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REGIONALIZATION OF PARAMETERS OF THE HYDROLOGICAL REGIME OF FLOOD FLOWS IN BOSNIA AND HERZEGOVINA

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Water management systems and facilities are constructed with the purpose of creating conditions for efficient use of water, protection of water quality and protection from adverse effects of water. Their construction, maintenance and operation require major investments that burden the national economy in large measure. Construction costs of water management systems and facilities significantly depend on characteristics of the water regime, i.e. water regime is the determining factor for planning and implementation of water-related works and activities. Since the activities of planning and design of water facilities and systems often take place in areas with completely unknown or insufficiently known water regimes, the method of regional analysis is often used as the method to define and evaluate the parameters determining the water regime. This paper describes the conducted regional analysis of flood flows for the area of Bosnia and Herzegovina, which involves establishing regression dependences of hydrological water regime parameters and physical and geographic characteristics of catchment areas as the basis for defining the water regime in a particular area.

INTRODUCTION

From the very beginning of civilizations, flood flows have been treated as adverse natural events with negative effects on everyday human activities, material resources and, ultimately, on human lives. One of the major problems of our time, along with droughts, is floods that can be defined as a state when water spills out of its primary riverbed and floods the riverside terrain Hrelja (2007), Prohaska (2003). One of the most important problems faced by planners and designers of water control systems is to assess the risk of damages resulting from the occurrence of flood flows, as well as financial investments required to reduce these risks to an acceptable measure. On the other hand, the level of the risk is directly related to characteristics of the water regime, the knowledge of which being the first step in solving the complex of these problems. Thus, the importance of knowledge of flood flows and selection of relevant flows when sizing facilities in engineering practice are especially emphasized, all aiming at reducing the risk of damages (Zelenhasic, 1991).

Defining a regime of flood flows is generally based on long-term monitoring and recording of hydrological and meteorological phenomena and their statistical analysis. However, in the absence of measured hydrological data at a location of interest, it is not possible to carry out conventional hydrological statistical analysis, but the determination of the necessary values requires application of other methods, and one of the frequently used is the method of regional analysis.

THE METHOD OF REGIONAL ANALYSES

Assessment of parameters of flood flow regimes on unexplored hydrological profiles uses the method of regional analysis, which is generally based on a comparison of the factors determining formation of flood flows in the considered basin with the same factors in neighboring basins.

If there is a good correlation between specific parameters, it is possible to draw conclusions on the values and other relevant characteristics of the parameters in the area in which they are not studied by using the parameters from studied areas. The above can also be applied for maximum flows, or flood flows, which are of primary interest in this paper. The method finds application in the conditions of a complete absence of measured hydrological data and in the case of facilities that pose a relatively low risk to downstream areas.

The aim of regional hydrological analysis is to zone basins by homogeneity, or to define the areas with the same factors that are decisive for formation of flows (flood, low or average) on catchment areas. Here, It is necessary to emphasize that the assertion of homogeneity of an area is relative, considering that it is related to different and heterogeneously represented physical and geographical characteristics of a particular area.

According to Zugaj (2000), regional analyses are conducted on the basis of the following procedures:

Analyses of basic data

Determining the treatments of characteristic parameters whose interconnections will be explored

Examining the relationships between individual characteristic parameters based on the linear and nonlinear correlation

Defining the general patterns of satisfactory relationships with graphical representations

Comparing the results of regional hydrological analyses of the studied region with results of analyses of other regions

This paper presents the results of the regional analysis of flood flows in the territory of Bosnia and Herzegovina, which are obtained on the basis of available hydrological data on flood flows for six basins and 93 gauging stations with lengths of observation series from 10 to 60 years:

Table 1. Numbers of processed gauging stations by basins for series of maximum annual flows

Basin	Sava	Bosna	Drina	Neretva	Una	Vrbas	Total
Number of GSs	12	31	14	9	18	9	93

In the territory of Bosnia and Herzegovina, flood flows usually occur in the form of torrential flows with short flood waves and large runoff modules ranging from 1 to 1.5 $m^3/s/km^2$ (Institute of Water Management Sarajevo, 2012). Based on hydrological parameters that were at disposal, regional analyses of quantities of surface water were made for the territory of Bosnia and Herzegovina and their description is given by primary basin and sub-basin area. In most cases, the data recorded in the period of operation of hydrologic stations 1961-1990 were used for the analysis, which, according to the World Meteorological Organization WMO, is a sufficient length of data series to carry out the hydrological analyses.

The following regression dependencies were considered and established in the paper:

$Q^T_{max} = f(F)$,

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$Q^T_{max} / Q_{sr} = f(c_v)$,

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meanings of which will be explained in the following. After establishing the dependences, we give conclusions on their quality, as well as spatial distribution of parameters of the hydrological water regime, and their regional characteristics for the analyzed catchment areas.

Defining the regional dependence $Q^T_{max} = f(F)$

Due to its simplicity for use in hydrological practice, the most commonly used type of regional dependence is the dependence of the maximum flow of a certain recurrence interval, Q^T_{max} , on the basin area *F*. Once this dependence is established, determining characteristic values of maximum flows for an unexplored watercourse involves only knowing the basin area for the desired profile as the only unknown parameter in the regression equation that defines the regional dependence $Q^T_{max} = f(F)$. Entering all the values of available hydrological data of ordered pairs (Q^T_{max} , *F*) into the coordinate system gives a field of points that can be in most cases well described by an equation of the form:

$$Q^T_{max} = a \cdot F^b_{sl} \tag{1}$$

where “a” and “b” are parameters of the model. The parameters “a” and “b” are usually determined by minimizing the sum of squared deviations of actual measurement values from the values obtained by using the regression functional relationship or some other correlation and regression method.

Figure 1 illustrates an example of dependence curve for the return period of 2 years for all basins in Bosnia and Herzegovina, while the results for all return periods are presented in Table 2.

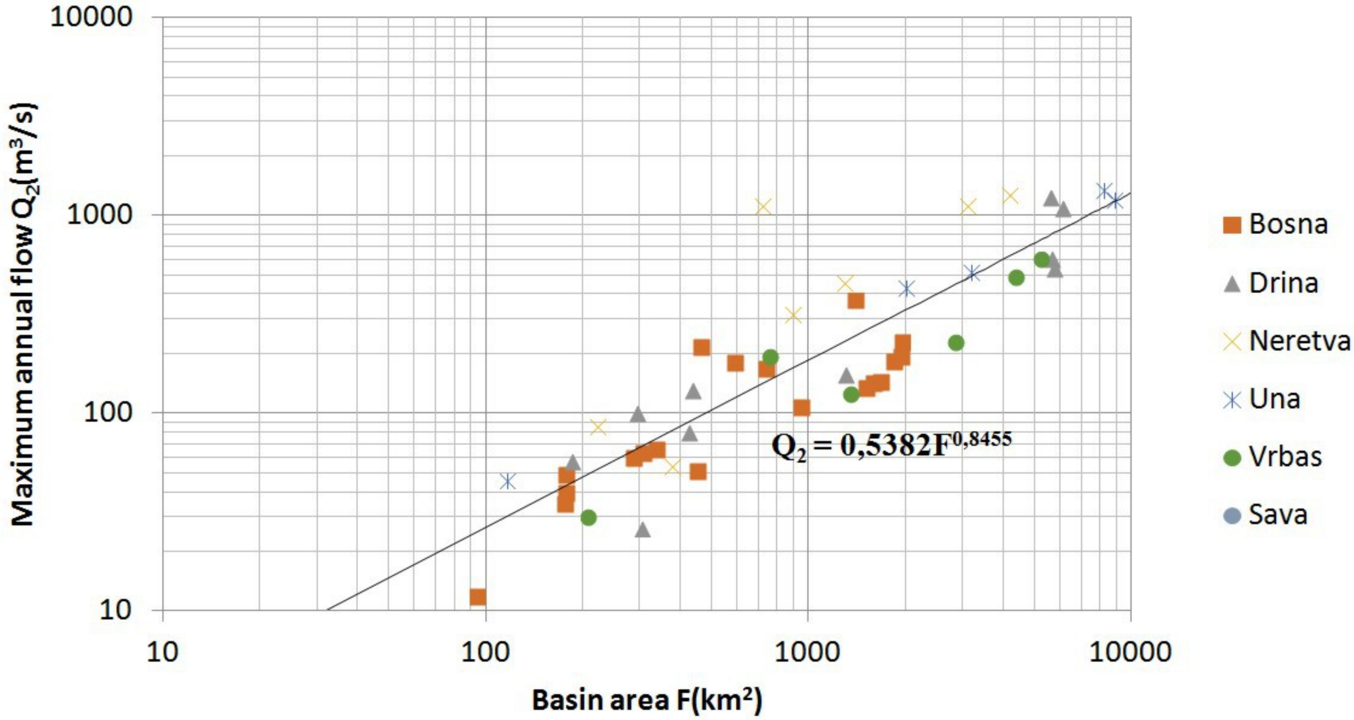

Figure 1. Dependence curve of maximum annual flows of the return period of 2 years

Table 2. Values of regional parameters of curves of the form $Q_{max}^{T} = a \cdot F_{sl}^{b}$ for basins in Bosnia and Herzegovina

Return period T(years)	Regression coefficients		Correlation coefficient
	a	b	r
2	0.538	0.845	0.885
5	1.002	0.805	0.872
10	2.419	0.703	0.883
20	1.867	0.764	0.852
50	7.098	0.607	0.868
100	8.050	0.605	0.859
1000	15.817	0.555	0.813
10000	25.236	0.521	0.778

As there is a deviation of the field of points (Q_{max}^{T} , F) from the dependence defined for the entire territory of Bosnia and Herzegovina, regionalization was also conducted in some smaller and more homogeneous areas (six considered basins), thereby reducing the discrepancies considering the greater homogeneity of the causal factors. For the same form of dependence as for the entire territory of Bosnia and Herzegovina, the results for smaller basins within Bosnia and Herzegovina and different return periods are given in Table 3.

Table 3. Values of regional parameters of curves of the form $Q_{max}^{T} = a \cdot F_{sl}^{b}$ separately by basins

Regression coefficients	Return period T(years)							
	2	5	20	10	50	100	1000	10000
Bosna River Basin								
a	0.8415	1.583	2.883	0.883	5.225	5.48	14.286	22.571
b	0.745	0.704	0.669	0.828	0.661	0.672	0.594	0.578
Drina River Basin								
a	0.5203	1.199	2.688	3.469	7.283	7.3252	11.533	16.312
b	01.843	0.787	0.735	0.680	0.633	0.657	0.648	0.631
Neretva River Basin								
a	0.1615	0.197	0.263	0.477	0.617	0.684	0.973	1.237
b	1.091	1.094	1.084	0.984	0.9749	0.9711	0.949	0.938
Una River Basin								
a	1.1728	1.828	2.786	1.945	3.203	3.862	6.607	9.918
b	0.769	0.739	0.709	0.739	0.699	0.683	0.636	0.602
Vrbas River Basin								
a	0.4202	0.766	1.345	0.753	1.348	1.551	2.733	4.161
b	0.945	0.801	0.774	0.812	0.777	0.724	0.745	0.724
Sava River Basin								
a	/	/	/	33.619	54.874	68.464	106.69	151.85
b	/	/	/	0.423	0.389	0.3721	0.3424	0.319

The correlation coefficient, ranging between [-1, 1], is an indicator of the quality of the correlation and the selected form of functional relationship. The closer the correlation coefficient is to the value of 1 by its absolute value, the better the correlative dependence is, while the closer it is to the value of 0, the less the dependence between the variables is, that is, their correlation does not exist. Average correlation coefficients for different basins are given in Table 4.

Table 4. Average correlation coefficients of curves of the form $Q_{max}^{T} = a \cdot F_{sl}^{b}$ separately by basins

Basin	Correlation coefficient (r)
Sava	0.783
Bosna	0.816
Drina	0.923
Neretva	0.861
Una	0.871
Vrbas	0.91

In general, maximum flow defined on the basis of the pattern $Q^T_{max} = f(F)$ should be accepted only as an estimate of the real value, and consequently its verification by some of the other methods for calculation of flood flows should always be sought.

Defining the envelope curves $q^T_{max} = f(F)$

In the following is a description of analyses of maximum specific runoffs of a certain recurrence period q^T_{max} dependent on the basin area *F*. Specific runoff is a very convenient indicator of flood flows, particularly if comparing extreme values of runoffs from different basins. Two significantly different precipitation regimes are present in Bosnia and Herzegovina: maritime and continental, which lead to different runoff regimes and inhomogeneity of the territory of Bosnia and Herzegovina in terms of the hydrological regime. Thus, the maximum specific runoff decreases with the size of basin area, and the strength of the correlation decreases or weakens. Therefore, for this dependence we define the envelope curve, or the upper limit of maximum specific runoffs the analytical expression of which is:

$$q^T_{max} = a \cdot F^b_{sl} \quad (2)$$

where "a" and "b" are the regression coefficients or regional parameters that are defined by the usual procedures of mathematical correlation and regression.

Two envelope curves are formed, specifically for:

- the zone of large lowland watercourses, for which basins have considerable inundation areas with an adequate retardation effect (*F*> 20,000 km^2)

- the zone of smaller watercourses (*F* < 20,000 km^2).

The results are shown in Tables 5 and 6.

Table 5. Values of regional parameters of envelope curves of the form $q^T_{max} = a \cdot F^b_{sl}$ for the zone of lowland watercourses

Return period T (years)	Regression coefficients			
	Basin areas F<20 000 km^2		Basin areas F>20 000 km^2	
	a	b	a	b
10	11.309	-0.395	3.6983	-0.36
50	21.529	-0.429	1.9024	-0.285
100	22.724	-0.398	1.7519	-0.275
1000	43.322	-0.429	0.9065	-0.201
10 000	68.946	-0.447	0.8479	-0.189

Table 6. Values of regional parameters of envelope curves of the form $q^T_{max} = a \cdot F^b_{sl}$ for smaller watercourses

Return period T (years)	Regression coefficient for basins of the area F < 20 000 km^2	
	a	b
2	1.0848	-0.135
5	4.419	-0.285
20	7.344	-0.31

Defining the regional dependence $Q_{max}^{T}/Q_{sr}=f(c_v)$

The previous analyses lead to the conclusion that maximum flows (Q_{max}^{T}) vary 10 times or more for the same catchment area (*F*), with a possible cause in the impossibility of determining the exact basin areas (differences in the topographic and hydrogeological divide) and a large percentage of karstification of the territory of Bosnia and Herzegovina. Therefore, there is a need to define a dependence in which catchment area will not participate as a direct parameter, which was the case in the previously shown dependences. The relationship proposed in the following can be used in implementation of control or even defining of flood flows.

In the dependence $Q_{max}^{T}/Q_{sr}=f(Q_{sr})$, Q_{max}^{T}/Q_{sr} is a dimensionless module coefficient, where Q_{max}^{T} is the maximum flow of the recurrence period *T* in years (m^3/s), Q_{sr} is mean multi-annual flow (m^3/s), and c_v is the coefficient of variation of a statistical sample of maximum flows.

The analytical form of the dependence, on the basis of which the regression curve is determined, is:

$$Q_{max}^{T}/Q_{sr}=a\cdot F_{sr}^{b} \tag{3}$$

where (a) and (b) are regression coefficients, or regional parameters.

Table 7. Values of regional parameters of curves of the form $Q_{max}^{T}/Q_{sr}=a\cdot F_{v}^{b}$ for basins in Bosnia and Herzegovina

Return period T (years)	Regression coefficients		Correlation coefficient
	a	b	r
2	11.883	0.5233	0.579
5	20.997	0.7664	0.698
10	25.967	0.8824	0.697
20	38.032	1.0418	0.794
50	42.438	1.0718	0.742
100	50.848	1.1418	0.756
1000	83.673	1.3295	0.776
10000	112.25	1.4091	0.776

Defining the regional dependences and envelope curves $Q_{max}^{T}/Q_{sr}=f(Q_{sr})$

The module coefficient Q_{max}^{T}/Q_{sr} , depending on the mean value of flow, forms regional dependence with the adopted analytical expression:

$$Q_{max}^{T}/Q_{sr}=a\cdot F_{sr}^{b} \tag{4}$$

where (a) and (b) are regression coefficients, or regional parameters.

A large scatter of points was observed for this relationship, i.e. values of the module coefficient are mainly several times larger for approximately the same mean annual flows. Table 8 gives an overview of regional parameters and correlation coefficients of the regression curves.

Table 8. Values of regional parameters of curves of the form $Q^T_{max}/Q_{sr}=a\cdot F^b_{sr}$ for basins in Bosnia and Herzegovina

Return period T (years)	Regression coefficients		Correlation coefficient
	a	b	r
2	14.115	-0.191	0.548
5	25.894	-0.267	0.631
10	38.987	-0.338	0.753
20	47.933	-0.347	0.685
50	65.21	-0.394	0.768
100	77.911	-0.412	0.767
1000	130.18	-0.465	0.764
10000	171.09	-0.481	0.748

The pairs of values Q^T_{max}/Q_{sr} , Q_{sr}) show a very large scatter above the defined dependence, derived from the available data from the entire territory of Bosnia and Herzegovina. That is why this dependence can be considered highly unreliable and should not be used for determining flood flows and can be used only for orientation, or for estimation of actual values, bearing in mind the possible significant error.

In further analysis, the upper limit of largest module values of runoff was determined for the same group of data. Thus, the upper envelope line, which has the same analytical form as the curve of regression dependence, is defined.

Tabulation of regional parameters and correlation coefficients for envelope curves is given in Table 9.

Table 9. Values of regional parameters of envelope curves of the form $Q^T_{max}/Q_{sr}=a\cdot F^b_{sr}$ for basins in Bosnia and Herzegovina

Return period T (years)	Regression coefficients	
	a	b
2	45.535	-0.343
5	103.98	-0.470
10	204.91	-0.537
20	166.13	-0.493
50	264.54	-0.521
100	267.13	-0.497
1000	453.15	-0.518
10000	593.75	-0.469

CONCLUSION

A general picture of spatial nonuniformity of flood flows in the territory of Bosnia and Herzegovina can be obtained from the previously described results of the conducted analyses.

Regardless of the spatial and temporal heterogeneity of the factors affecting runoff, past experience in studying the hydrological regime indicate the presence of a certain degree of regularity in the behavior of water regime, which allows certain generalizations and regionalization of the parameters important in the formation of runoff.

Based on the established, previously described, regression dependences, it is possible to estimate the parameters of hydrological regime in the areas where there is the case of complete absence of relevant data, or of appropriate hydrological observations and measurements.

It is important to emphasize that a relatively poor pool of data was available during the analyses, and that scatters of points were observed. A better evaluation of flood flows in the territory of Bosnia and Herzegovina would require additional analyses to be made, which would involve additional gauging stations, including data from neighboring basins.

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REFERENCES

Drazic, P. 2007. The criteria for the evaluation and selection of variants of regional water management system, Vodoprivreda, Vol. 39,pp. 229-234.

Hrelja, H. 2007. Inzenjerska hidrologija. Faculty of Civil Engineering University of Sarajevo. Sarajevo.

Hrelja, H. 2005. Some elements of the hydrological regime of the method of regionalization, Vodoprivreda, Vol. 37,pp. 21-34.

Institute for Water Management Sarajevo. 1994. The Framework Water Management in Bosnia and Herzegovina, Sarajevo.

Institute for Water Management Sarajevo. 2012. The Water Management Strategy of the Federation of Bosnia and Herzegovina 2010-2022. Sarajevo.

Jovanovic, S. 1989. Hydrology. Gradjevinska knjiga Beograd. Belgrade.

Prohaska, S. 2003. Hydrology I, Faculty of Mining and Geology. Belgrade.

Zelenhasic, E., and M. Ruski. 1991. Hydrological engineering, Scientific Book. Belgrade.

Zugaj, R. 2000. Hydrology, University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering. Zagreb.

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