sciendo Ovidius University Annals Series: Civil Engineering, Year 20, 2018
DOI: 10.2478/ouacsce-2018-0013

GIS Based Flood Flow Assessment in Small Catchments for Flood Mapping in Bosnia and Herzegovina

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Abstract – **An initial step in flood hazard mapping is hydrological modelling. We present a recent river flood modelling approach in Bosnia and Herzegovina (BiH) for small ungauged catchments of drainage area up to 32 km^2. To estimate peak flow of required probability in small catchments, we use the rational method. The paper focus is GIS based procedure for producing the runoff coefficient map for BiH from the DTM and land cover map. For validation of the peak flow modelling results in small ungauged catchments we use diagrams of peak flow per catchment area (specific runoff) versus catchment area in medium and large gauged catchments. The results indicate agreement in specific runoff for 100 and 500 years return period compared to reference runoff in gauged catchments and a mild drop in specific runoff for 20 years.**

Keywords – rational method, runoff coefficient map, slope map, ungauged catchment

1. INTRODUCTION

Flood hazard maps are important tools in the effort to protect human health, the environment, cultural heritage and economic activity. Article 6 of the Floods Directive [1] requires Member States to prepare flood hazard and flood risk maps (at the river basin level) for the areas of potential significant flood risk identified under Article 5 or 13.1(a), or for the areas for which Member States decided to prepare flood maps according to Article 13.1(b). Flood hazard maps show the geographical area which could be flooded under different scenarios (Article 6.3) [1].

The on-going Project "Flood Hazard and Flood Risk Maps in Bosnia and Herzegovina" (WB12-BIH-ENV-04C1) includes scenarios of fluvial (river) flood events with return periods of 20, 100 and 500 years. There are 211 areas of potential significant flood risk (APSFR) identified in the process of preliminary flood risk assessment. The provision of input data on design peak flows for hydraulic modelling in river reaches covering APSFRs, comprises hydrological modelling of 75 ungauged catchments encompassing 146 ungauged sites. The drainage area of the ungauged catchments range between about 1 km2 and 1499 km2, and therefore a range of methods are used to estimate the design peak flows (Q20, Q100 and Q500). For the group of small ungauged catchments with drainage area up to 32 km2 the rational method is applied.

The rational method has been proposed by the Irish engineer Thomas Mulvaney in 1851 and developed by the American scientist Kuichling in 1889. It is often referred to as rational equation, because of the simplicity of its form. The peak discharge is obtained by using the runoff coefficient of the area, rain intensity, and drainage area size.

The assumptions underlaying the rational method [2], are often strictly interpreted as limitations for the application of the method. The assumption on nearly uniform runoff occurrence from all parts of the watershed means that the runoff coefficient has to be nearly the same over the entire drainage basin. Because this assumption is less likely to be valid as the drainage basin size increases, the application of the method is interpreted as limited to area as small as 0.8 km^2 [3], although there are limits set to 15 km^2 [4] and 25 km^2 [5]. However, in [6] it is shown the rational method can be applied to much larger catchment sizes than conventionally accepted.

Along with a question of rainfall intensity, the estimation of runoff coefficient is a challenge in the rational method. There are variety of empirical indications provided for its estimation, from the simplest ones that consider land use only, to functions linking the land use, soil type and area slope [5].

In the paper we present GIS based procedure for obtaining the runoff coefficient map for the whole territory of BiH. As input data we use the Digital Terrain Model (DTM) and land cover map. We show the peak flow modelling results of rational method in small ungauged catchments relative to the statistically modelled peak flows in medium and large gauged catchments in BiH.

2. METHOD DESCRIPTION

The rational equation is the simplest method to determine peak flow from drainage basin runoff:

$$\mathrm{Q = c\ i\ A} \tag{1}$$

where,

Q is peak discharge, m^3/s
c is rational method runoff coefficient
i is rainfall intensity, m/s
A is drainage area, m^2.

The equation (1) is dimensionally correct with SI units shown, while conversion factors are applied when using usual units for *i* (mm/min or mm/hr) and *A* (km^2 or ha).

The rainfall intensity *i* is typically found from Intensity/Duration/Frequency curves for rainfall events in the geographical region of interest. We use the specified storm frequencies of 20, 100 and 500 years, and the duration equivalent to the time of concentration (*Tc*) of the drainage area. Instead of catchment decomposition, for each catchment we use a composite *Tc* to obtain the design storm depth using the most geographically representative of the adopted Depth/Duration/Frequency curves (Fig. 1-left) and reduction factor curves (Fig. 2) applied to the daily precipitation of specified frequency at the closest or most representative meteorological station (MS) to the ungauged catchment (Fig.1-right). We calculate runoff with a constant rainfall intensity *i* in each catchment.

The rational method runoff coefficient (*c*) is a function of the land use, soil type and drainage basin slope. We use the composite *c* for each ungauged catchment and before returning it to the rational equation we apply runoff coefficient adjustment factor to account for reduced infiltration during intense storms with high return periods. The composite *c* for the catchment we find/calculate from the runoff coefficient raster map.

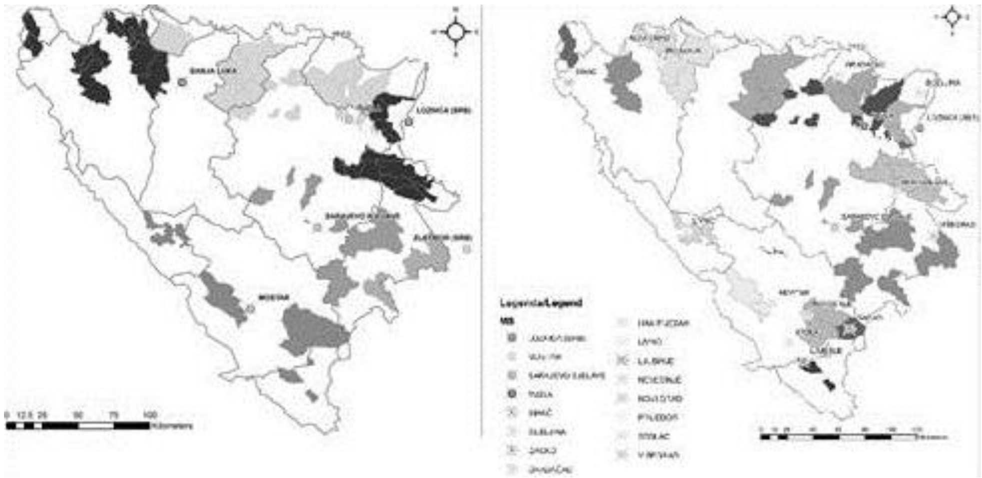


Fig. 1 Left - 6 Selected MS with DDF curves and associated ungauged catchments
Right - MS with daily design storms and associated ungauged catchments

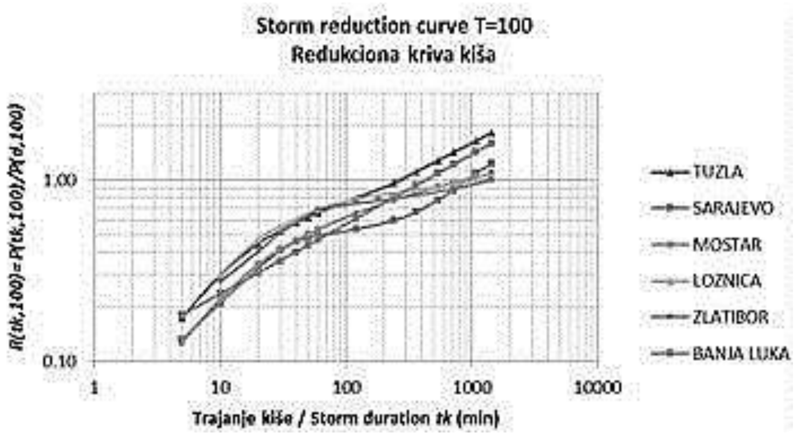


Fig. 2 Storm reduction factor curves for 100-year return period at 6 meteorological stations. The reduction factor shows rainfall depth ratio of less than 24 hrs. to daily precipitation

The procedure we used to create the runoff coefficient raster map for the whole territory of BiH is shown in Fig. 3.

The procedure starts as two-tier process. First, we prepare the land cover data from the Corine Land Cover database [8] with 14 land use classes; we reclassify it to 7 classes according to the runoff coefficient table entries, and vectorize the data. After that, we start the second-tier process by creating slope map from the available DTM data. Because the slope class ranges do not conform our requirements, we reclassify the raster map to obtain three slope classes (0-5, 5-15, >15%) corresponding to flat to rolling, rolling to hilly and hilly to mountainous terrain respectively. We vectorize the map and insert 4 new fields in the attribute table (Fig. 4). These fields are false Hydrologic Soil Group (A, B, C, D) because we follow the procedure from HEC-GeoHMS [9] for producing CN (Curve Number) raster map. Then, we calculate percentage of each class within the polygon.

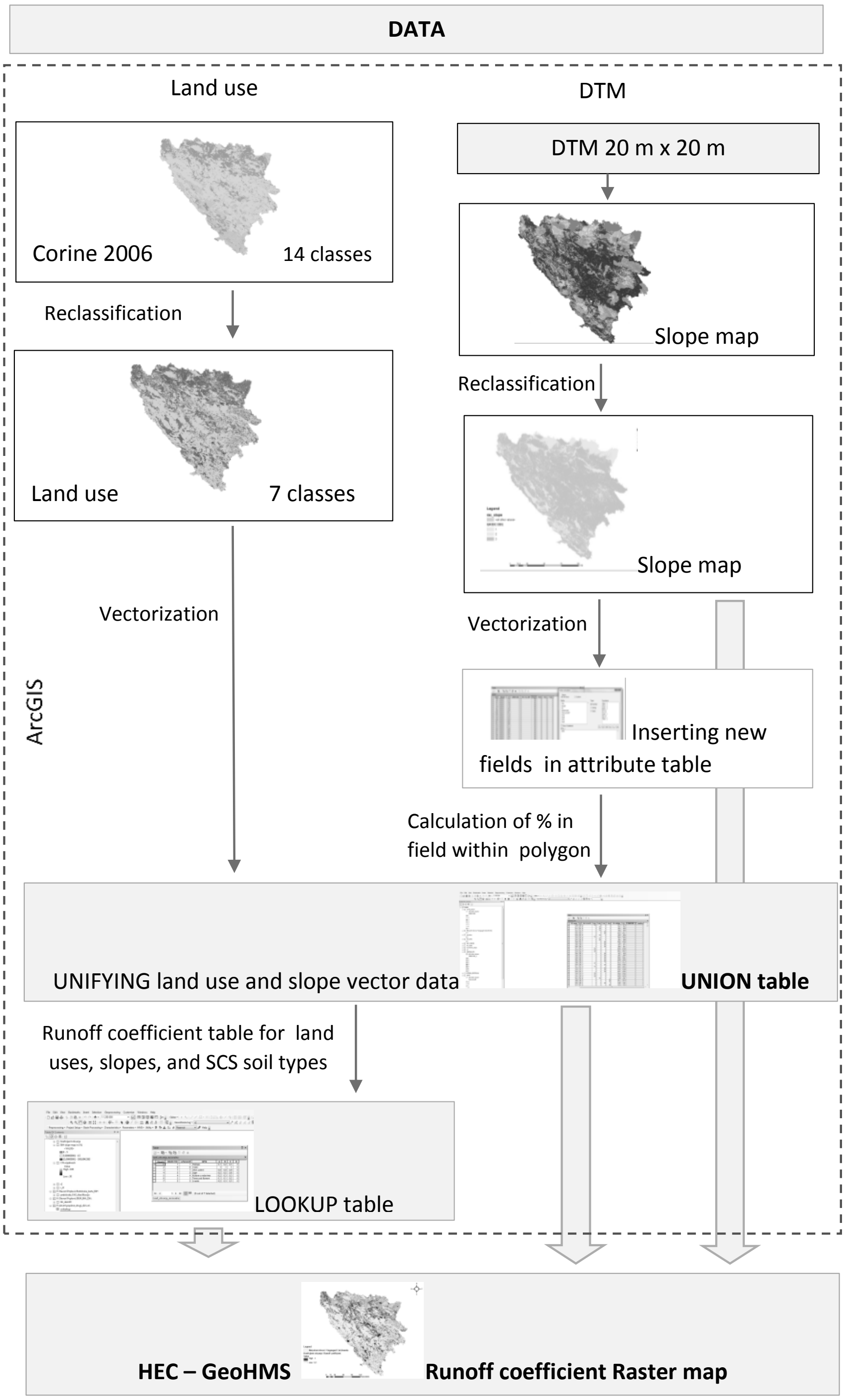
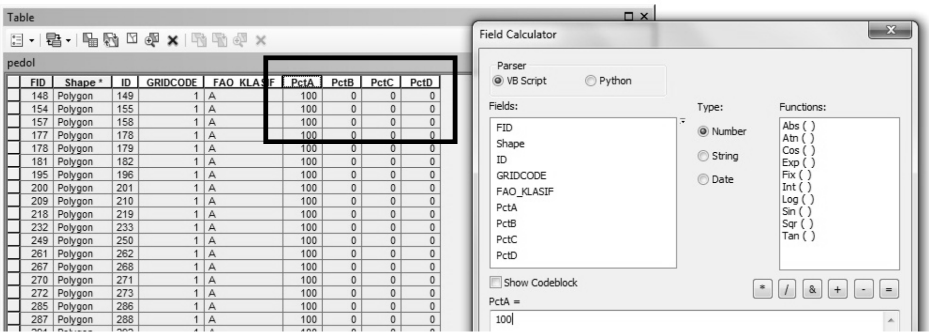


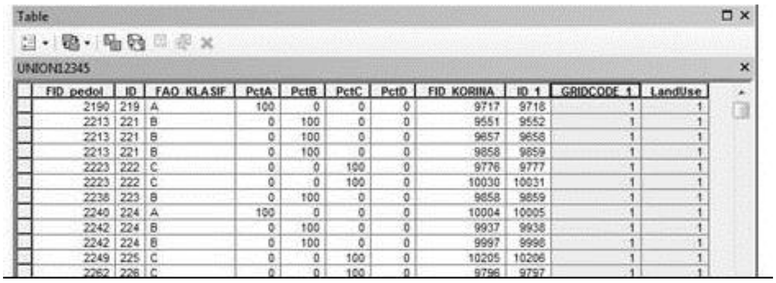
Fig. 3 Procedure of creating raster runoff coefficient map



FID	Shape *	ID	GRIDCODE	FAO_KLASIF	PctA	PctB	PctC	PctD
148	Polygon	149	1	A	100	0	0	0
154	Polygon	155	1	A	100	0	0	0
157	Polygon	158	1	A	100	0	0	0
177	Polygon	178	1	A	100	0	0	0
178	Polygon	179	1	A	100	0	0	0
181	Polygon	182	1	A	100	0	0	0
195	Polygon	196	1	A	100	0	0	0
200	Polygon	201	1	A	100	0	0	0
209	Polygon	210	1	A	100	0	0	0
218	Polygon	219	1	A	100	0	0	0
232	Polygon	233	1	A	100	0	0	0
249	Polygon	250	1	A	100	0	0	0
261	Polygon	262	1	A	100	0	0	0
267	Polygon	268	1	A	100	0	0	0
270	Polygon	271	1	A	100	0	0	0
272	Polygon	273	1	A	100	0	0	0
285	Polygon	286	1	A	100	0	0	0
287	Polygon	288	1	A	100	0	0	0

Fig. 4 Inserting 4 new fields (boxed) in the attribute table to store percentage of slope class within polygon

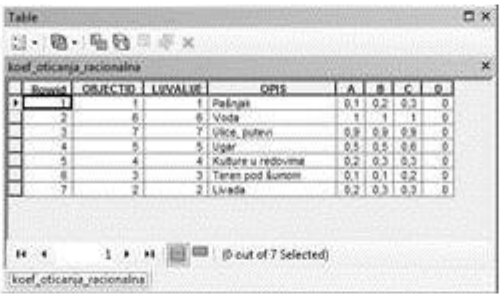
Now, we have all the data we need to join two separate process tiers i.e. land use data and slope data in the union table (Fig. 5).



FID_pedol	ID	FAO_KLASIF	PctA	PctB	PctC	PctD	FID_KORINA	ID_1	GRIDCODE_1	LandUse
2190	219	A	100	0	0	0	9717	9718	1	1
2213	221	B	0	100	0	0	9551	9552	1	1
2213	221	B	0	100	0	0	9857	9858	1	1
2213	221	B	0	100	0	0	9858	9859	1	1
2223	222	C	0	0	100	0	9776	9777	1	1
2223	222	C	0	0	100	0	10030	10031	1	1
2238	223	B	0	100	0	0	9858	9859	1	1
2240	224	A	100	0	0	0	10004	10005	1	1
2242	224	B	0	100	0	0	9937	9938	1	1
2242	224	B	0	100	0	0	9997	9998	1	1
2249	225	C	0	0	100	0	10205	10206	1	1
2262	226	C	0	0	100	0	9796	9797	1	1

Fig. 5 Union layer attribute table

The runoff coefficient table links land use and slope classes. Important step in the process is creation of "Landuse" field in Union layer's attribute table that corresponds to "GRIDCODE" field. We proceed to creation of a lookup table in ArcGIS (Fig. 6).



Rowid	OBJECTID	LUVALUE	OPIS	A	B	C	D
1	1	1	Pašnjak	0,1	0,2	0,3	0
2	6	6	Voda	1	1	1	0
3	7	7	Ulice_putevi	0,9	0,9	0,9	0
4	5	5	Ugar	0,5	0,5	0,6	0
5	4	4	Kulture u redovima	0,2	0,3	0,3	0
6	3	3	Teren pod šumom	0,1	0,1	0,2	0
7	2	2	Livada	0,2	0,3	0,3	0

Fig. 6 Lookup table

Here, we turn to HEC-GeoHMS to create runoff coefficient raster map by assigning value to each raster grid cell assisted by Lookup table - overlapping the Slope layer and Union layer. The final step is to generate a raster with "Generate CN Grid" tool found under Utility tab of HEC Geo-HMS, for which we need DTM, Union layer and Lookup table. The resulting runoff coefficient map is shown in Fig. 7.

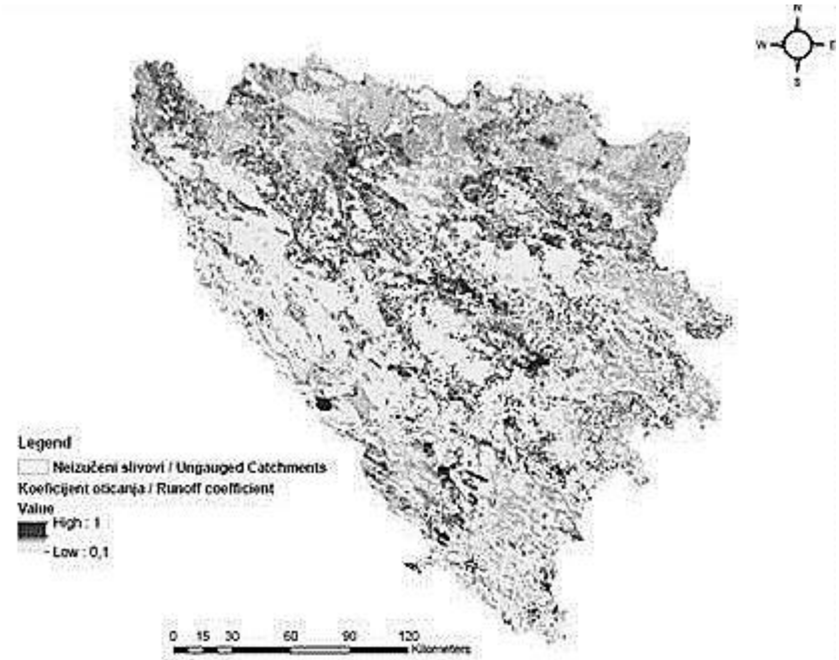


Fig. 7 The runoff coefficient map of Bosnia and Herzegovina

3. RESULTS AND SIGNIFICANCES

The results of peak flow modelling by the rational method in our assignment can be verified indirectly. There are a few gauging stations controlling small catchments in BiH. Therefore, we have to use medium and large catchments for verification of results. We visually compare the modelled peak flow per catchment area (specific runoff) in small ungauged catchments to gauged catchments as a function of catchment area. The division of the territory we select for comparison of specific runoff comprises three hydrogeologic - karstic belts of the Dinaric Alps (Fig. 8), because karstic area presence is an influential flood factor in BiH.

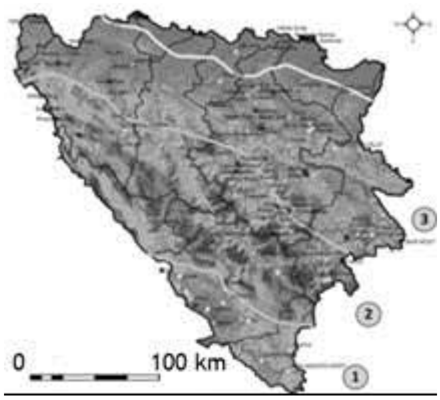


Fig. 8 Three karstic belts of the Dinaric Alps in Bosnia and Herzegovina [10]

The modelling results indicate a mild drop in specific runoff in both belts 2 and 3 for 20 years return period compared to reference runoff at gauging stations, and agreement for 100 and 500 years. Figure 9 shows example of specific runoff for 100 year flood in the belt 3 of the Dinaric Alps.

It is important to note the results from medium and large size gauged catchments are based on statistical modeling of the 1961-1990 discharge series. The results we obtained in ungauged catchments reflect more recent period when it comes to design storm base which is the period until 2016, and land use situation considering CLC data from 2006-2012.

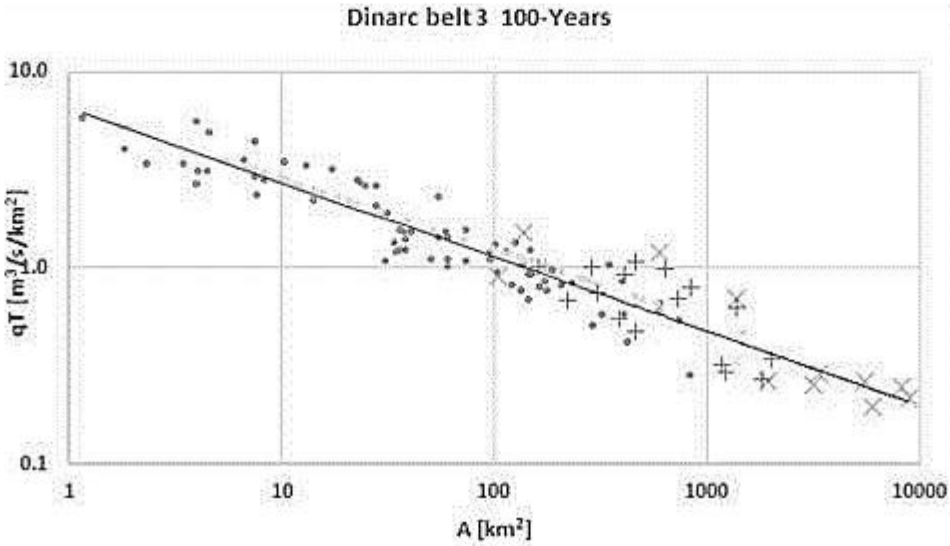


Fig. 9 100-year specific discharge from gauged catchments (x, +) and ungauged catchments (•) in the Dinaric belt 3. The regression line constructed for gauged catchments is extended in the plot only to show the fit in the range of small catchment area

4. CONCLUSION

GIS environment plays an important role in flood flow assessment, as shown in the case of the runoff coefficient map development for the territory of BiH. The map then improves river flood assessment procedure and decreases uncertainties in peak flow estimation for small ungauged catchments. It facilitates all the hard work and valuable time for determination of runoff coefficient that plays important role in the accuracy of flood modelling results. By overlapping the runoff coefficient map as a raster layer format and catchments as a vector (polygon) layer format, we can now easily determine runoff coefficient for any catchment area in the country in only few steps.

5. ACKNOWLEDGEMENTS

The authors wish to thank Mr. Michael Jacobsen, the WB12-BIH-ENV-04C1 project director, for providing the agreement from the contracting authority to submit this paper, as well as Ms. Dalila Jabučar, the project team leader, for her suggestions on the paper improvement. The project funding source is "EU IPA II Multi-Beneficiary Programme for

Albania, Bosnia and Herzegovina, the former Yugoslav Republic of Macedonia, Kosovo*, Montenegro and Serbia". The Contracting Authority is the "European Investment Bank".

*This designation is without prejudice to positions on status, and is in line with UNSCR 1244/199 and the ICJ opinion on the Kosovo declaration of independence."

6. References

[1] European Parliament and the Council of the European Union (2007), *Directive 2007/60/EC of the European Parliament and of the Council of the European Union of 23 October 2007 on the assessment and management of flood risks* [Online] available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32007L0060&from=EN

[2] V.P. Singh (1992), *Elementary Hydrology, Prentice Hall*, Englewood Cliffs, pag. 598

[3] Texas Department of Transportation (2016) *Hydraulic Design Manual*, pag. 4-48 [Online], available at http://onlinemanuals.txdot.gov/txdotmanuals/hyd/hyd.pdf

[4] HRU (1972), *Design Flood Determination in South Africa*. Report No. 1/72, Hydrological Research Unit, Department of Civil Engineering, University of Witwatersrand, RSA.

[5] OPW (2012), FSU, *Urban and Small Catchment Flood Estimation*, pag. 4 [Online], available at http://opw.hydronet.com/data/files/FSU%20Work%20Package%204_2.pdf

[6] G.G.S. Pegram (2003), *Rainfall, Rational formula and regional maximum flood - some scaling links*, Australian Journal of Water Resources, Vol. 7, nr. 1, pag. 29 - 39.

[7] EEA (2012) Corine *Land Cover inventory*

[8] – (2005) *Hydrology - Appendix F – Rational method* [Online] available at: ftp://ftp.odot.state.or.us/techserv/Geo-Environmental/Hydraulics/Hydraulics%20Manual/Chapter_07/Chapter_07_appendix_F/CHAPTER_07_appendix_F.pdf

[9] US Army Corps of Engineers, *Geospatial Hydrologic Modelling Extension* HEC-GeoHMS, [Online], available at: http://www.hec.usace.army.mil/software/hec-geohms/

[10] O. Bonacci (2015), *Karst hydrogeology/hydrology of dinaric chain and isles*, Environ Earth Sci 74: 37. [Online], available at: https://doi.org/10.1007/s12665-014-3677-8

Note:

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