GIS ANALYSIS OF HYDROGRAPHIC FEATURES OF MOSTAR MUNICIPALITY

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Using geographic information systems based on hydrology tools, selected hydrology objects of the municipality of Mostar were analyzed. Geodatabase was created using topographic maps scaled 1:25 000. Cisterns and water sources were analyzed and the hypothesis about spatial distribution was confirmed. Map of water sources was compared with the geological map and the largest spatial distribution was determined in lithostratigraphic units of Jurassic and Cretaceous limestones.

Keywords: *GIS, hydrographic objects, digitization, Mostar*

UVOD
INTRODUCTION

The subject of the research is hydrological objects in the Mostar municipality area. The aim of the paper is to correlate the spatial distribution of wells, springs and cisterns with geological substrate, and higher or lower occurrence of these objects with respect to the distance from watercourses. Up to the present, hydrographic objects of Mostar municipality as a separate entity have not been covered by a detailed study. The absence of such publications, analyses and applications of GIS in hydrology significantly hampered the work, but at the same time were an impetus for the analyses that have been performed by using topographic maps of the area. These maps were the basis for identifying and defining hydrographic features of the study area.

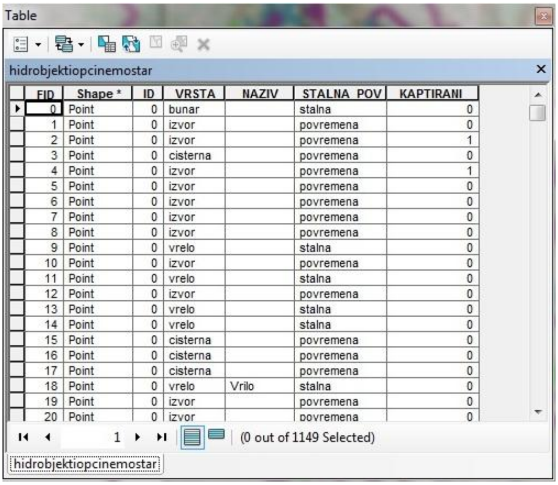
The text of this paper is based on the possibilities of GIS in analysis of hydrological objects. The research was begun by digitizing the selected objects from topographic maps 1:25 000. The data digitization was followed by the phase of digital data analysis using tools *Spatial Analyst, Analysis Tools* and *Data Management*.

Of previous publications, the author who should be emphasized is Shamsi. In his 2005 book *"GIS Applications for Water, Wastewater and Stormwater Systems,"* he writes about proper management of water ecosystems in a way to protect and preserve water resources. In the book *"GIS for Water Resources"* by Maidment, the author explains the use of GIS in analysis of rivers, sources and other water elements, and explains how to use this tool to control some natural disasters caused by water, whether by the lack or by the excess thereof. Literature in the languages spoken in our region is underrepresented because of the lack of the same.

DISKUSIJA
DISCUSSION

The collection and entry of data were carried out in the software package ArcGIS 10 and its software component ArcMap, and the data were digitized from topographic maps at

1:25 000 scale (TK 25), which were first scanned, and then geocoded in the zone 5 of the Gauss-Krüger projection on Bessel's ellipsoid.



Table

hidrobjektiopcinemostar

FID	Shape *	ID	VRSTA	NAZIV	STALNA_POV	KAPTIRANI
0	Point	0	bunar		stalna	0
1	Point	0	izvor		povremena	0
2	Point	0	izvor		povremena	1
3	Point	0	cisterna		povremena	0
4	Point	0	izvor		povremena	1
5	Point	0	izvor		povremena	0
6	Point	0	izvor		povremena	0
7	Point	0	izvor		povremena	0
8	Point	0	izvor		povremena	0
9	Point	0	vrelo		stalna	0
10	Point	0	izvor		povremena	0
11	Point	0	vrelo		stalna	0
12	Point	0	izvor		povremena	0
13	Point	0	vrelo		stalna	0
14	Point	0	vrelo		stalna	0
15	Point	0	cisterna		povremena	0
16	Point	0	cisterna		povremena	0
17	Point	0	cisterna		povremena	0
18	Point	0	vrelo	Vrilo	stalna	0
19	Point	0	izvor		povremena	0
20	Point	0	izvor		povremena	0

1 (0 out of 1149 Selected)

hidrobjektiopcinemostar

Fig. 1. Attribute table for „Hidroobjektiopcine Mostar“

The objects that were studied are presented by the vector data structure and divided into four categories, namely: hydrographic objects, caves, streams and rivers. All the data were recorded in a database with their graphic form and descriptive contents specified in the attribute table. Two columns *"FID"* and *"Shape"*, representing the object shape (point, line or polygon), are automatically entered in the attribute table *("Table")*. In order to add other data that are required for further analysis, it is necessary to open the attribute table *("Open Attribute Table")* and a field in it *"Add Field"* and thus add the necessary columns.

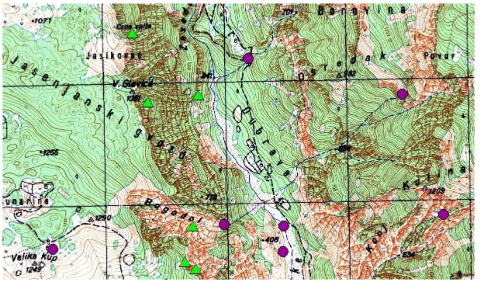


Fig. 2. Vectorization map of hydrological (purple) and cave (green) objects

Data were entered into the database directly by the keyboard, starting with hydrographic objects (hidroobjektiopcinemostar.shp) which are zero-dimensional objects (0D), so this data layer is a point data layer and as such does not have an area, but is defined by some other attributes in the attribute table. Descriptive contents for these objects are arranged in four columns as follows: object, name (if any), whether the water at the object is constant or intermittent, and whether the source is tapped or not (Fig. 1). Objects were differentiated as cisterns with constant and intermittent water, wells, pools, sources with constant and

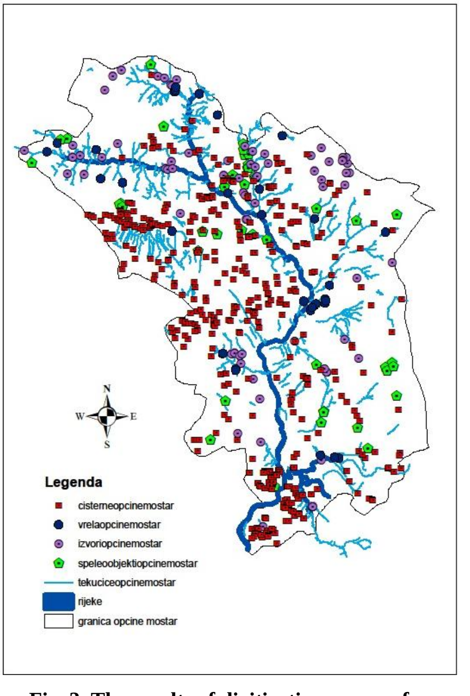


Fig. 3. The results of digitization process for Mostar municipality

intermittent water, tapped sources with constant and intermittent water, water supply tanks, water supply pump stations, sinkholes and sinkhole-caves. Waterless pits and caves (speleoobjektiopcinemostar.shp) are point objects that were entered in the database within cave objects as the second layer. The vectorization method was the same as for water objects, only with a different symbol on the map (Fig. 2). Attribute table contains two columns: object name and type.

The vectorization process is slightly different for streams. These are no longer point but line objects, which require the use of line tools and line connecting options *Snapping options.* The objects were then vectorized and descriptive contents entered in the attribute table, and for streams these are name, and whether the stream is constant or intermittent. Streams that are shown on the surface of topographic maps fall into the category of rivers. Vectorization was performed in the same way as with the previous objects with the difference in the window *Construction Tools* where *Polygon* is selected now.

Figure 3 shows all vectorized objects upon completion of vectorization. As shown in the legend, red square shows cisterns, blue circle springs, purple circle represents wells, and caves are shown by green pentagon. Streams that are vectorized as linear are represented by cyan line, and polygonal by blue polygon. The boundaries of the Mostar municipality are marked as a polygon with empty interior and black rim.

ANALIZA GUSTOĆE CISTERNI
CISTERN DENSITY ANALYSIS

Calculation of spatial density of cisterns per unit area of the study area included interpolation of the vector layer of cisterneopćinemostar.shp in the raster layer of the GRID

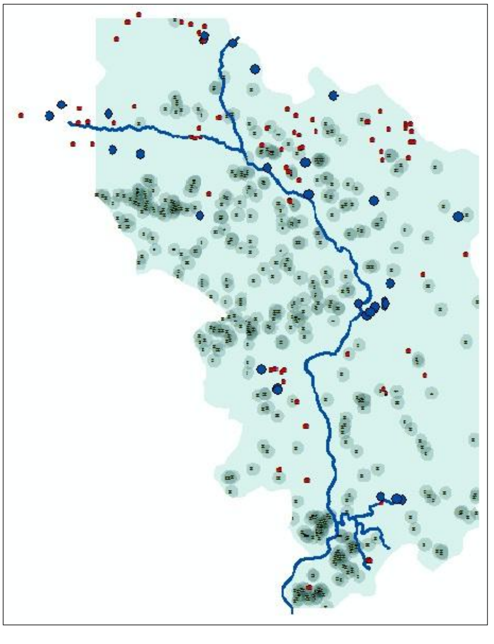


Fig. 4. Correlation between cisterns, wells and springs (green, blue and red)

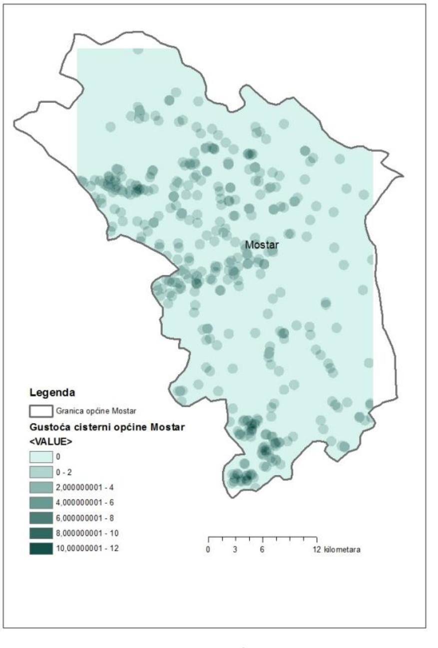


Fig. 5. Cistern density of Mostar municipality

structure. The GRID format represents raster data models used by the ArcInfo information system, and they are suitable for overlapping layers and different spatial analyses (Pahernik, 2005). Density of point objects around each origin cell of the raster is calculated in this way. All cisterns that belong to a circle are summed up and divided by the area of the circle. The set radius of the circle was 564 meters with the cell size 10 m x 10 m (Houser, 2006).

Cistern density data are categorized into seven classes, namely: 0 cis/km^2, 0 – 2 cis/km^2, 2 – 4 cis/km^2, 4 – 6 cis/km^2, 6 – 8 cis/km^2, 8 – 10 cis/km^2 and 10 – 12 cis/km^2 (Fig. 5). According to the presented distribution of cisterns, and springs and wells, it can be concluded that the density of cisterns is higher in the areas with very few wells and springs, which is a logical way of storing water in the absence of sources.

ANALIZA GUSTOĆE IZVORA I VRELA
WELL AND SPRING DENSITY ANALYSIS

Well and spring density analysis was conducted in the same way. Vector layers of wells and springs were interpolated in the raster GRID layer. Wells and springs were examined separately in the program during the analyses, therefore they were analyzed separately.

Density of wells in the Mostar municipality was categorized into four classes, where the first class is 0 wells/km^2, then 0 – 2 wells/km^2, 2 – 4 wells/km^2 and 4 – 6 wells/km^2. The total number of vectorized wells is 76, of which 10 are tapped, or created by anthropogenic influence. Other 66 were developed by natural forces (Fig. 7).

Density of springs is also categorized into four classes, where the first class is 0 spr/km^2, second 0 – 1 spr/km^2, the next 1 – 2 spr/km^2 and finally 2 – 4 spr/km^2. In this area, 33 springs were vectorized. Out of these 33, 9 or nearly 30% are tapped, which indicates that quite a large number of springs in the municipality of Mostar have been developed under the influence of man (Fig. 8).

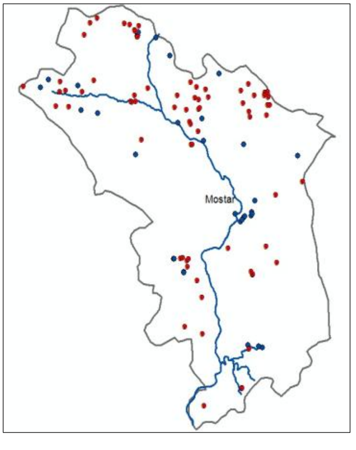


Fig. 6. Spatial distribution of wells and springs

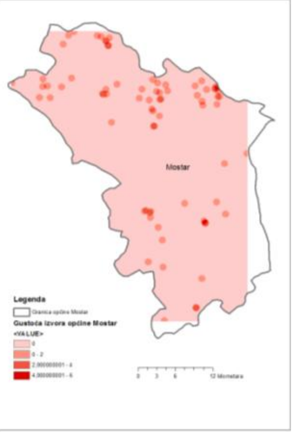


Fig. 7. Wells density of Mostar municipality

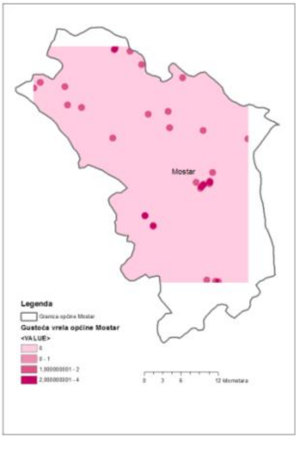


Fig. 8. Springs density of Mostar municipality

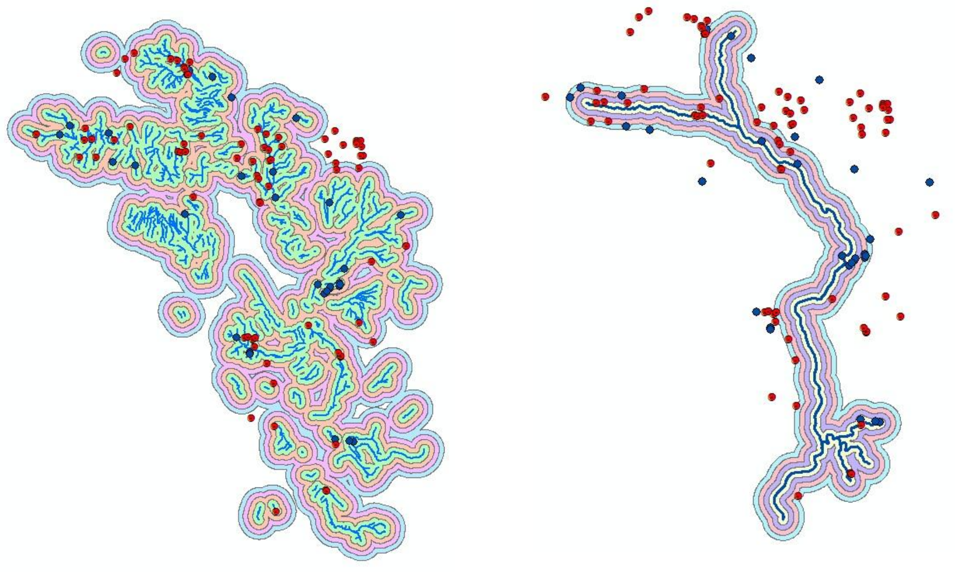
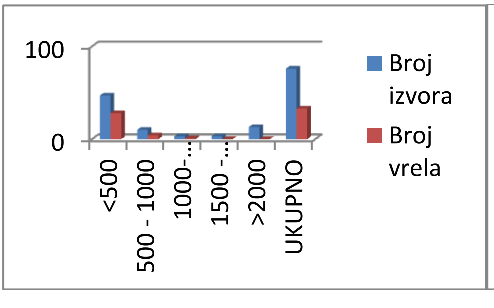


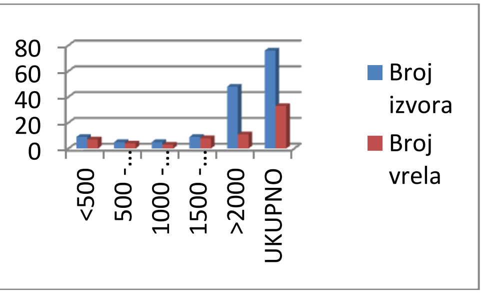
Fig. 9. Buffers of Mostar municipality a) line rivers b) polygon rivers

Analyzing positions of hydrological objects in relation to distance from watercourses *(buffer),* we attempted to reach a conclusion on the spatial distribution of these objects. Thus, we analyzed the point objects izvoriopćinemostar.shp and vrelaopćinemostar.shp, then line objects tekućiceopćinemostar.shp, and polygon objects rijeke.shp. In order to conduct the analysis, it was necessary to convert the polygon objects rijeke.shp.

Then we proceeded to create *buffers* using the tools from *Arc Toolbox* and the command *Multiple Ring Buffer*. As input objects, in the first case the streams tekućiceopćinemostar.shp were selected, and in the second case it was the polygonal rivers rijeke.shp, which had been converted into line objects. The distances of 500 m, 1000 m, 1500 m and 2000 m were specified. In this way, objects were categorized into four classes, and exact numbers of objects in each particular class was obtained by selecting each particular class by using the tool *Select by Location*.



Graph 1. Graphic display of wells and springs within certain buffers (line rivers)



Graph 2. Graphic display of wells and springs within certain buffers (polygon rivers)

By analyzing Graph 1, where the tool *Select by Location* was applied with line objects, we obtained the results that 47 wells and 28 springs are at a distance of less than 500 m from the watercourse. There are 10 wells and 4 springs in the second class between 500 m and 1000 m, 3 wells and 1 spring are situated in the third class between 1000 m and 1500 m. Three wells and no springs occur in the range between 1500 m and 2000 m, and 13 wells and again one spring are found in the last class, where the distance from the watercourse is greater than 2000 m.

The next *buffer* is made is the same way, but the input objects are the rivers that had been polygonal and then converted into line rivers in order to perform this analysis. There are 9 wells and 7 springs in the first class, where the distance is less than 500 m, 5 wells and 4 springs are situated in the second class at the distance between 500 m and 1000 m. Five wells and 3 springs belong to the class between 1000 m and 1500 m, and 9 wells and 8 springs to the fourth class between 1500 m and 2000 m.
At a distance greater than 2 000 m, 48 wells and 11 springs are situated (Graph 2).

From this spatial distribution of hydrological objects, we can say that the dependence of smaller streams on water coming from these objects is greater, while larger streams or those with greater water flow depend the most on their tributaries and smaller streams that bring water and thus make large river formations of Neretva, Drežanka and Buna.

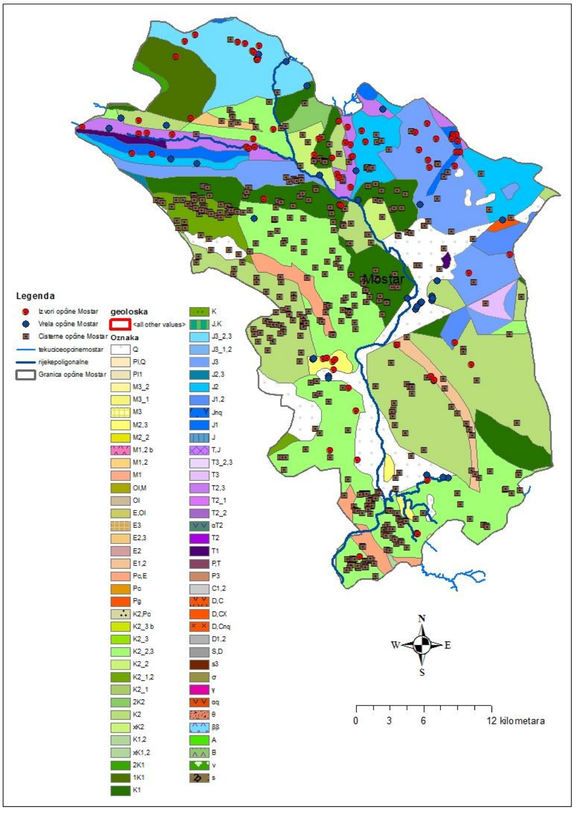


Fig. 10. Spatial distribution of hydrologic objects inside geological surface of Mostar municipality

ANALYSIS OF NUMBER OF WELLS AND STREAMS INSIDE EACH GEOLOGICAL LAYER

The geological structure of the study area consists of different lithostratigraphic units within the range from Triassic to Quaternary. Most of them are represented by different types of limestone (Jurassic, Cretaceous and Paleogene), while a smaller number are represented by clastics (Paleogene and Neogene) and the youngest sediments in the river beds (Fig. 10).

The analysis was made by overlapping layers of the geological map geološka.shp BGM MOSTAR 1: 100 000, which was scanned and then geocoded in the zone 5 of the Gauss-Krüger projection on Bessel's ellipsoid and vectorized objects of wells and springs of the Mostar nicipality. As a result, we obtained the spatial distribution of these objects within particular lithostratigraphic units.

The oldest layer in which wells and springs are registered is Triassic (T2,3). Gray dolomites with minor partitions of limestone prevail in this layer, in which we identified 13 wells, which account for 17.11% of the total number of vectorized wells. The number of springs is smaller, and it is 3, which makes 9.09% of the total number of springs.

Wells and springs are found in nearly all layers (J3_2,3; J3 J2; J1,2 and J1) from the Jurassic period. They are characterized by limestones with different additions. On the topographic map we read a total of 32 wells, accounting for 42.1% of the total number of wells. Seven springs, which make 21.21%, are distributed on younger Jurassic layers.

Cretaceous is the geologic period younger than Jurassic and it is divided into Upper and Lower Cretaceous. Lower Cretaceous is older and its layers containing study objects are K1 and 1K1. Seven wells, accounting for 9.21%, and 2 springs, which make 6.06%, are found in this layer. When we make a comparison with Upper Cretaceous, these objects occur more frequently in the younger period. The layers K2 and K2_2,3, are made of limestone with rudists, and the number of registered wells is 13, which make 17.11%, and of springs is 10, the percentage of which is 30.3%.

In the layer E1,2, made of alveoline-nummulitic limestone from the Paleogene period, we found 4 wells and 1 spring, which accounts for 3.03%. By overlapping the layers of Miocene age on the geological map and vectorized layers, we registered 4 wells, which account for 5.26%, and 2 springs or 6.06%. According to this analysis, 3 wells, which account for 3.95%, and 8 springs or 24.24%, originate in layers from the youngest period, Quaternary (Q).

This spatial distribution of the analyzed objects precisely confirms the hypothesis of the highest occurrence in the area of limestones of Jurassic and Cretaceous age because limestone cracking and solubility in water in the presence of carbonic acid are of crucial importance for this karst region (Slišković, Zelenika, Smith, 2005)

CONCLUSION

Applying GIS applications can be a fast and efficient way to get high-quality and reliable data with which it is possible to make an analysis on the use of water as a resource. The paper demonstrates the spatial distribution of cisterns in places with a very small number of wells and springs. It was concluded that a larger number of wells and springs are distributed along streams that are line oriented or that have narrower flow (width of streams is less than 12 meters) while a smaller number of these objects are along polygonal streams, with a larger quantity of water (wider than 12 meters).

On this basis it was concluded that the rivers of this karst region depend the most on their tributaries, rather than on the amount of water that flows out of wells and springs. Within the geological substrate in Mostar municipality, wells and springs are mostly located on limestone with various additives, and these limestones are mainly of Jurassic and Cretaceous age. The observed area belongs to the most complex areas of karst part of the Dinarides and it is tectonically very complex, and it is the same with its hydrogeological characteristics and properties of deposits registered here.

This very complex, but hydrogeologically logical set of interdependencies of today's surface shape or appearance of relief and stratigraphic-tectonic specifics of the structure underlying the relief, allow us to be able to better understand the present state in the future and to take targeted action in order to preserve it for future generations.

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