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Application of an Automated Technique for Topographic Watershed Deriving Using DEM Analysis

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Basic topographic features play major role in deriving basin hydrological characteristics for water resources modeling. Algorithm used in this paper for defining watershed contours relies on digital elevation model (DEM) as primary input data. Accuracy of automatic deriving of watershed contours primarily depends on DEM resolution. On the other hand, accuracy can depend on raster method that is used for stream network delineation into Stream Network raster. To perform this function it is necessary to know how much water flows through each pixel. This means that it is necessary to set the threshold of how many cells flow into each downslope cell to recognize it as a stream. There are several ways to set up the threshold value and herein the calibration method is used. This paper treats Gornja Lisina source, where this method was used to determine watershed contours for 9 springs. Source DEM had 25 m resolution. Various threshold values were tested. For each value catchment area was calculated and compared to area values calculated using common hydrological methods.

Key words: *Topographic watershed, DEM, Stream Network raster, Gornja Lisina*

1. INTRODUCTION

Automated deriving of hydrological characteristics has advanced lately that much that now it represents integral part of most of the GIS software packages. Automated techniques are faster and may give more precise results than traditional so called manual techniques [1]. Basic requisition for high-quality output is resolution and quality of DEM, which was confirmed by Zhang & Montgomery [2], Wolock & Price [3], Garbrecht & Martz [4], DeBarry [5] and others in their research.

On the other hand, what can have significant effect on quality of calculation is the method itself, because there are various ways of generating DEM.

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The accent of the research presented in this paper is on precision of deriving watershed characteristics, i.e. testing of the method of delineation of drainage network into the Stream Network raster.

Previously, Spanish scientists Lopes Garcia & Camarasa [6] have been focused on a very similar topic, so this paper represents sublimation of their work on the data acquired during hydrogeological research campaign for Gornja Lisina groundwater source in 2008-2012.

2. RESEARCH AREA

Geographical Location. Research area is located in SE Serbia, on the territory of Surdulica and Bosilegrad, bordering municipalities with Bulgaria (Figure 1).

Generally, this part of Serbia is sparsely populated, with average of less than one household per km^2.

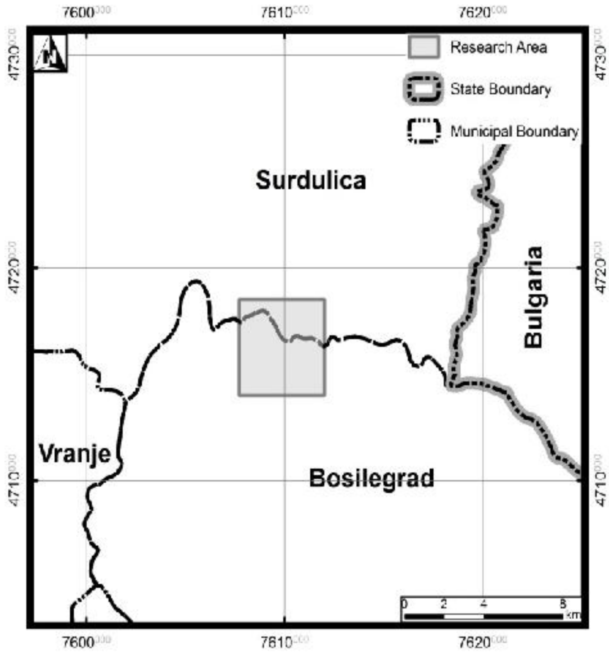

Figure 1 - Geographical location

Geomorphological Setting. Terrain is hilly with mild peaks and clearly expressed gullies. There is significant ground level difference, going from below 1000 m asl in the river valley; up to 1400 m, on locations of several springs; and even higher, on extents of the basin, where elevation goes over 1650 m. Higher zones and peaks are generally dry and uninhabited.

Regarding morphometric characteristics, slope angles in particular, the terrain of the most of the research area (46.67%) can be described as steep, with slope angle 15-25 very steep (26,19%), with slope angle 25-40; and moderately steep (23,00%), with slope angle 7-15.

Geological Setting. There are two dominant geological structures representing the whole area (Figure 2): Božica granitoid body and crystalline schist, while other units are significantly less common.

Božica granitoid is intrusive body that intruded into specific rock formation called Božica series, probably before Devonian [8], causing progressive alteration of the contact part of the series by various processes of granitization and felsparization of schist.

On the extent of the intrusive body, wide aureole of altered schist and gneiss enriched with felspars and other granitic content was formed, making fine gradation from the intrusive body to the metamorphic complex.

Therefore, on-site distinction of these two formations is very difficult, due to a very similar mineral and chemical composition but slightly different structure [9].

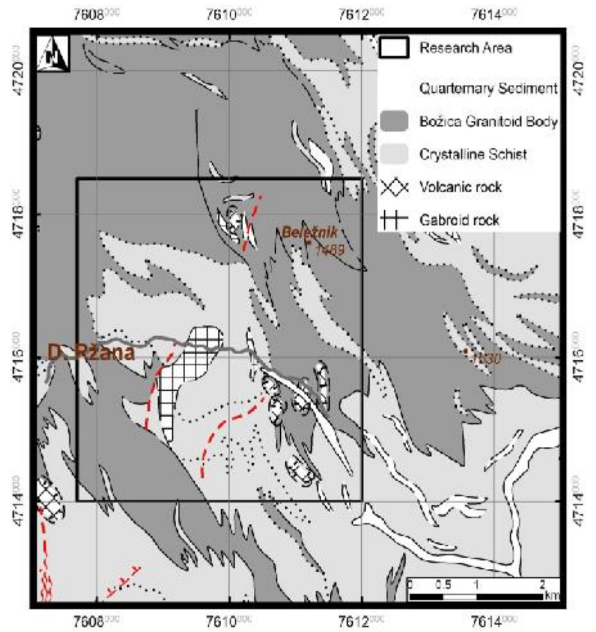

Figure 2 - Geological map

Hydrogeological Setting. Aquifer is formed in shallow fissured environment in the aeration zone i.e. above the local erosive basis. Due to conditions of zones of recharge, groundwater flow and drainage, this aquifer is predisposed to form an open hydrogeological structure [10]. Due to geomorphological, geological and hydrogeological setting, all springs are descending (Figure 3). Aquifer recharges from precipitation directly on the catchment area and because of its elevation (locally higher than 1600 m asl) process of snowmelt plays a significant role in recharge. Groundwater flows through unconfined system of fractures and fissures from recharge zone to the area of descending springs where this aquifer gets drained. Groundwater flow velocity is proportional to the gradient (locally over 0.3) and inversely proportional to the level of infill volume [11].

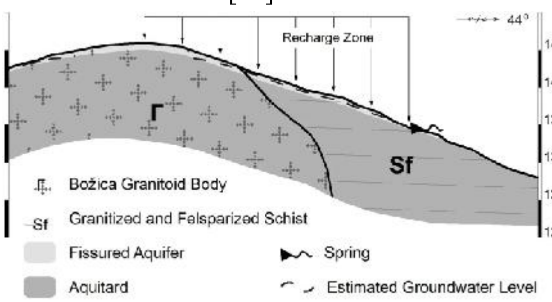

Figure 3 - Typical Hydrogeological cross-section

Source Setting. Groundwater source is located in the catchment area of Lisinska River, cca. 7 km upstream from Gornja Lisina local community. There are nine springs taken into consideration out of which six (#1-6) are positioned on northern and other three (#7-9) on southern side of the catchment area (Figure 4). Each spring is equipped with adequate tapping construction suitable for monitoring, and therefore suitable for defining of yielding regime. During their construction it was necessary to do additional excavation and cleaning around each spring in order to catch groundwater as efficiently as possible, when it was observed and determined that material was unconsolidated, heterogeneous, with fragments varying from 10 cm to over 1 m, with middle to fine grained matrix.

Having in mind geotechnical classification on: fines, debris and blocks, underlayed by monolith, it can be concluded that these springs have been formed in the zone of debris and blocks. This indicates that the zone of weathering in the drainage area is up to 1 m thick and that the whole aquifer in general is probably only several and not more than 6-7 m thick.

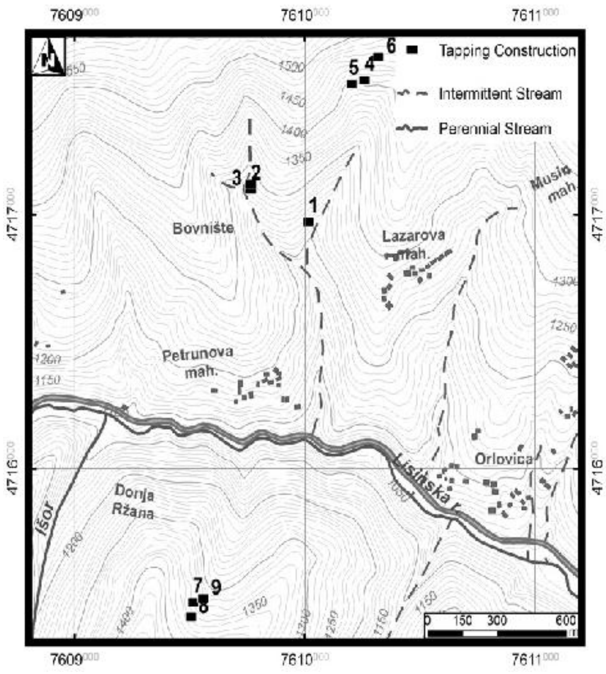

Figure 4 - The source site map

Regarding spatial distribution, i.e. distance between each spring, it is obvious that there are 4 separate sub-watersheds that are getting drained through 9 springs of interest. The first one drains through the spring 1. Second one drains through the springs 2 and 3. Third one drains through 4, 5 and 6 and fourth one through 7, 8 and 9 (Figure 4).

Groundwater yield and temperature regime is under the influence of climatic regime. All springs have relatively low yielding capacity (Tab. 1). Still, the yield is continuous (no drying up along the year), with difference between maximal and minimal value of c. 2.85. Hydraulic conductivity is adopted from empiric values, calculated for granitoid rocks of eastern Serbia [12].

Table 1. Yield and Temperature Properties According to the Monitoring Data Period sep 2008- dec 2009

Spring	Q [l/s]		T [ºC]		K [m/s]
	min	max	min	max	
1	0.15	0.34	6.1	7.9	10^{-6}
2	0.14	0.40	6.1	6.9	
3	0.32	0.93	5.9	7.7	
4	0.10	0.14	5.4	8.5	
5	0.08	0.11	6.0	8.2	
6	0.27	0.38	6.2	8.6	
7	0.09	0.12	6.2	8.8	
8	0.07	0.10	6.2	8.1	
9	0.56	0.79	6.3	8.0	

This all unambiguously confirms that the groundwater flow in this shallow aquifer is directly depending on basic topographic features, meaning that groundwater flow modelling can be regarded as hydrological modelling of surface water flow.

3. METHODOLOGY

For automated deriving of hydrological characteristics Hydrology tool of the Spatial Analyst extension of the ArcGIS 9.2 software package was used. In general, when delineating watersheds it is necessary to proceed through a series of steps. Some steps are required, while others are optional depending on the characteristics of the input data. Those used in this paper are marked on general hydrological modelling flowchart (Figure 5).

The first step considered creating of 25 m resolution DEM [13], generated from digitized topo-contours (10 and 5 m equidistance), using Topo to Raster, an interpolation method specifically designed for creation of hydrologically correct DEMs [14], [15]. From this DEM Flow Direction raster (showing the direction of flow-out of each cell) was derived [16], using the according tool. This raster has integrated information on direction vector in each cell i.e. pixel [17] of the research area, which makes it essential for further calculation. Next step considered deriving Sink from Stream Network raster, showing that there was no significant number of sinks. This was „expected“, because naturally occurring sinks in elevation data with a cell size of 10 m or larger are rare, except in glacial or karst areas [18]. Otherwise, sinks would be considered as errors. This means that the main reason for Sink raster deriving was to verify that DEM was hydrologically correctly generated.

Next step was to determine accumulated flow i.e. to derive Flow Accumulation from Flow Direction raster, using the according tool. This tool calculates accumulated flow to each cell, determined by accumulating the weight for all cells that flow into each downslope cell.

According to the flowchart (Figure 5) next step is supposed to be derivation of Stream Link raster i.e. defining every stream channel and junction of the drainage network. However, there is a sub-step of Applying Threshold (Figure 5), which considers prior delineation of stream channels into Stream Network raster. This sub-step in fact represents the essence of this paper. For this purpose, delineation was achieved using Map Algebra tool i.e.

Setnull, sub-tool which sets identified cell locations to NoData based on a specified criterion. In this case, it considered creating a raster where the cell with value 1 represented a stream network on a background of NoData cells. For the processing it was required to "understand" natural processes of the research area in the way to be able to estimate the quantity of water flowing into each cell. This means that in order to create a stream network it was necessary to apply a threshold value to select cells with a high accumulated flow [19], [20]. There are many ways to adjust the threshold value [21] and here a "calibration" was used by appliying several different values: 50, 100, 150 and 200. For each applied value delineation of Stream Network was done in order to calculate Stream Link raster. Final step of given flowchart (Figure 5) considered calculation of Watershed raster.

In order to calculate areas of each sub-watershed that is drained through the springs of interest, it was required to make conversion from raster to polygon (vector). Comparatively, sub-watershed areas were calculated using common hydrological methods [22] so the final step was to make comparison between results from both methods (Table 2).

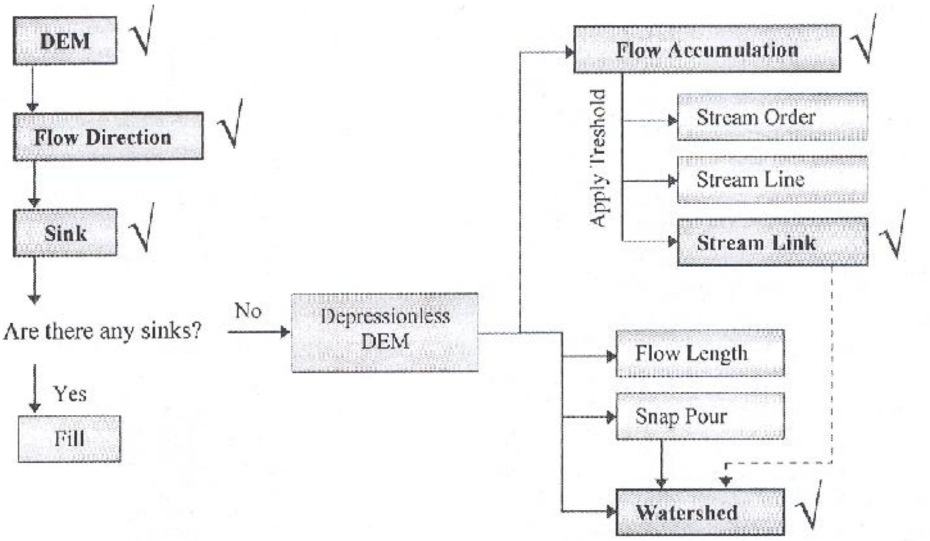

Figure 5 - Hydrological modelling toolset flowchart [23]

4. RESULTS

The fact that has been obvious even before the calculation is that using higher threshold values results in getting lesser cells recognized as the stream and vice versa. Consequently, lesser number of sub-watersheds having greater areas gets identified and vice versa, greater number of sub-watersheds having smaller areas.

Primarily, during analysis of the results in this paper, visual inspection was done. First observation was that applying 200 as threshold value results in obtaining sub-watershed contours not matching realistic natural conditions, since the output result is in fact the whole research area that represents one big watershed draining through all 9 springs of interest. Second observation was that, when applying threshold values 50, 100 and 150, it results in obtaining visually approximately the same sub-watershed areas extents. Then, values of sub-watershed areas, calculated using common hydrological methods, were compared with values of sub-watershed areas, calculated using each applied threshold (Table 2).

Regarding sub-watershed draining through the spring 1, it is apparent that the results are approximately the same for each method used. For thresholds values 50 and 100, sub-watershed area values are identical and only slightly deviate from values obtained from hydrological budget, while sub-watershed area value for the threshold 150 is slightly lower (Table 2).

Regarding sub-watershed draining through the springs 2 and 3, area value for applied threshold 50 is significantly different from other calculated values, which are approximately the same (Table 2).

Table 2. Sub-watershed Areas -Comparison between Results from Various Methods

		Area [km^2]			
	Sub-watershed →	Spring 1	Springs 2 and 3	Springs 4, 5 and 6	Springs 7, 8 and 9
Method ↓	Deviation[%]				
Hydrological		0.121000	0.324000	0.125000	0.117000
Automated	Streamnet_50	0.122230	0.016228	0.124598	0.112851
	(HL-SN_50)/HL	-1.02	94.99	0.32	3.55
	Streamnet_100	0.122230	0.323071	0.124598	0.117553
	(HL-SN_100)/HL	-1.02	0.29	0.32	-0.47
	Streamnet_150	0.123183	0.335671	0.127339	0.125311
	(HL-SN_150)/HL	9.40	0.12	-1.57	5.04
	Streamnet_200	48.607749			

Regarding sub-watershed draining through the springs 4, 5 and 6, the results are approximately the same for each method used (Table 2). For thresholds 50 and 100, sub-watershed area values are identical, slightly lower than values from hydrological budget, while sub-watershed area value for the threshold 150 is slightly higher (Table 2).

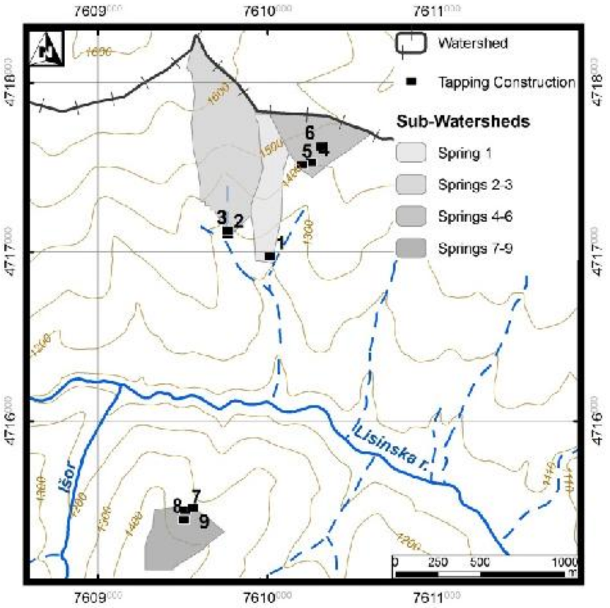

Figure 6 - Position of Sub-watersheds Draining Springs of the Gornja Lisina Source

Regarding sub-watershed draining through the springs 7, 8 and 9, the results are also approximately the same for each method used (Table 2). For thresholds 50 and 150, sub-watershed area values area slightly lower, while the value for threshold 100 is almost equal to the value from hydrological budget, i.e. less than 1% different.

Finally, the conclusion is that, for applied threshold 100, sub-watershed area values are closest to the values obtained from the hydrological budget and therefore their spatial distribution should be adopted as correct and realistic.

5. DISCUSSION

So far only advantages of this method have been pointed out. However, it is also necessary to discuss its limitations. Latest researches proved that this method was more precise in steeper terrains as a consequence of apparent elevation difference between neighboring cells. On the other hand, application of this method in moderately steep and flat terrains is unreliable, therefore unsuitable [24].

In order to add correction to the calculation, researchers from the Institute for Environment and Sustainability from Varese (Italy) suggested landscape classification, which takes into consideration possibility of drainage density development [25]. The criterion for 5 classes that they offered is: vegetation, climate, terrain morphology, soil type and lithology. In research shown in this paper, this effect was achieved by calibration of Stream Network raster, which considered being well acquainted of terrain properties. However, without that, subjectivity can be brought to the calculation process along with minimizing of analysis effect.

Another limitation can be urbanization and jeopardizing of natural conditions since application of this method is viable only in intact natural conditions.

Finally, eventual fracturing anisotropy in the rock mass and its system of fissures and fractures can limit application of this method. This means that any kind of privileged groundwater flow, which cannot be described as gravitational, cannot be modeled with this method. This method is generally supposed to be used only for hydrological modelling i.e. modelling of surface water flow, but there are exceptions when it can be applied on groundwater flow as well. That is only when it can be adopted that both ground-and-surface-water flows have same directions, which was the case in the research presented in this paper.

6. CONCLUSION

Automated techniques of deriving hydrological characteristics are fast, precise and relatively simple. DEM is used as basic input so its resolution represents basic variable. For the research presented in this paper 25 m resolution DEM was used and the variable in fact was the method of drainage network delineation into Stream Network raster i.e. the threshold value applied for the calculation. Sub-watershed areas calculated with this method were compared with areas calculated using common hydrological budget methods. Analyzing results for the research area and given 25 m resolution DEM, it is apparent that applying lower threshold values, when deriving Stream Network raster, results in getting bigger number of sub-watersheds with smaller areas and vice versa.

Finally, limitations of this method were presented, where probably the most significant one is that the groundwater flow modeling can be done using this method, but it is only justified when it can be adopted that both ground-and-surface-water flows have same directions.

7. AKNOWLEDGEMENT

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REFERENCES

[1] Johnson L. E., 2008: Geographic Information Systems in Water Resources Engineering, CRC Press, Taylor and Francis Group, ISBN 978-1-4200-6913-6.

[2] Zhang, W., Montgomery, D.R., 1994. Digital elevation model grid size, landscape representation, and hydrologic simulations. Water Resources Research, V. 4, pp. 1019–1028.

[3] Wolock, D.M., Price, C.V., 1994. Effects of digital elevation model map scale and data resolution on a topography-based watershed model. Water Resources Research, V. 30, pp. 3041–3052.

[4] Garbrecht J., Martz L. W., 1999, TOPAZ: An automated digital landscape analysis tool for topographic evaluation, drainage identification, watershed segmentation and sub-catchment parameterization; TOPAZ Overview. ARS Publication No. GRL 99-1. U.S. Department of Agriculture, Agricultural Research Service, Grazing lands Research Laboratory, El Reno, Okla.

[5] Debarry P., 1999: GIS modules and distributed models of the watershed, Reston, Va.: ASCE.

[6] Lopez-Garcia M. J., Camarasa A. M., 1999: Use of geomorphological units to improve drainage network extraction from a DEM - Comparison between automated extraction and photointerpretation methods in the Carraixet catchment (Valencia, Spain), International Journal of Applied Earth Observation and Geoinformation, Volume 1, Number 3, 1999 , pp. 187-195(9).

[7] Petrović R., 2012: Elaborat o rezervama podzemnih voda izvorišta u Gornjoj Lisini (Izvor 10), Departman za hidrogeologiju, Rudarsko-geološki fakultet, Beograd.

[8] Dimitrijević M. D, 1995: Geologija Jugoslavije, Geoinstitut, Beograd.

[9] [9]Grupa autora, 1977: Tumač za OGK SFRJ 1:100000, list K 34-57 Trgovište sa Radomirom, Savezni geološki zavod, Beograd.

[10] Grupa autora, 1976: Geologija Srbije, VII-1, Hidrogeologija, Zavod za regionalnu geologiju i paleontologiju Rudarsko-geološkog fakulteta, Univerzitet u Beogradu.

[11] Tomić V., 1981: Vodonosnost ispucalih stena i hidrogeološka svojstva pukotinskih izdani u nekim našim terenima, OOUR grupa za hidrogeologiju, Rudarsko-geološki fakultet, Beograd.

[12] Tomić V., 2012:Vodonosnost stena sa pukotinskom strukturom poroznosti i metodologija određivanja rezervi podzemnih voda u pukotinskim izdanima, Zbornik radova XIV srpskog simpozijuma o hidrogeologiji sa međunarodnim učešćem, Zlatibor 17-20. maj 2012. godine, ISBN 978-86-7352-236-4, pp. 446-452.

[13] Hutchinson M. F., 1996: A locally adaptive approach to the interpolation of digital elevation models, Proceedings, Third International Conference-/Workshop on Integrating GIS and Environmental Modeling. Santa Barbara, CA: National Center for Geographic Information and Analysis.

[14] Hutchinson M. F., 1988: Calculation of hydrologically sound digital elevation models, Third International Symposium on Spatial Data Handling at Sydney, Australia.

[15] Hutchinson M. F., 1989:A new procedure for gridding elevation and stream line data with automatic removal of spurious pits, Journal of Hydrology 106, pp. 211-232.

[16] Jenson, S. K., Domingue, J. O., 1988: Extracting topographic structure from digitalelevation data for

geographic information system analysis, Photogrammetric Engineering and Remote Sensing, 54 (11), pp. 1593–1600.

[17] Grenlee, D. D., 1987: Raster and vector proccessing for scanned linework, The Imaging and Geospatial Society, Photogrammetric Engineering and Remote Sensing, Vol. 53, pp. 1383-1387.

[18] Mark D., 1983: Automated Detection of Drainage Networks from Digital Elevation Models, Proceedings of the Sixth International Symposium on Computer Assisted Cartography (Auto-Carto VI), Vol. 2, pp. 288–298.

[19] Tarboton, D. G., Bras R. L. & Rodriguez–Iturbe I., 1991. On the Extraction of Channel Networks from Digital Elevation Data, Hydrological Processes. 5: pp. 81–100.

[20] Helmlinger, K. R., Praveen K., Foufoula-Georgiou E., 1993: On the use of digital elevation model data for Hortonian and Fractal analyses of channel networks, Water Resources Research 29(8): pp. 2599-2613.

[21] Gandolfi C., Bischetti G.B., 1997: Influence of the drainage network identification method on geomorphologcial properties and hydrological response, Hydrological Processes 11: pp. 353-375.

[22] Jemcov, I., Petrović, R., 2010: Elaborat o rezervama podzemnih voda izvorišta u Gornjoj Lisini, Departman za hidrogeologiju, Rudarsko-geološki fakultet, Beograd.

[23] webhelp.esri.com/arcgisdesktop/9.2/. [Online] Environmental Science Research Intitute.

[24] Wu W., Fan Y., Wang Z., Liu H., 2008: Assessing effects of digital elevation model resolutions on soil–landscape correlations in a hilly area, Agriculture, Ecosystems and Environment, Vol 126, 3-4, pp. 209-216.

[25] Vogt, V. J., Colombo, R., Bertolo, F., 2003: Deriving drainage networks and catchment boundaries: a new methodology combining digital elevation data and environmental characteristics, Geomorphology, Vol 53, 3-4, pp. 281-298.

REZIME

PRIMENA AUTOMATIZOVANE TEHNIKE ODREĐIVANJA TOPOGRAFSKIH VODODELNICA ANALIZOM DEM-A

Osnovne topografske osobine igraju važnu ulogu u određivanju hidroloških karakteristika sliva, prilikom modeliranja vodnih resursa. Algoritam, koji je korišćen, u ovom radu, za definisanje kontura vododelnica, se oslanja na digitalni elevacioni model (DEM), kao osnovni rasterski ulazni podatak. Preciznost automatskog načina određivanja kontura vododelnica zavisi, pre svega, od rezolucije DEM-a. Sa druge strane, preciznost može zavisiti i od načina delineacije mreže tokova u raster Stream Network. Da bi se izvela ova funkcija, potrebno je znati koliko vode struji kroz svaki pojedinačni piksel. To znači da je neophodno zadati graničnu vrednost, prag, iz koliko je piksela potrebno da struji voda ka pojedinačnom pikselu, da bi on bio prepoznat kao rečni tok. Taj broj se određuje na različite načine, a na ovom konkretnom primeru utvrđen je tariranjem. Analiza DEM-a je primenjena na Izvorištu u Gornjoj Lisini, gde je za 9 izvora izvršeno određivanje kontura vododelnica, pomenutom metodom. Korišćen je DEM rezolucije 25 m. Za tariranje granične vrednosti broja ćelija, korišćene su različite vrednosti, na osnovu kojih su računate vrednosti površina neposrednih slivova, koje su upoređivane sa vrednostima površina, izračunatim uobičajenim hidrološkim metodama.

Ključne reči: *topografska vododelnica, DEM, raster Stream Network, Gornja Lisina*