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FLOODPLAIN ANALYSIS FOR DIFFERENT RETURN PERIODS OF RIVER VARDAR IN TIKVESH VALLEY (REPUBLIC OF MACEDONIA)

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Abstract: Floodplain analysis is usually used in hydrology for calculating the possibility of high water stage features. Floods are treated like a human problem. In the concrete case was taken maximum annual stage data for a period of 34 hydrologic years (1971/72-2004/05) for Gauge station "Demir Kapija" on River Vardar and Boshava. The analysis is created using some probability distributions like Normal, Pearson distribution type III, Gumbel distribution, Log-Pearson distribution type III and Lognormal distribution. Calculated results from the water stage frequency analysis are treated with the Kolmogorov-Smirnov test and χ^2 test for obtaining best fitting distribution with empirical Weibull formula. The frequency distributions results were plotted on probability paper and compared with empirical Weibull points besides the statistical testing. The best fitting distribution is Lognormal. Maximum theoretical stages of best fitting distribution for different return periods were mapped on the rivers Vardar and Boshava banks in Tikvesh Valley. The map presents all flooded areas in treating territory for different return periods.

Keywords: River Vardar, floodplain, probability distribution, return period, K-S test, X-square test, GIS.

1. INTRODUCTION

One of the most common natural disasters that occur in the world was floods. In most cases, they are caused by heavy and intensive rain. They can cause a material damages, but also human casualties. There is a case when damages caused by the floods exceed 20% of the GDP, as is an example on Savinja Basin in the northern and north-eastern in Slovenia in 1990 (Zorn & Hrvatin, 2015). It is a national interest to predict when, where and in what extend they can be manifested. Beside the continued statistical data, Geographic information systems are widely used for measurement of floodplain extent (Curebal et al., 2016; Khattak et al., 2016; Traore et al., 2015; Icaga et al., 2016).

River Vardar is in the central part of the Balkan Peninsula, with general northwest-southeast way of streaming. It belongs to the Aegean watershed basin. River Vardar has a composite Valley, created by more valleys and gauges. Therefore, the river springs below Shar Planina, called Vrutok at 683.5 meters above the sea level (Gashevski, 1972), in the Polog Valley, then river streams in Derven Gauge, Skopje Valley, Taor Gauge, Veles Valley, Veles Gauge, Tikvesh Valley and Demir Kapija Gauge. The highest point of the basin is Titov Vrv (2748 meters above sea level), which is located on Shara Mountain. The lowest point of analyzing area is Gauge Station Demir Kapija, located at 94.27 meters above the sea level. The gauging station basin area is 21350 km^2 and it occupies an upper and central section of the river Vardar. The main left tributaries are Lepenec, Pchinja and river Bregalnica and the main right side tributaries are river Treska and Crna Reka.

The total water course length (from spring to gauge station "Demir Kapija" is long 237.8 km while the stream length in analyzing area of Tikvesh Valley is 4.3 km. The basic stream regime is nival-pluvial with a lot of torrential streams in Tikvesh Valley, so called "River Luda Mara" or "River Mad Mara" like some streams in Romania (Romanescu, et al., 2011). They are subjected to flash flood features especially in April (26% of annual maximum stages) and May (15% of annual maximum stages). The recent studies show that the snowmelt process trend is rising because of the global warming and increasing of the air temperature (Birsan et al., 2014). Also, study case in Switzerland shows trend of increasing of the minimum annual temperatures (Birsan et al., 2005). Their genesis is based on heavy rain, combined with snow melt water from the high mountains in the spring area of the River Vardar Shar Mountain (2748 m), Mountain Baba (2601 m), Jakupica (2548 m), Nidze (2520 m) and several other lower mountains. Also, significant percent of high water level was recorded in December with 12% of maximum annual water stages besides these maximum annual stages with highest occurrence the maximum multi annual water stage for whole analyzed period was measured in XI, 1979 with water stage of 506 cm, occurred as a result of the intensive rain in November. In generally the poorest hydrological period on Macedonian streams was registered in 1987-1995 period. The absolutely lowest amount of maximum annual stages occurred in 1988 with 168 cm.

The river Boshava sprig point is located at 1070 m above the sea level, from the northern side of Mountain Kozhuv. The whole basin belongs to Tukvesh valley and this stream has a significant influence after confluence point in River Vardar, which means that the River Vardar is richer with water flow after getting the water from the Boshava River. The confluence point is located at 95 m above the sea level. The total stream slope is 979 m, and average slope is 26‰. The basin area has 460 km^2 (Gashevski, 1978). The Gauge Station on Boshava River is located at 790 meters above the sea level.

The historical floods in the river Vardar basin occurred in 1778, 1876, 1895, 1897 and 1916 (no measured data), 350 cm in 1935 and 605 cm in 1962 year (Sibinović, 1968), differently from the other great Balkan streams (Morava, Danube, Tamish, Tisza, Sava), where the greatest floods occurred in 1965 and 2006 (Gavrilović et al., 2012). The greatest floods on Romanian rivers occurred also on different dates. For example, the biggest floods in Siret hydrographic basin have been in 1969, 1975,1991, 2004, 2005 and 2008 and for the river Prut hydrographic basin were in 1969 and 2008 (Romanescu, 2006).

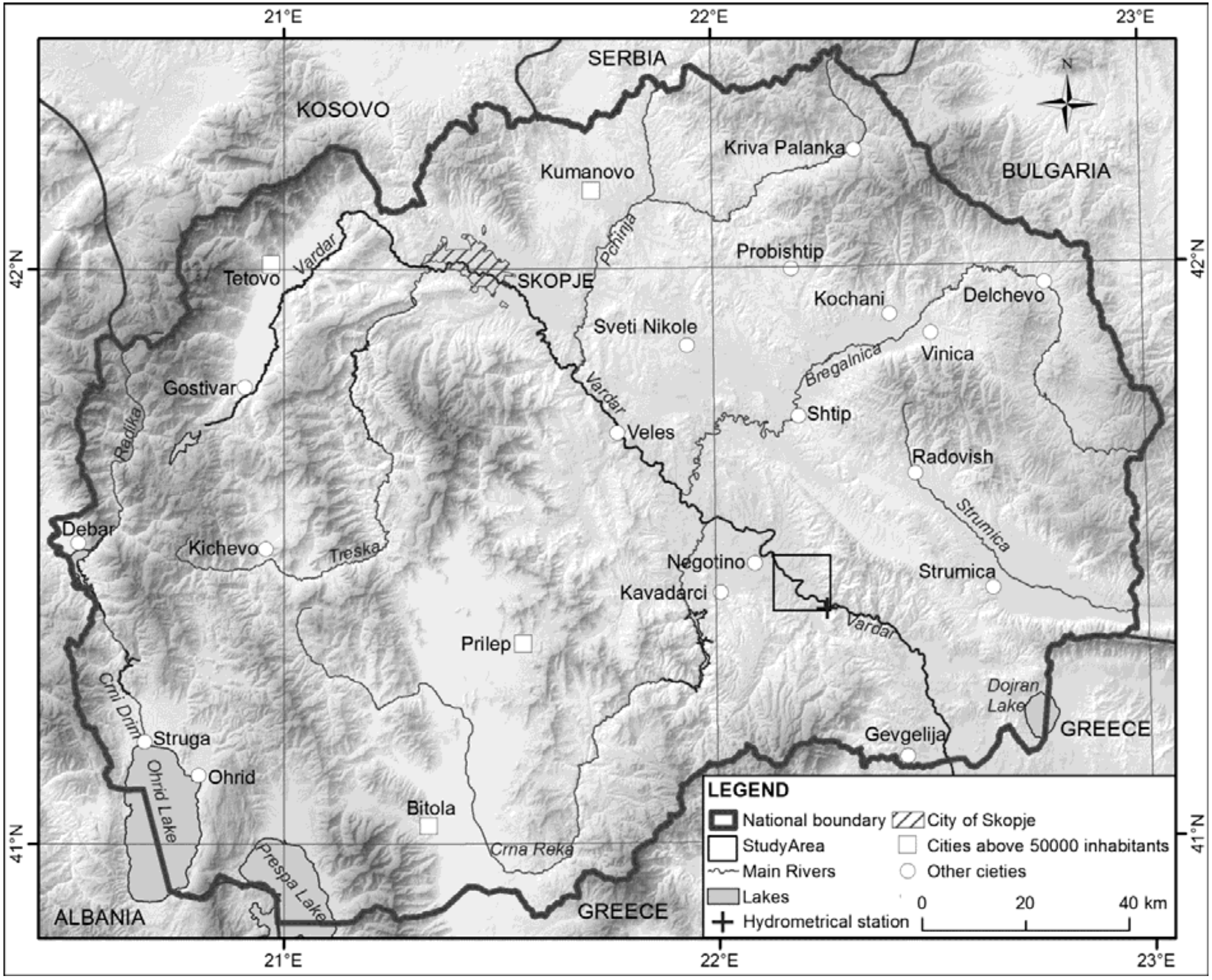

Figure 1. The map of the analyzed area in the Republic of Macedonia.

There is a highly significant positive correlation between recurrence intervals and building losses ratios. Building loss ratios rise with decreasing probability of the damaging flood event of the object location (Elmer et al., 2010). Floods also have a high consequence on human life, the population is usually unprepared for flood features and its reaction is slow, with no organized activity. The authorities haven't supported in reaction by the local population during the floods (Ceobanu & Grozavu, 2009). In the River Vardar water regime annual maximum water levels/water discharge were occurred in November in the autumn, while spring flood features were detected in May and June, differently from the Romanian rivers, which are frequently detected in spring (Romanescu et al., 2011).The high stage in spring period is a result of combination of snowmelt process from the highest basin mountains (Shar Mountain, Jakupica, Baba and Osogovo Mountain) and heavy rain in May, and the highest stage in autumn is result of the heavy and intensive rain features.

In the analysis of probability of occurrence of floods in the Western part of the Republic of Macedonia, the Pearson distribution III type (Vasileski, 1997) for the river of Radika has the best correspondence as well as the Gumbel distribution (Radevski, 2010) and Log-Pearson distribution for Spring area at Gauge Station "Dolenci" for the river of Crna Reka (Vasileski & Radevski, 2011; Vasilevski & Radevski, 2015), which indicates a smaller annual fluctuation of water stages. Geographic information systems are used as technology for mapping flood extent. Also, it can be used in managing, forecasting and population education about floods.

2. MATERIALS AND METHODS

The methodology of in concrete paper is based on statistical and cartographic methods and the basic analyzed parameter of those researching is a maximum annual water stage for the period 1971/72-2004/05 (see Table 1). The basic data were obtained from the National Hydrometeorologic Service of Republic of Macedonia. The series must also be long enough, which means that for statistic processing of maximum discharge a period of 30 years is necessary (Srebrenović, 1986). The way of data analysis is flood frequency analyses, with using of five theoretical distributions - Pearson III type, Log-Pearson, Gauss, Gumbel and Log-normal distribution (Ahilan et al., 2012; Radevski & Gorin 2014; Vasilevski & Radevski, 2015). The methodology uses mathematical-statistic methods beginning with the homogeneity test of the data series, covering a standard period in hydro research, calculating maximum potential high waters for different return periods (from 2 to 10000 years) and graphic comparison and testing of concordance between empirical and theoretical distribution.

Return period of 10000years flood is usually used in flood frequency analysis before building dams that would endanger human lives in downstream settlements. For obtaining the best fitting distribution of empirical maximum annual stage data were used two methods (graphical, with using probability plot and statistical with using Kolmogorov-Smirnov and χ-square test). The calculated results from flood frequency analysis on the gauging station Demir Kapija are presented on the thematic flood frequency map. In the map creation, the method of contours was used for presenting the isolines with same return periods of floods.

From the figure 2 is evident that the time series of 34year maximum annual stage data for the Gauge Station "Demir Kapija".

Table 1. Maximum annual water stage at the Gauge station "Demir Kapija"

Hydro./Year	h (cm)	Hydro./ Year	h (cm)	Hydro./Year	h (cm)	Hydro./Year	h (cm)
1971/72	271	1981/82	362	1991/92	292	2001/02	188
1972/73	316	1982/83	327	1992/93	216	2002/03	384
1973/74	351	1983/84	306	1993/94	224	2003/04	230
1974/75	236	1984/85	248	1994/95	204	2004/05	294
1975/76	348	1985/86	350	1995/96	354		
1976/77	369	1986/87	382	1996/97	286		
1977/78	272	1987/88	168	1997/98	249		
1978/79	277	1988/89	249	1998/99	298		
1979/80	506	1989/90	200	1999/00	280		
1980/81	428	1990/91	309	2000/01	212		

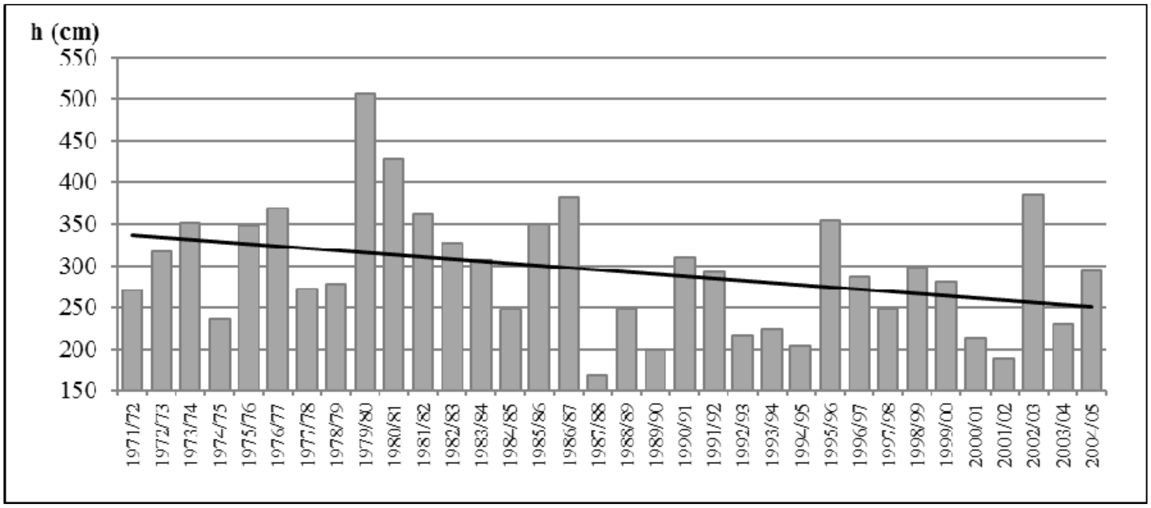

Figure 2. Maximum annual stages and their trend line of river Vardar at the Gauging Station Demir Kapija (1971/72-2004/05)

The maximum annual water stage has the highest values in 1979/80 hydrologic year. The second highest value occurred in 1980/81 hydrologic year. In the calculations of the empirical distribution and the return periods according to which theoretically high waters will further be calculated, the Weibull formula will be used, and that is as follows:

$$Pm = \frac{m}{N+1} \tag{1}$$

The calculation of the theoretical high water stage was made after determining of basic parameters of each statistical distribution. Theoretical maximum annual water stages were calculated according to separate formulas for each distribution.

- Gaussian (normal) distribution

$$h_{\max} = \overline{x} + z \cdot \sigma \tag{2}$$

where $\overline{x}$ is arithmetic mean of the time series, z is standard variable, which obtained from the Gaussian tables, and σ is standard deviation.

- Pearson type III distribution

$$h_{\max} = (C_\upsilon \cdot \varphi + 1) \cdot \overline{x} \tag{3}$$

where h_{max} is a maximum theoretical water stage for each return period, $\overline{x}$ is arithmetic mean in time series, C_v is Variation coefficient and φ is frequency factor, which is obtained from Pearson's tables.

- Log-Pearson distribution type III

$$h_{\max} = (C_\upsilon \cdot \varphi + 1) \cdot \log \overline{x} \tag{4}$$

where h_{max} is a maximum theoretical water stage for each return period, $\log \overline{x}$ means logarithmic arithmetic mean in time series, C_v is Variation coefficient and φ is frequency factor, which is obtained from Pearson's tables.

- Gumbel distribution

$$h_{\max} = h_m + z \cdot \overline{x} \tag{5}$$

$$h_{\max} = \overline{x} - 0.577 \cdot \frac{1}{a} \tag{6}$$

$$\frac{1}{a} = 0.78 \cdot \sigma \tag{7}$$

In the above mentioned equations according to the Gumbel distribution (Gumbel, 1958; Ahilan et al., 2012) the maximum theoretical water stage depends on the mode (h_m), standard variable obtained from the Gumbel tables, and arithmetic mean of maximum annual water stage for the treated period.

- Log-normal distribution

$$H_{\max} = \log \overline{x} + z \cdot \sigma \tag{8}$$

$$h_{\max} = 10^{H_{\max}} \tag{9}$$

In the above mentioned equations according to the Log-normal distribution the maximum theoretical water stage depends logarithmic arithmetic mean in time series ($\log \overline{x}$), standard variable obtained from the Log-normal distribution tables for each return period, and standard deviation (σ) of maximum annual water stage for the treated period. In the Table 2. were presented the main parameters for each distribution in the article.

After the calculation of theoretical water stages was necessary to choose the best fitting probability distribution. The choice was made with three methods. The first method is comparison on probability paper, where is easy to see the fitting of the probability distribution (presented in lines) with the empirical distribution (presented in points in Fig. 2). The second method is the Kolmogorov-Smirnov test with calculating the maximum difference (Dmax) between the empirical and theoretical distribution and x-square test, where the data series are separated into 5 classes. The final decision of best fitting distribution is made by comparison of the three above mentioned methods.

According to best fitting distribution the thematic flood extent map with isolines for different return periods (from 2 to 10000 years) was made (De Moel et al., 2009). The map presents the area of Tikvesh Valley, which is endangered in different flood cases. The highest measured value of the maximum annual water stage was in the 1979/80 hydrologic year with 506 cm. The second highest value was measured in 1980/81 hydrologic year with maximum water stage of 428 cm. The lowest water stage value was measured in 1987/88 hydrologic year with 168 cm.

The basic data of the maximum annual stage were used for flood frequency analysis. From the Figure 1 is evidently the descendant trend line of maximum annual stages on the Gauge station "Demir Kapija" on River Vardar. The time series peaks are higher in the first half of the graph and lower in the second part of the graph except for 1995/96 and 2002/03 hydrologic year, when the maximum annual peak. The term floodplain, which is the main subject in the article was defined like periodically inundated area by the lateral overflow of rivers and lakes, made by direct precipitation or groundwater (Junk et al., 1989).

According to the article goal, second part is dedicated to the floodplain mapping. Floodplain maps are presenting the inundated areas of specific historical or hypothetical events (De Moel et al., 2009). In this study, geographic information systems are used as a tool for creating map of flood extend. There is a many study where combination of ArcGIS, HEC Tools are used for mapping floodplain (Ahmad & Simonovic, 2001; Goodell, & Warren, 2006, Jie et al., 2006; Thomas & Nisbet, 2007, Cook & Merwade, 2009; Beilicci & Beilicci, 2014; Tyler et al., 2011).

In this approach following data were used: topographic maps in scale 1:25000, GPS measurement data, triangulated irregular network (TIN), Land Use/Land Cover data and statistically calculated values for different returning periods (5, 10, 50, 100, 1000 and 10000 year returning period).

First methodological step was digitalization of the river, banks and profile lines. Hec-RAS and Hec-GeoRAS need TIN for modeling. TIN was created by combination of digitized contours and GPS measurements. The extent of the inundation area covered by the flood depend of the by the Flood plain extend depend, also as flood depth, velocity etc. depends of the manning`s coefficient. For that reason, Land Corine/Land Use for year 2015 map is created (Gorin et al., 2014). For more realistic mapping, each LC/LU class is assigned a suitable manning`s n values (Henderson, 1966; Streeter, 1971; Arcement Jr. & Schneider, 1989; Chow, 2009). Created model of floodplain is exported in ArcGIS, where final map is created. At last the final map (Fig. 3) is a result of overlaying of six separate maps for different returning periods.

3. RESULTS AND DISSCUSION

The Table 2 presents the obtained results of theoretical maximum water stages with using of five theoretical probability distributions. The calculation was made according to a Gaussian distribution, Pearson distribution type III, Log-Pearson distribution, Gumbel probability distribution for maximum values and Log-Normal distribution for different return periods (from 2 to 10000 year period).

Table 2. Theoretical water stages for different return periods per five probability distributions of river Vardar at Gauging Station Demir Kapija

Distribution	Gaussian (Normal)	Pearson III	Log-Pearson III	Gumbel	Log-normal
Parameter/ return period	$\overline{x}$, σ	$\overline{x}$,C_v,C_s	C_v, C_s, $\log\overline{x}$	h_m,σ	$\log\overline{x}$,σ
10000	569	675	723	792	**717**
1000	522	591	617	659	**613**
200	484	529	543	566	**540**
100	466	500	511	526	**507**
50	446	470	476	486	**474**
25	424	439	441	446	**440**
10	390	394	394	392	**393**
5	358	355	354	349	**353**
2	297	289	289	285	**288**

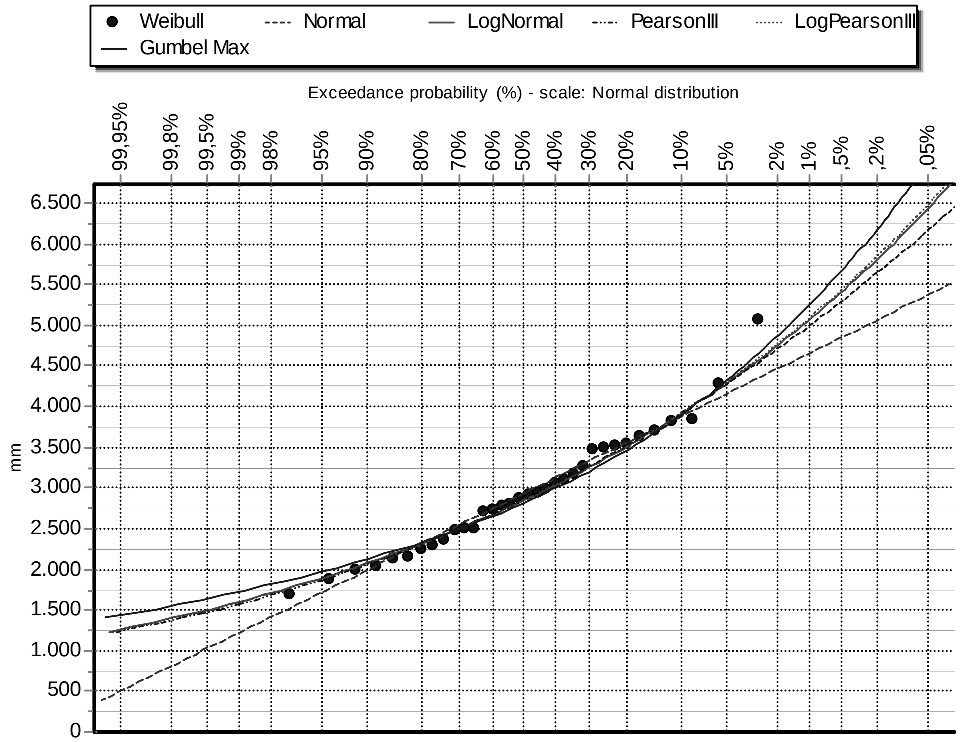

Figure 3. Probability paper with empirical distribution (points) and five theoretical distributions

The probability paper (Fig. 2) presents empirical water stage data, presented using Weibull formula, and five theoretical distributions. All five theoretical distributions have a good fitting with empirical data. Asymmetrical distributions (Log-normal, Gumbel, Pearson III and Log-Pearson III have a better fitting for highest water stage values (two highest points on probability paper), but for rest of maximum annual water stages, Normal distribution has better fitting. According figure 2 the best fitting distribution is Log-normal distribution (rose line on probability paper), because of good fitting with all of the empirical data from the lowest to the highest blue point. For surely decision the K-S and X-Square test was made.

From the results obtained by the Kolmogorov-Smirnov test we can conclude that it accepts all five distributions, because for all levels of significance (a = 1, 5 or 10 %), are compatible. Since the rest of the distributions the best correspondence is shown by the Normal distribution with maximum difference between the empirical and the theoretical distribution being the smallest, (Dn=0,069). This means that this distribution, per the K-S test, has best adjusted to the empirical distribution of Weibull.

The results once again confirm that the maximum annual water stages at Gauge station “Demir Kapija” have a symmetrical distribution, but the testing is possible only to highest measured point (506 cm) for the analyzed period (1961/62-2005/06 hydrologic year). The geographic implications of those results are changes in the river bed, damages from flood features on infrastructure (bridges, roads, houses, etc.), changes of relief structures and other landscape changes in Tikvesh Valley. According to X-square test the same result is obtained as with the K-S test, so the Pearson parameter (0.7) and a level of significance attained “a” is 70.2 % of the Normal distribution and this distribution is the best adjusted one of the empirical distribution. The other five distributions are also compatible with the empirical data distribution.

After these decisions, the thematic map of Tikvesh Valley was made according to Log-normal distribution for all return periods. From the created map (Fig. 4.) we can see that left river bank is more flooded, than right river bank. This is result of flat surface slope. Demir Kapija town is secured even from 10000year flood. According to the map, the highway E-75 and international railway (which connects Skopje and Thessaloniki) is also secured even from 10000year flood. The flooded area generally covers agricultural land (crop land, vineyards, grassland, orchards, bushes and one industrial building.

Table 3. Kolmogorov-Smirnov and X-Square test for five theoretical functions

Kolmogorov-Smirnov test	a=1%	a=5%	a=10%	Attained a	D_{max}
Normal	ACCEPT	ACCEPT	ACCEPT	99,0332%	0,06993
Log-normal	ACCEPT	ACCEPT	ACCEPT	97,7483%	0,07606
Pearson III	ACCEPT	ACCEPT	ACCEPT	98,9445%	0,07050
Log Pearson III	ACCEPT	ACCEPT	ACCEPT	98,3639%	0,07356
Gumbel	ACCEPT	ACCEPT	ACCEPT	92,2749%	0,08885
X-Square test	a=1%	a=5%	a=10%	Attained a	Pearson Param.
Normal	ACCEPT	ACCEPT	ACCEPT	70,2619%	0,70588
Log-normal	ACCEPT	ACCEPT	ACCEPT	39,0169%	1,88235
Pearson III	ACCEPT	ACCEPT	ACCEPT	20,7578%	1,58824
Log Pearson III	ACCEPT	ACCEPT	ACCEPT	20,7578%	1,58824
Gumbel	ACCEPT	ACCEPT	ACCEPT	12,0314%	4,23529

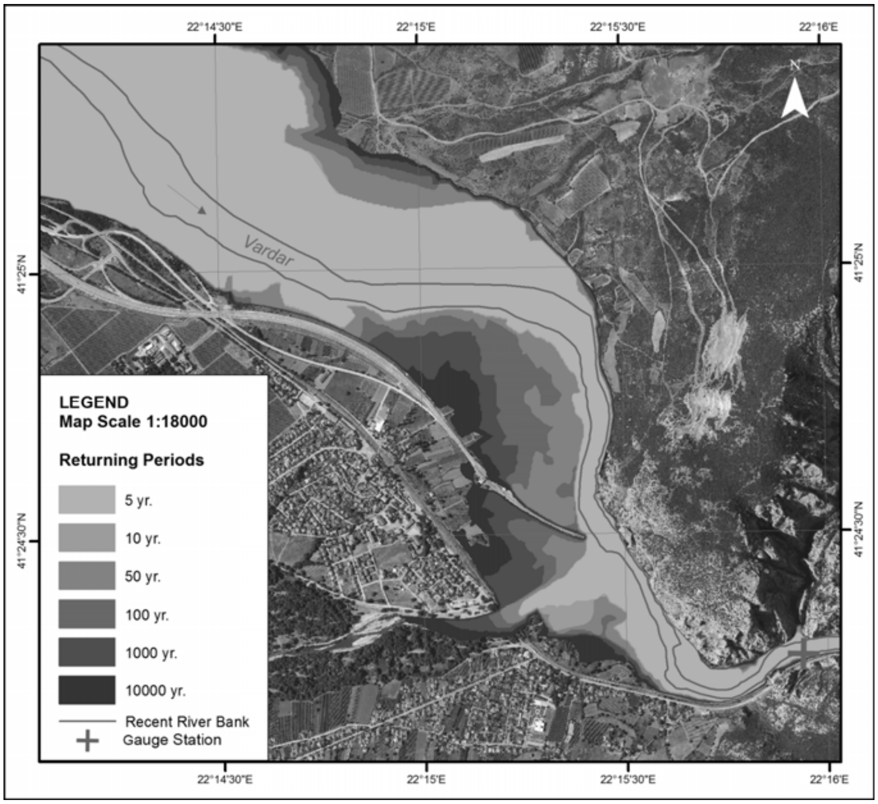

Figure 4. Flood plain map for different returning period

Table 4. Flood covered areas for different return periods.

Return period	5 years	10 years	50 years	100 years	1000 years	10000 years
Area (km^2)	1.319	1.357	1.585	1.756	1.928	2.072

The floodplain area is rising with longer return period up to 2.072 km^2 in case of 10000 year return period. The study is a basis for several possible works in future, as flood damage assessment, spatial planning projects and articles etc. Even in case of 10000 year return period, flood doesn't cover any inhabited area of Demir Kapija town. The damages can be caused mainly in agricultural area which is dominantly in the flooded area.

4. CONCLUSION

The floodplain analysis at gauging station Demir Kapija on River Vardar was made per Lognormal distribution, which was chosen like best fitting with probability paper compare and statistical testing (Kolmogorov-Smirnov test and X-square test). The Lognormal distribution results have a range between 288 cm for return period of 5 years to 717 cm for return period of 10000 years, so it was chosen because of good fitting of maximum annual stages, especially on small probabilities, which is evident on probability plot, and good results on K-S and X-Square testing. Statistical results were used for floodplain mapping. Floodplain mapping was made with combination of HEC tools (HEC RAS and HEC-Geo RAS) and ArcGIS. Created floodplain map shows the extent of the flood, were 10000 returning period covers 2.072 km^2.

Last few years the region of Western Balkans is under flood risk. In Republic of Macedonia, this spring Pelagonia was flooded by River Crna. The economic damage was very high. This approach can be used in future for more accurate floodplain analysis. For that reason, bigger availability of hydro meteorological data for scientific purposes is more than a necessary, also as availability of LiDAR data for more accurate floodplain mapping.

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