Floods in the Vrbas River Basin and Climate Changes

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Abstract: Catastrophic floods have caused numerous human fatalities and extensive material damage in the past twenty years. Particularly devastating were the floods that struck the territory of the Republic of Srpska and the Federation of Bosnia and Herzegovina in May 2014, when nearly 70% of these entities was covered with water. According to the National report of Bosnia and Herzegovina, in line with the UNFCCC, and long-term meteorological projections, there is a strong likelihood that such elemental disasters could strike again by the end of this century. Forecast is further rise in the average air temperature and more frequent occurrence of both dry and rain spells, exerting intense influence on agriculture, waterworks, economy, human health as well. The damage caused in the aforementioned period in the River Sava basin, as well as in the basins of its tributaries (Una with Sana, Vrbas, Bosna and Drina) is the result of various factors, such as: intense precipitation in the Sava basin (up to 200-250 L/m^2 in three days), non-existence of the water works protective objects, a reduced level of protection or collapse of the existing objects for the protection of high waters. The River Vrbas basin was also struck by an enormous amount of precipitation in that period, which resulted in extremely high water levels on the River Vrbas and its tributaries, especially its right-hand tributary, the River Vrbanja (based on preliminary readings, the historic high).

Key words: the River Vrbas basin, floods, causes of floods, water level, flow, precipitation, climate changes.

1 Introduction

A flood in a basin is a result of an area covered with significant amount of water due to the rise of water level in rivers, the cause of the flood being the occurrence of high waters, also known as a deluge. The notion of high waters implies the condition of water regime when the water level, that is, flow, increases and when the water pours over the river bed and floods the terrain around [1]. This increase in the level and flow in the Vrbas basin is a relatively rapid one, due to the coincidence of high waters on both the main river and the tributaries, followed by a gradual decrease once the maximum is reached. Essentially, this notion encompasses three phenomena: the onset, culmination and decline of the flood wave. High waters in the Vrbas basin are the result of the following factors: heavy rains, melting of snow, change of water regime on tributaries and depositing of solid waste, inadequate flow capacity of bridges, especially on minor waterflows in urban areas.

The Vrbas basin is a homogeneous hydrological category determined by corresponding physiogenic and anthropogenic parameters. Defining these parameters, their hydrodynamic morphological, hydrometeorological and hydrometric characteristics is of great significance for any soil study. There are many constant and temporary tributaries in this basin, from the spring in the range of Mt Vranica to the mouth in the River Sava, which clearly points to the complexity of research into the cause of floods in this basin. The square area of the basin is 6,386 km^2, the length of the river being 235 km.

Table 1. Basic characteristics of the River Vrbas

Vrbas basin	Square area (km^2)	6,386
	Square area in the Republic of Srpska (km^2)	3,924.13
	Square area in the Federation of Bosnia and Herzegovina (km^2)	2,461.87
	Average flow (m^3/s)	132
	Specific flow off (l/s/km^2)	20.7
	Flow of small waters ($Q_{min.mjes.95\%}$)	26.3

The timetable and range of high waters in the Vrbas basin on the dry and rain period (cyclic nature of dry and rain periods). Among themselves, conditions, causes and consequences of floods can be very different. Apart from urbanization of some parts of the Vrbas basin, a significant role in the occurrence of high waters and flood waves is played by the untreated riverbed of the Vrbas and its tributaries as well. Our research show that it is the lower flows of the basin that are more threatened by flood waves, and that flood waves and occurrence of high waters are directly connected to the morphology to the riverbed of the Vrbas and its tributaries.

The analysis of the precipitation measured in the Vrbas basin for the period 1961-1990 and projection of precipitation for the periods 2001-2030 and 2071-2100 respectively, as well as the analysis of the water level and flow of the Vrbas, shows that floods can be expected in an urban area in the basin during any month, which means that the causes are diverse [2]. Therefore, one should accept the fact that flood is a complex phenomenon, where high waters on a river depend on several mutually conditioning and complementing factors, having both direct and indirect influence on forming a flood wave on the Vrbas.

The most important direct causes of a flood are: precipitation, occurrence of ice on river, nival retention, condition of water level of the main flow during its increase, meandering of the flow, landslides, during which the riverbed is blocked, and coincidence of high waters of the main river and its tributaries.

On the other hand, the most important indirect causes of a flood are: size and shape of the basin, density of river network, level of saturation of soil with water, water levels of ground waters, level of forestation, land cultivation methods in the basin etc.

2 Formulation of the problem

The research done after previous flooding of the areas around the Vrbas and its tributaries revealed rather grim flood risk forecast. Unless the basic principles and goals of the Study of waterwork management of the Vrbas basin are timely designed, the consequences could be devastated for the population and property. Accordingly, the protection against high waters is undoubtedly a priority that needs to be harmonized with the range and quality of the projects realized within urban, economic, infrastructural systems that require this way of protection. This approach emerges from the universal principle that protection against water is a dynamic category which varies depending on the change in value of the assets endangered and new approach to hydrological processing of morphological changes in the basin and change in water regimes.

The basic step towards a viable and time-efficient solution for the protection of basins against floods is the design of technical documentation. It will require a quality analysis of all relevant aspects of the Vrbas basin, followed by clear definition of basic directions in future design phases. As for this phase, the absolute necessity is to work out the most suitable form of technical solution that will provide a high level of protection against the high waters in the Vrbas basin.

The knowledge about high waters is crucial for determining the measures of hydrotechnical objects, both in safety and economic terms. If the level of high waters is underestimated, the objects might not prove adequate for the task, leading to catastrophic consequences for the objects themselves and the assets protected [3]. If the level is exaggerated, the objects are a waste of funds, exceeding the safety risks by far.

This poses the issue to what extent the projections of the Second national report of Bosnia and Herzegovina on climate change (2013) are relevant to the flood protection projects. When cyclic oscillations in climate are concerned, it is evident that over shorter time periods, under the influence of solar activity, there are certain weather disturbances, that is, greater or smaller deviations from the so-called 'average weather'. Most people, including official institutions, understand it as a climate change. They are evidently wrong, since these changes are of local character. Namely, it is a cyclic oscillation of 'average weather' in its extreme, which is accepted as deterioration or improvement of

climate over years. In order to evaluate the scope of climate changes, it is necessary, in the first place, to analyze anthropogenic influence on weather and climate. Deforestation of great magnitude over centuries has been mankind's tool in changing climate across vast geographic areas. This is particulraly true when deciduous forests of moderate belt, possessing their own climate, are concerned, which have been turned by the process into steppe with different climate and a series of variants of microclimate. It is not that the outcome was wanted, however. As for mountainous regions, human agency through deforestation has led to changes in microclimate, accelerated erosion and altered size of components of water balance [4].

Therefore, the decision made by the Norwegian parliament concerning 'zero deforestation' is highly commendable. In addition, the Norwegian Government is a significant financier of the 'Forest Conservation' global project. In 2014, in measures attempted at the protection of biodiversity, realized through introduction of new laws and harmonization of the existing ones, Norway, along with Germany and Great Britain, made a committment at the Summit on Climate held in New York to promote adoption of national policies preventing further deforestation. This process alone is responsible for the increase of carbon-dioxide in the atmosphere for a staggering 44%, the countries notorious in this respect being Argentine, Bolivia, Paraguay, Indonesia, Malaysia and others.

The basic problem in researching the basin and flow of the Vrbas is structurally contained in defining the characteristics of the basin, the complex of natural factors of the basin, the analysis of water regime and major waterpower issues in the basin. In order for the research to be referential, a wide spectre of methods and techniques, relevant for soil research, needs to be applied. Some results of the research will serve, to some extent, as the basis for rational management of the waterflows in the Vrbas basin.

3 Solution of the problem

The analysis of hydrometerological data and water regime data (level and flow) in Bosnia and Herzegovina shows that this geographic area is exposed to high flood risk. On several occasions, the year of 2014 included, a huge damage was caused to the economy, accompanied, unfortunately, by human fatalities.

Although the floods could not have been completely avoided, their negative consequences would have been reduced if the authorities had taken all the necessary protection measures. Our research show that the existing flood protection system is substandard concerning saving lives and assets.

In addition, the analysis of the legislative in Bosnia and Herzegovina (Republic of Srpska and Federation of Bosnia and Herzegovina) governing this area shows that the system is, generally speaking, too complex, inadequate, difficult to control and, due to incompetence and lack of coordination, unable to meet the people's needs.

3.1. Precipitation and flows in the Vrbas basin

Precipitation is one of major climate elements. In terms of their origin and duration, they are rather changeable. There are few precipitation stations in the Vrbas basin compared to meteorological ones, so we conducted certain precipitation analyses for the Banja Luka station, with precipitation projection for the periods 2001-2030 and 2071-2100 respectively. A comparative analysis was conducted for the precipitation stations of Bugojno, Prozor/Rama, Jajce and Kotor Varoš as well.

Table 2. Climate data for the Banja Luka precipitation station – average amount (l/m^2) by months and seasons for the period 1961 – 1990 and precipitation projection for the periods 2001 – 2030 and 2071 – 2100 respectively*

Per.	months												seasons (Σ)			
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Win	Spr	Sum	Aut
1961/1990	69.8	62.9	79.3	85.1	97.4	111	93.8	93.1	82.4	73.7	89.9	88.7	221	262	298	246

2001 2030	66.7	56.9	89.9	98.5	98.7	105	113	81.8	80.8	71	90.9	106	229	287	300	243
2071 2100	50.8	51.5	99.1	113	87.6	89.1	68.5	57.1	61.2	70.5	83.6	95.3	198	300	215	215

* values approximated

Source [5]

Table 3. Climate data for the Banja Luka precipitation station – average air temperature (^{o}C) by months and seasons for the period 1961 – 1990 and precipitation projection for the periods 2001 – 2030 and 2071 – 2100 respectively*

Per.	months												season			
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Win	Spr	Sum	Aut
1961 1990	-0.7	1.9	6.0	10.5	15.2	18.5	20.3	19.6	15.9	10.8	5.8	1.2	0.8	10.6	19.5	10.8
2001 2030	-0.8	2.3	5.9	10.9	15.3	19.3	20.9	20.3	17.1	11.9	7.1	1.5	0.9	10.7	20.2	12.0
2071 2100	3.2	5.3	7.6	12.9	18.1	22.2	24.9	23.9	20.2	14.4	9.0	5.1	4.5	12.9	23.7	14.5

Source [5]

Depending on the amount and duration of the precipitation, values of specific flow off, dimensions of the riverbed as well, high waters can cause floods on certain geographic area. Therefore, in case of high waters it is necessary to determine them on hydrologically studied profiles. The notion of maximum annual flow implies, essentially, the highest current value of the river flow on the concrete profile, registered in the course of calendar year. When the Vrbas is concerned, its profile is defined at the Delibasino Selo metre station. The line of talveg of the riverbed is at 141.05 metres of sea level, the bank line, in the widest sense, being at 148.27 metres of sea level. The occurrence of high waters of the 1/10 probability is registered at 146.34, those of 1/100 at 147.97, 1/500 at 148.99 and, finally, those of 1/1000 at 149.43 metres. With the water level of 816 cm and flow of 728 m^3/s in May 2014, the high waters reached their millennium high on the Vrbas (149.21).

By defining maximum flows on the precipitation stations in the Vrbas basin, based on practical application of the mathematical statistics theory and probability theory, we came to the probability of occurrence of maximum flows on the relevant precipitation stations in the upper flow of the Vrbas:

Table 4. Q_{max} in the upper flow of the Vrbas

Probability of occurrence	Precipitation station (m^3/s)	
	G. Vakuf	D. Vakuf
1/20	76	195
1/100	112	280
1/500	156	370

The genesis of the emergence of great (high) water is a complex process, predominantly caused by, in terms of manifestation, the worst deterioration of hydrological processes. As a result, the issue of protection against water has to be dealt with at the level of basin and its respective sub-basins, which implies research, analysis and registration of all phenomena in the basin, deforestation, erosive processes, anti-erosion protection et cetera. When the River Vrbas basin is concerned, its most significant sub-basin is the one of the Vrbanja River.

The latter is a right-hand tributary of the Vrbas River and, at the same time, one of the most important autochthonous waterflows of the geographic area of the Republic of Srpska. This fact is highlighted for the reason of the Republic of Srpska being known as a predominantly transitory water area. Namely, due to the territorial-political division imposed by the Dayton Agreement, that is, the inter-entity border line, there occurred the split of basins, so the Republic of Srpska, according to some estimates, disposes of a bit over of 10% of domicile waters [6].

The dominant course of stretching of the elongated basin of the Vrbanja River is SE-NW, that also being the prevalent course of the river itself. Seen as a whole, the basin belongs, on the one hand, to the southern rim of the Panonian basin (greater part) and, on the other hand, part of it is situated in the Mountain-valley area (internal Dinarides). Therefore, it can be concluded that the biodiversity of the basin, understood as physico-geographical diversity, is characterized by the following: diversity of geological phenomena and tectonic relations, geomorphological diversity (alluvial plains, plains formed by river agency, that is, the complex of foothill-mountain area dissected by minor or major valleys), geodiversity of water phenomena and forms, climate geodiversity, geodiversity of paedospheric complex, biogeodiversity and ecogeodiversity.

After detailed analyses, we suggest the following solutions to the problem of high waters in the Vrbas basin:

- analyze the whole of the basin (geographic position, borders of the basin, erosion processes in the basin, coefficient of forestation etc);
- conduct a hydrological-morphological and hydraulic analysis in urban areas of the river and its tributaries;
- view how endangered the municipalities are by torrential erosion and landslides and propose adequate reclamation measures;
- analyze the objects erected in the riverbed of the Vrbas and its tributaries and their influence on the reduction of flow capacity of riverbeds;

- propose various solutions to increase the flow capacity of the rivers belonging to the basin, especially in urban areas;
- propose a general concept of sewage systems in the basin;
- multi-municipal action directed at protection measures;
- define pre-emptive monitoring system in case of high waters.

Positive effects of civil engineering aimed at preventing floods are visible in immediate physical protection of human population and their property in flood areas. Among these one can include transformation of great flood waves, where major part is played by accumulative lakes and retentions (retaining water from pouring out and flooding or using it for melioration etc). Accumulative lakes have to be designed in such a way as 'to absorb the whole of the wave from its emergence up to the moment of its decline. If the purpose and size of the lake do not allow for the absorption of the whole wave, then retentions are built in upstream areas of the basin, with the sole task of reducing the natural flow of the wave, which is called flattening of the wave or transformation of the hydrogram' [7].

4 Conclusion

It is possible to forecast future high waters in the Vrbas basin by means of mathematical statistics method, based on combined meteorological and hydrological observations (unit hydrogram method and isochrone method, by registering high waters for future comparison and check of the results of other methods and mathematical statistics method, which are used to define the high waters of different recurrent periods. The recurrent period χ - is a long-term average time interval or number of years in which one phenomenon will occur again. Defining this interval for high waters is significant in terms of determining maximum flows or the volume of the flood wave in certain period of time. The probability method is used, where the recurrent period is calculated from a series of data. In cases when there is a value of maximum water level at which the measurement was done and maximum observed water level, we apply the method of extrapolation, that is, expanding the rule or conclusions established for one area to a wider, still unexplored one.

The damage inflicted in the basins of major rivers in Bosnia and Herzegovina (Una with Sana, Vrbas with Vrbanja, Bosna with Spreča, Usora and Drina) was caused by abundant precipitation in the Sava basin (200-250 l/m^2 in three days), non-existence of waterworks protective objects and a reduced level of protection or collapse of the existing objects for the protection of high waters. Based on this damage, it is evident that the flood risk forecast in the Vrbas basin is a disturbing one. The protection against high waters should be an absolute priority, but it must be harmonized with the needs and level of threat.

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