4-a), with a slight increase in *PCI* values during the dry season (April to September) respectively (Fig. 4-b).

Trend analysis of the supra-seasonal scales for wet (October to March) and dry (April to September) seasons, with the computed *p-value* (p=0.016) lower than the significance level (α=0.05) indicate the presence of a trend in the time series for the wet season, with the risk to reject the null hypothesis while it is true of 1.60%. Contrary to that, trend in the time series for dry season was not pronounced since the computed *p-value* (p=0.142) is greater than the significance level (α=0.05).

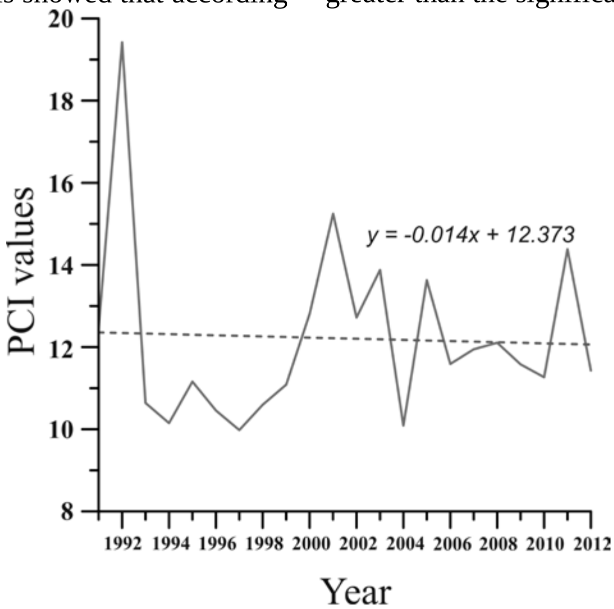

Figure 3. Precipitation Concentration Index (*PCI*) per year for the period 1991 – 2012

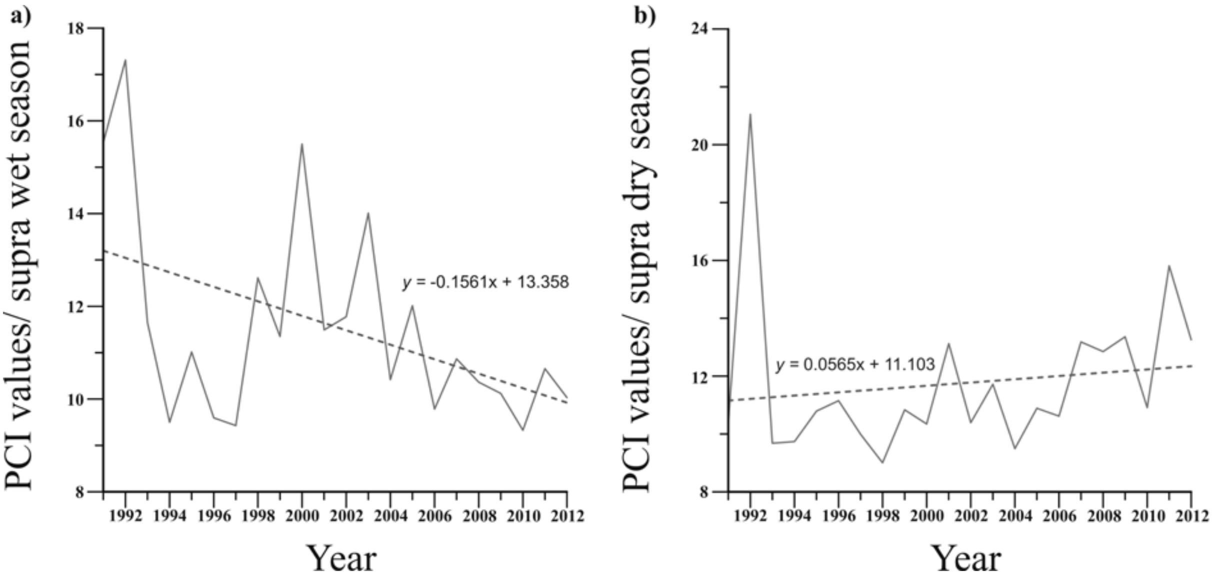

Figure 4. *PCI* values for supra wet- **a)** and dry- **b)** season (1991 – 2012)

4.3. Fournier indices (*FI/MFI*)

The multiannual average value of the Fournier Index (*FI*) is 25.9. The values of the Fournier Index generally display low aggressiveness in the study area with two extreme values of 66.1 in 1992 and 64.0 in 2001 respectively, with a pronounced severe erosivity class (Fig. 5-a). There was only one case of a moderate erosivity class recorded during 2010 (45.4). For the Modified Fournier Index (*MFI*), the multiannual average values for the investigated period range up to 72.9 mm, with two extreme values of 120.9 recorded during 1992 and 121.4 in 2001 respectively (Fig. 5-b).

Rainfall aggressivity recorded by the Modified Fournier Index (*MFI*) is relatively low during most of the observed period (reaching from 34.9 up to 121.4) in the study area, with higher values observed in 1992 (120.9 mm), 1999 (97.1 mm), 2001 (121.4 mm), 2005 (96.9 mm) and 2010 (96.1 mm). *MFI* values for these years vary between moderate and severe. The Modified Fournier Index value only reached values higher than 120.0 mm (120.9 and 121.4 mm respectively) in 1992 and 2001, thus reflecting a high class of erosion aggressiveness. The values of Fournier indices were very low in 38.09% of observed cases – low values were observed in 52.38%, moderate in 4.76% and severe in 9.53%. The values of the *MFI* for the investigated area show a very low erosivity in 38.09% of the cases, while low erosivity values are present in 33.33%, moderate in 19.05% and high in 9.52% of the observed cases. Overall trend evaluation for the *FI* and *MFI* indices suggests that there are no indicative trend changes during the observed period of twenty-one years.

5. DISSCUSION

Soil erosion has long been recognised as one of the most threatening environmental processes that results from climatic driven factors and faulty land use (Gobin et al., 2004). The major climatic variable affecting water erosion is precipitation (Wischmeier & Smith, 1978; Mello et al., 2013).

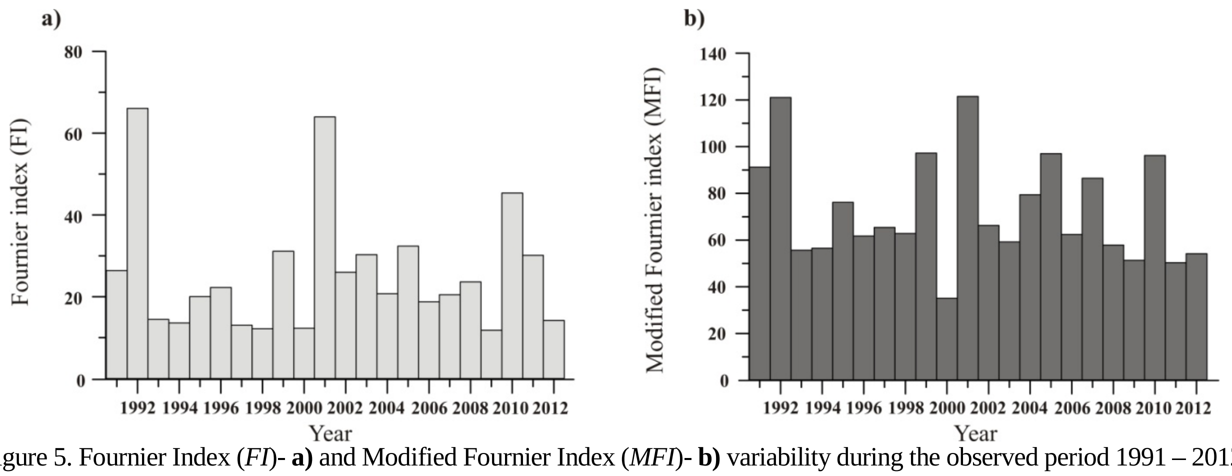

Figure 5. Fournier Index (*FI*)- **a)** and Modified Fournier Index (*MFI*)- **b)** variability during the observed period 1991 – 2012

The potential of rain to generate soil erosion is known as rainfall erosivity and its estimation is fundamental for the understanding of climatic vulnerability of a given region (De Luis et al., 2011; Mello et al., 2013). Therefore, erosion and precipitation distribution are important elements concerning the implications of climate variability in the Panonnian basin. Changes in total annual and seasonal precipitation, as well as distribution and concentration are key to understanding and quantifying these processes on a regional scale (De Luis et al., 2010). The amount of precipitation (*Pt*) for annual, seasonal and monthly observations are the most important elements affecting excessive piping erosion alongside the loess cliff presented in this study. Accordingly, understanding, analysing, and interpreting the relationship between annual, seasonal and monthly trends of *Pt*, *PCI*, and *FI*/*MFI* are of great importance to understand, predict and successfully mitigate landslides. This approach is useful to describe rainfall aggressivity evolution during 1991–2012 in the environment subjected to a high erosion risk, and to look for spatial distribution patterns.

Since the mean annual precipitation for the investigated area is 639 mm, available energy for erosion and transport increases positively according to Langbein & Schumm (1958). The precipitation trend analysis shows no general pronounced variability in annual distribution during the observed period (Fig. 2). The Precipitation Concentration Index (*PCI*) exhibit a different pattern from those observed for Total Annual Precipitation (*Pt*). During the last decade of the observed period, a slight decline of *PCI* values is noticeable. All four registered major landslides (May 1996, April 2001, May 2010 and June 2011) happened during the dry season – a season for which our investigation pointed out a distinctive trend increase of *PCI* supra-seasonal values, with maximum peak in 2011 (Fig. 4-b). If this data is analysed on a seasonal basis, three of the four landslides (or 75%) happened during the period from March till May, when the values of *PCI* indices reached 10.2, which according to Oliver (1980) represents a uniform precipitation distribution (i.e. low precipitation concentration). There is a positive relationship suggesting that the rainfall erosivity trend strongly depends on the annual rainfall distribution (the Pearson correlation coefficient is 0.69).

Indices based on mean monthly data, such as the Fourier Index (*FI*) and its modification (*MFI*) suggested by Arnoldus (1980), are often used to quantify the nature of rainfall variability and its effects on the soil erosion. As described by Apaydin et al., (2006), *MFI* can be expressed as the product of Total Annual Precipitation and the Precipitation Concentration Index described by Oliver (1980). Consequently, opposite trends observed in the total rainfall and precipitation concentration values draw a complex trend pattern for rainfall aggressivity in the research area.

The highest *MFI* value for the study area was in 2001 (121.4) during which precipitation totalled at 796.1 mm. The end of April 2001 saw the biggest landslide after a total of 81.3 mm was discharged during this month. The second highest value of the *MFI* is calculated for 2010 (96.1) when precipitation totalled at 852.9 mm. May of that year received a considerable amount of rainfall reaching 101.7 mm. This value represents the highest amount of monthly precipitation occurring on the 21st of May 2010. As a result, a landslide occurred causing a total estimated damage of 14.626 USD (Building Inspection of Kula municipality, 2012). During 2011, precipitation totalled at only 349.2 mm, characterising this period according to the works of Sepulcre-Canto et al., (2014) and Spinoni et al., (2015) as the driest year in this century, with a recorded *MFI* value of only 50.2 mm. However, landslide damage of 40.473 USD was caused in the area of the Kula settlement during this year. The 2011 landslide was mostly triggered by leakage from a water pipeline damaged by the previous year's landslide (Building Inspection of Kula municipality, 2012).

Derbyshire (2001) pointed out that dry loess can sustain nearly vertical slopes, being perennially under-saturated. However, when locally saturated, it disaggregates instantaneously. Such hydrocompaction is a key process in many slope failures in the loess terrains. Therefore, the stability of loess is mainly influenced by the climatic conditions. Prolonged rainfall events affect the loess in the Vojvodina region (North Serbia). After discharge, many parts of the Bačka loess plateau are saturated, causing the loess to disaggregate instantaneously under its own weight. The higher primary porosities and the weaker cementation characteristic of undisturbed younger Late Pleistocene loess sediments, make it much more susceptible to rain-induced erosion. Also, according to Abramson et al., (2002), loess is highly erodable by water flow even at a low to moderate volume and 5 to 10 percent gradient. The pronounced loess cliff in the investigated area has a slope gradient varying between 275 and 1000 percent. In spite of different thickness between loess-paleosol sections in the Vojvodina region, consistent pedostratigraphy and detailed sedimentologic, geochemic and chronostratigraphic data presented by Marković et al., (2008), Zech et al., (2009) and Stevens et al. (2011) could therefore be used to aid interpretation of the morphological evolution of landslides in the investigated area. Interplay between sedimentologic characteristics of loess (Fig. 6) and precipitation distribution leads to enhanced erodibility (for more information see Marković et al., 2008). According to the work of Derbyshire (2001), occurring landslides in the Kula settlement correspond to the paleosol contact landslides. Classification of mass movements in loess terrains is based on the composition and the site of the failure plane (Derbyshire, 2001). This type of landslide involves sliding of a loess mass on or within the palaeosols on the Bačka loess plateau.

The geomorphological model proposed by Lukić et al., (2009) suggest's that the morphogenesis of the landslides (occurring in the investigated area) has been shown to be closely related to the sedimentological characteristics of the Late Pleistocene loess-paleosol sequences, however, this does not explain the initiation of the feature, nor its wholesale development. It can be used to describe the nature of the dynamic erosional processes on the steep cliffs of the soft loess sediment. In the initial phase, precipitation is percolated through initial vertical loess cracks and partly accumulated as a hanging aquifer in loess layer V-L1L2, above paleosol V-S1 (Fig. 7). Water percolation to an ephemeral hanging aquifer in loess layer V-L1L2, above paleosol V-S1, leads to flow out at the cliff face and likely accelerate erosion and cliff collapse. Also, relatively high proportion of carbonate, especially in the loess layers (Fig. 6) along with processes of carbonate dissolution contributed to this erosion process where processes of de-cementation allowed loose material to be transported by percolated water out of the exposed loess profiles (Fig. 7).

These processes are enhanced by the removal, discontinuous presence or lack of vegetation due to the soil cultivation and urbanization. Because of this feature loess deposits are inherently unstable and highly susceptible to pluvial erosion (e.g. Derbyshire, 2000; 2001).

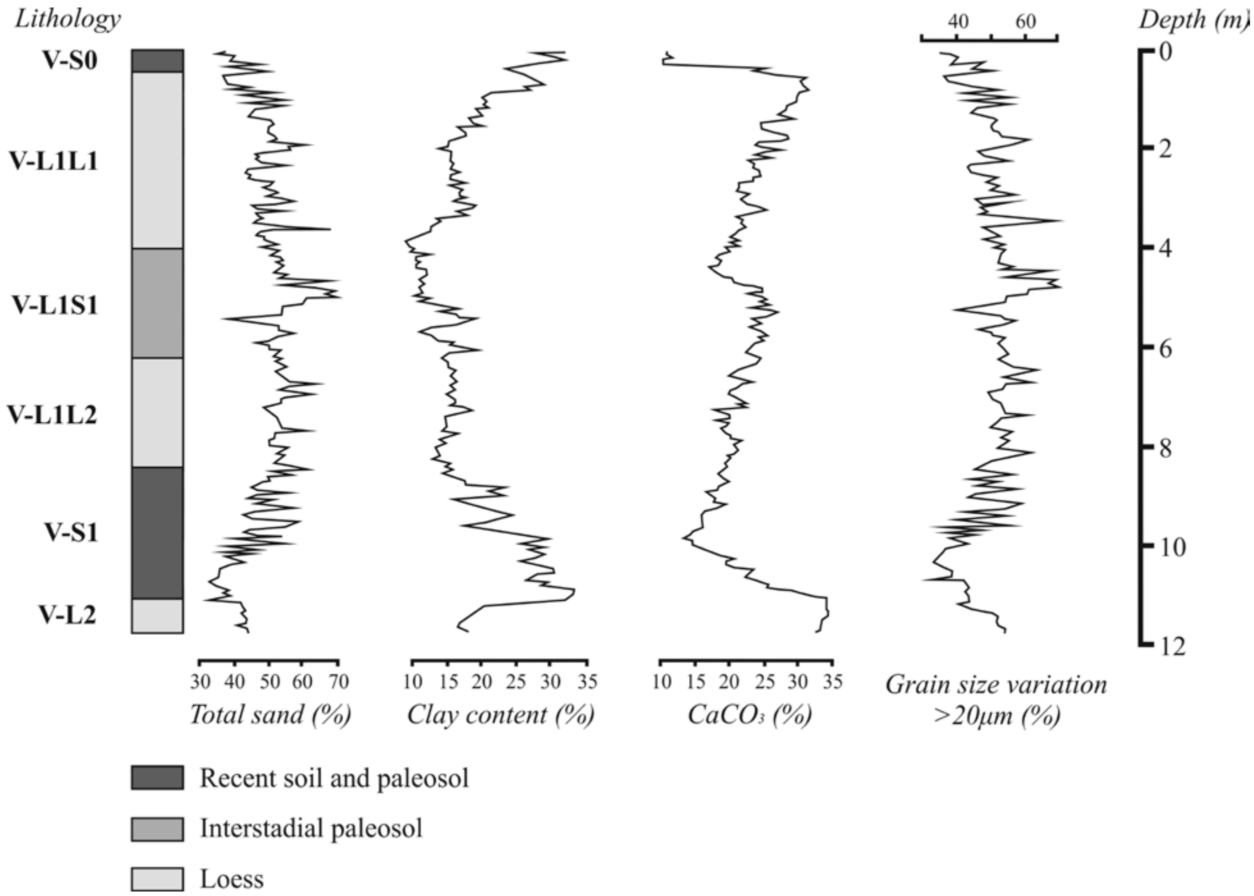

Figure 6. Pedostratigraphic scheme of the Late Pleistocene loess-paleosol section "Crvenka" (reference profile for the Bačka loess plateau) with grain size distribution, clay and carbonate content (The authors designate the Vojvodinian "L" (loess) and "S" (paleosol) stratigraphic units, numbered in order of increasing age, while the prefix "V" was used to refer to the standard Pleistocene loess– paleosol stratigraphy of the Vojvodina region, North Serbia) (Modified after Marković et al., 2008; Stevens et al., 2011)

Internal hydrology, weathering potential, shear strength and failure behavior influence loess deformation and the stability of pronounced loess cliff. The condition of the cementation bonds is regarded as a reflection of the relative influences of the above mentioned properties and processes. The fabric of loess consists of fine, loosely arranged angular grains of silt, fine sand, calcite, and clay. Most of the grains are coated with thin films of clay and some with a mixture of calcite and clay (e.g. Parsons et al., 2009). Loess has an open, cohesive particle structure with low density, high dry strength and is characterized by coarser material. It also possesses a metastable structure due to the high degree of settlement and large loss of strength that may occur upon saturation. Calcite is believed to be a significant cementing material in loess. It can be leached into the soil from upper horizons or can be brought into the soil by evaporation of capillary water from the groundwater below. However, clay is more commonly the bonding agent that gives loess its cohesive nature. Pronounced clay maxima, up to ~30% is registered in the paleosols of the Bačka loess plateau (Zech et al., 2013). High values of $CaCO_3$ (%) are measured in loess units, in contrast to low values of carbonate in paleosols (Fig. 6). Therefore, pedogenic horizons have a higher proportion of clay-sized material than the loess layers. Variations of grain size distribution show many abrupt, small amplitude changes (due to wind transport intensity) (e.g. Marković et al., 2008; Stevens et al., 2011; Zech et al., 2013). The loess deposits of Vojvodina (North Serbia) predominantly comprise cohesionless silt-sized quartz particles supported by cemented bridges of clay sized grains and shows strong similarities to the properties of the Chinese loess-paleosol sequences (e.g. Dijkstra, 2001). This imparts to the materials a generally low plasticity index (6-8% in loess and up to 14-15% in paleosols with greater clay content) and low plastic limit. Also, it is important to point out that consolidation is the most outstanding physical and structural property of loess. Its susceptibility to settlement makes it a potentially unstable foundation material. Because of the sensitivity of montmorillonite to moisture, an increase in moisture content due to precipitation may cause clay bonds to weaken, reducing the original soil strength. Variations in clay and moisture content can cause localized consolidation or collapse. Because the structure of loess is loosely arranged and filled with voids, rainfall quickly infiltrates and loess may remain dry within a few feet of the surface (unless there is a water table near the surface). Due to the mineralogical characteristics of the bonding material, it is highly hydrophilic, containing soluble salts and clay particles. In addition, the surfaces of the predominantly quartz silt particles are also highly hydrophilic. The dipolar nature of water molecules renders them particularly effective in penetrating the bonds and loosening the bridge-silt grain contacts.

Explanation of the catastrophic failure behavior of loess deposits is driven by particle packing transformations. Transformation from an open to close particle packing leads to the phenomenon enhanced by leaching processes and degradation of cementation bonds. Generally, failure of cementation bonds leading to soil structure collapse and slope failure is a major problem encountered in loess terrains in the southern parts of the Bačka loess plateau.

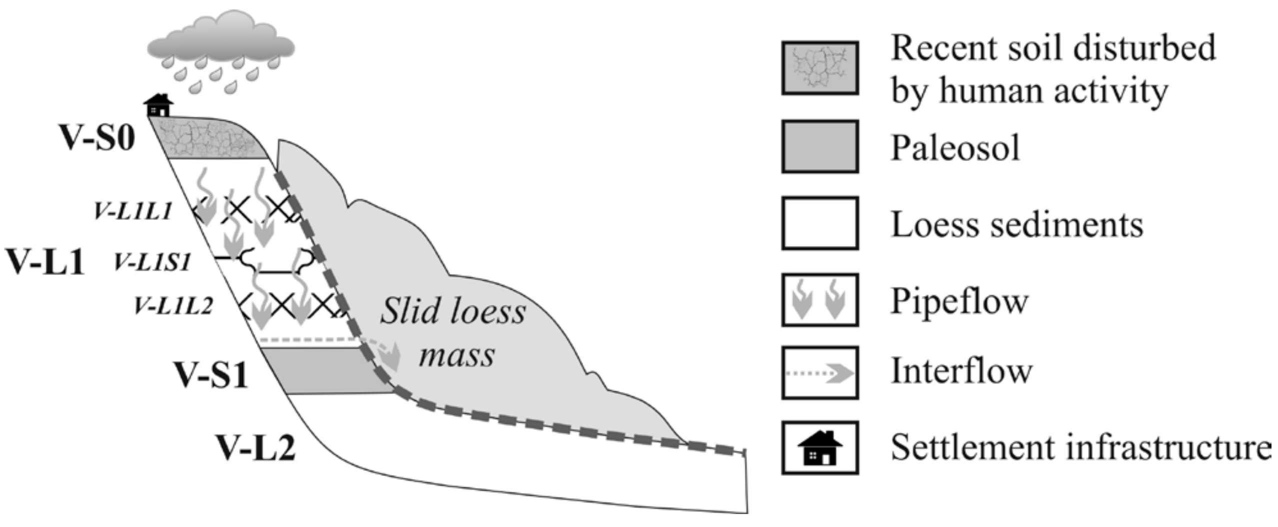

Figure 7. Slope evolution scheme and morphology of the study area (landslide within loess or paleosol- contact landslide)- pedostratigraphy is the same as shown in Figure 6.

Therefore, the observed decrease in *PCI* values should not be interpreted as a decrease in the risk of erosivity. Soil erosion is closely linked to geological characteristics (loess terrains are highly susceptible to erosion), vegetation type and dynamics; and the probability of disturbances is mainly linked to seasonal rainfall distribution and concentration. Also, anthropogenic influence to the landslide occurrence is presented by the wetting conditions and cultivation caused by human activity and urbanization processes on the plateau surface, while the magnitude of this influence depends of the continuity of these processes.

6. PROPOSED MITIGATION STRATEGIES

According to Gori et al., (2003) landslide hazard mitigation generally involves landslide mapping, control structures, warning systems, local and regional planning. Most effective approaches include a combination of these above mentioned strategies, with good coordination between the scientific, engineering, and planning communities. In the work of Larsen (2008) it is highlighted that communities can reduce their exposure to landslide hazard if they understand the threat, its potential impact, and their mitigation options.

Even though landslides along the loess cliff present a lasting problem for inhabitants of the Kula settlement, landslide control, mitigation and management are not administered. Municipality officials only take action after landslide occurrences, resulting in adverse economic impacts for the area.

A retaining wall was built during 1989 to support the most endangered part of the loess cliff. The wall comprises a system of reinforced concrete pillars reaching a height of 3 m, a base width of 110 cm and 40 cm in the crown. The slope deposits have an angular inclination of about 45° between the pillars and the wall surface, with a distance of 4 m between poles.

Mechanically compressed layers of different materials fill the decrease in slope. Re-cultivation was done by greening the slope primarily with black locust trees (*Robinia pseudoacacia*). As shown by Lukić et al., (2009), this type of vegetation aids terrain stability, maintained by very important root systems bounding slope material in the loess terrains.

Figure 8. Infrastructural damage caused by the landslides in the investigated period (Kula settlement, Vojvodina) (Photo: Igor Leščešen)

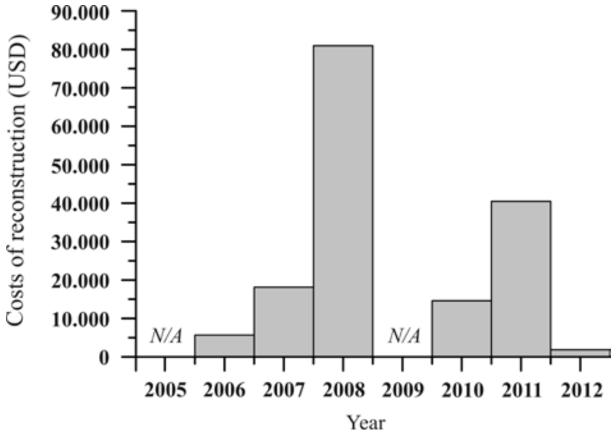

Figure 9. Costs of reconstruction for the period 2005-2012

After the second phase of construction (realised during 2007), the total length of the supporting wall reached 140 m – covering only 6.4% of the total length of the loess cliff. Regardless of this retaining wall, landslides continued to occur causing damage to inhabitants and their properties (Fig. 8).

The total estimated damage due to erosion and landslides occurrence during the period 2005 - 2012 reached up to 161.733 USD, affecting 18% of the length of the whole loess cliff. Annual expenditure was estimated at approximately 20.217 USD, with the highest expenses recorded during 2008 (80.954 USD) and 2011 (40.473 USD) respectively (The Institute for Development of the Kula municipality, 2012) (Fig. 9).

A potential solution for the present situation lays in preparedness, requiring municipality officials to introduce and conduct qualitative mitigations strategies by implementing a long-term cliff reinforcement programme. Examples of good practice are evident in the man-made slopes worldwide (e.g. Abramson et al., 2002; Kwong et al., 2004; Choi & Cheung, 2013). This adaptive strategy implies a four-stage programme for the design and construction of slope upgrading:

(a) Stage 1 - Preliminary study scouting the site to identify parts of the loess cliff that require a detailed investigation. Urgent repair works must be initiated where signs of immediate and obvious danger are identified.
(b) Stage 2 - Detailed study comprising a desk review, aerial photograph interpretation, site observations, stability analysis, and if needed ground investigation works to determine whether or not upgrading is needed.
(c) Stage 3 – Design cliff upgrade to ensure the required safety standards.
(d) Stage 4 – Construct slope upgrade, including tender documentation, contract administration and site super-vision (Choi & Cheung, 2013).

To ensure an adequate upgrade programme, the high-risk loess cliff areas must be identified. The key elements to predict the stability of a loess cliff are changes due to the rainfall: (I) reduction in shear strength of soil due to the increase of loess moisture; (II) the expected failure planes that are controlled by the soil type, thickness and cliff angle; (III) rainfall pattern of the study area and (IV) absorption and retention characteristic of land cover (Abramson et al., 2002; Kwong et al., 2004). Following high-risk identification, a risk-priority ranking system must be undertaken. The risk-based priority ranking system would take into the account both the likelihood of landslides and the consequence of cliff failure. The product of instability score and consequence score reflects the risk of the cliff. The instability score is determined by a number of factors including age of cliff, level of geotechnical input during the formation of the cliff, cliff geometry, signs of distress, records of instability, and other characteristics. The consequence score is determined by the type and proximity of the facilities affected.

Apart from upgrading, the old supporting wall requires regulatory enhanced maintenance. Sections in need of maintenance should be identified by regular inspections. Utilising consultancy services will ensure wider professional resources as well as faster cliff mitigation processes (Kwong et al., 2004). If the investment in cliff safety is not maintained, cliff deterioration over time will increase the landslide risk. This not only poses a risk on the lives of inhabitants, but will cause significant economic losses and social disruption, thereby compromising public safety (Choi & Cheung, 2013). A cliff information system is needed to create public awareness concerning potential hazards, and to cultivate a responsibility towards maintaining cliff safety within own property boundaries. Public education regarding cliff maintenance and landslide reporting is needed (Kwong et al., 2004).

Cliff upgrade requires substantial engineering works based on the principles of removal (e.g. cutting back the cliff to reduce its gradient), reinforcement (e.g. strengthening cliff by installation of steel bars called soil nails), retention (i.e. supporting cliff with retaining structures), and replacement (e.g. excavating and reforming of cliff with a denser surface soil layer) (Choi & Cheung, 2013).

Accordingly, to reduce material damage for inhabitants and landslide occurrence in the Kula settlement (Vojvodina, North Serbia), some of these measures should be implemented in mitigation strategies of this loess cliff.

7. CONCLUSION

Trend analysis of monthly mean precipitation data for the Kula settlement in the Vojvodina region indicates opposite behaviour between annual precipitation (*Pt*) and seasonal precipitation concentration (*PCI*). During the observed period 1991 - 2012, relative stability in the annual rainfall distribution shows no pronounced variability and decrease in precipitation concentration values, especially during the first decade of the 21st century. The observed trends in rainfall aggressivity (*MFI*) exhibit a positive relationship with the precipitation concentration. Considering that the *PCI* is a part of the well-known Fournier Index used in erosion research, the results show that the precipitation factor have great significance when conducting erosion studies. It can be concluded that precipitation is one of the main factors contributing to landslide occurrence in the Kula settlement due to geological features of the loess terrain and soil saturation. Thus, due to rainfall aggressivity, new risk areas highly susceptible to landslides were created. Also, soil erosion is frequently a partial result of land use practices on the Bačka Loess Plateau, and can be regarded as a “hidden hazard”.

For future spatial and urban plans of the Kula Municipality, protection from landslides along the pronounced loess cliff should represent an important segment of land use planning, especially in this erosion vulnerable part of the Vojvodina region (North Serbia). According to the degree of risk, specific aspects of spatial planning must be applied to this area. Involvement of the local community (e.g. public education program), would help inhabitants understanding the landslide characteristics. Apart from keeping the cliff safe, it is necessary to make it look as natural as possible in order to create a safer and better living environment for the inhabitants of this small town in the Vojvodina region. This is possible by applying different remediation and mitigation strategies.

Results presented in this study may contribute to improved understanding of the local dynamics of the main climatological agent of erosion in the loess terrains. Furthermore, it could aid in creating suitable mitigation strategies to avoid or reduce the impacts of landslide occurrence not only in the investigated area, but in the surrounding regions (with similar geological strata) as well.

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