

Review paper

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GROUNDWATER VULNERABILITY IN KARST OF JAHORINA

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ABSTRACT

Analysis has studied northern part of Jahorina, Ravna Mountain, whose karst plateau presents water aggregation surface for Paljanska Miljacka and Bistrica flows, which are used as water supply for Sarajevo and Pale. This paper presented hydrogeological and hydrological characteristics of the area and applied analyzes of other physical-geographic characteristics which are an essential indicator of the quality of groundwater. Applying various methods, we have obtained maps that shows different ways of groundwater pollution in karst. We analyzed spatial relationships and connections with individual socio-geographical components. Thought correlation methods we obtained results which provided conclusions for possible measures against pollution of groundwater in karst and karst in general.

Key words: *vulnerability of groundwater, karst, Jahorina, Paljanska Miljacka, Bistrica*

INTRODUCTION

Vulnerability of groundwater in karst areas in terms of pollution has been increased comparing to area where in geology structure are presented non-karst rocks. In karst terrain is much harder to define the conditions of catchment, and therefore even more difficult to predict measurements for protection of karst water. The obvious example that confirms this conclusion is the area of Jahorina and other karst mountain system with developed tourism. Considering that Sarajevo surrounding mountains are in upper layers predominantly made of limestone and represents groundwater collecting areas used to supply population of Sarejevo and East Sarajevo, and that here is built a number of infrastructure facilities, especially those adapted to the needs of tourism, vulnerability is even greater (Figure 1).

Jahorina (1916 m asl), as complex mountain system in south-eastern Bosnia and Herzegovina consists of three parts: Gola Jahorina, Trebević and Ravna Mountain. It is located nearby Sarajevo and is characterized by a complex orographic structure dominated by shallow articulated and extensively dissected karst surface. The area under karst includes central part of Jahorina and is bounded by geological boundaries (contact of limestone and clastic rocks). It is intensive dissected by a large number of faults that discovered Lower Triassic clastic in floor layers. These faults predispose the flows of water, whose springs occurs at contact of limestone and clastic rocks, and on their collecting

area consists of limestone coverage of Ravna Mountain and Gola Jahorina. Work examines how the phenomenon of mass tourism on karst terrain of Jahorina threatens to groundwater, where it is much harder to define the conditions of catchment, and thus predict the extent of the protection of these waters.

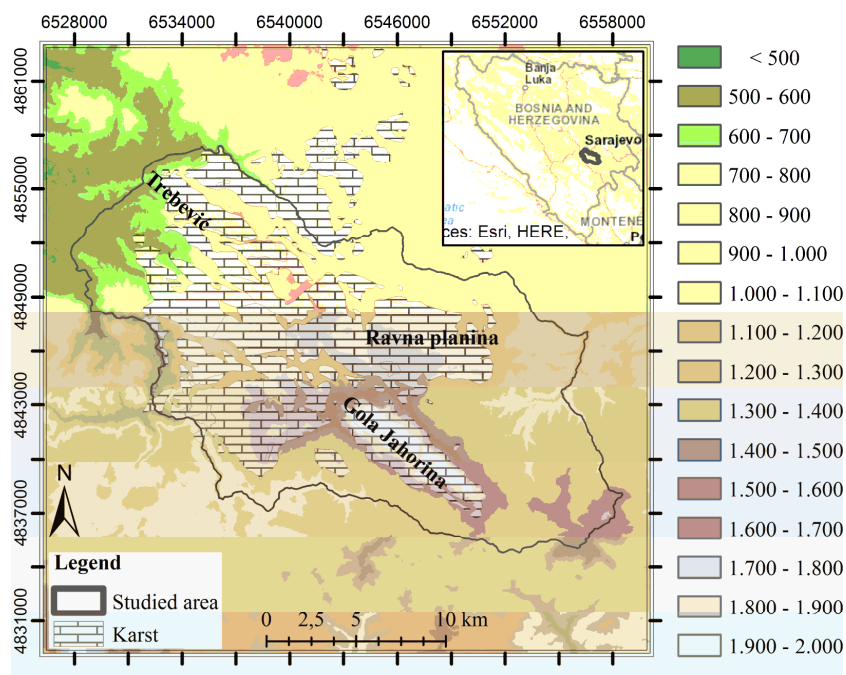


Figure 1 The position of Jahorina in Bosnia and Herzegovina

METHODOLOGY

This work used digitized and vectored topographic maps scale 1: 25.000 [1], geological map scale 1: 100.000, Main Geological Map of SFRY, sheets Sarajevo and Prača [2, 3], and part of BiH hydrogeological map scale 1: 500.000 [4]. Based on these cartographic documents we made models, ie. we formed a digital database that allowed implementation of spatial analysis using GIS. Also, on separate layers we carried mapping of infrastructure facilities in study area, based on cadastral data and forest management plan of municipality Pale [5, 6], which were used for more detailed and precise analysis of groundwater vulnerability of Jahorina karst. In addition to the cabinet research, work used experience and conclusions of field research.

HYDROGEOLOGICAL PROPERTIES

Complex lithographic structure and tectonics of area have caused complex hydrogeological relations. They are result of general water permeability of rocks, type of porosity, grade of tectonic fracture, the disposition of horizontal and vertical distribution of water permeable and impermeable rock masses, ability of rock to retain infiltrated water, speed, size and continuity of drain. Considering all these factors, lithographic unit, regardless of age, per functions in the hydrological sense can be divided into three categories: water permeable rocks, hydrogeological complexes and rocks with function of hydrogeological barrier (Figure 2).

Water permeable rocks

The rocks of intergranular porosity are important for retention of groundwater and definition of engineering-geological characteristics in urban and regional planning, planning and construction of

infrastructures, and due to excessive importance for determination of conditions for construction in seismically active areas. Rocks with intergranular porosity were presented by gravel-sand deposits, and build flattened alluvial areas of middle and lower flow of river Prača and small area along Sjetlinska river. A higher incidence has rocks with fissures porosity that is, in terms of lithographic, presented by conglomerates and sandstones. These rocks are represented at many sites in the valleys of Bistrica and Prača. Highest prevalence has rocks with fissure and cavernous porosity. They are presented by carbonate rocks, and covers highest parts of Ravna Mountain. As underlying water impermeable barrier beneath the limestone are shale and Werfenian sediments. Limestones are very karstified, and grade, density and size of fissures are dependent on the frequency of the local fissuring elements of system [7].

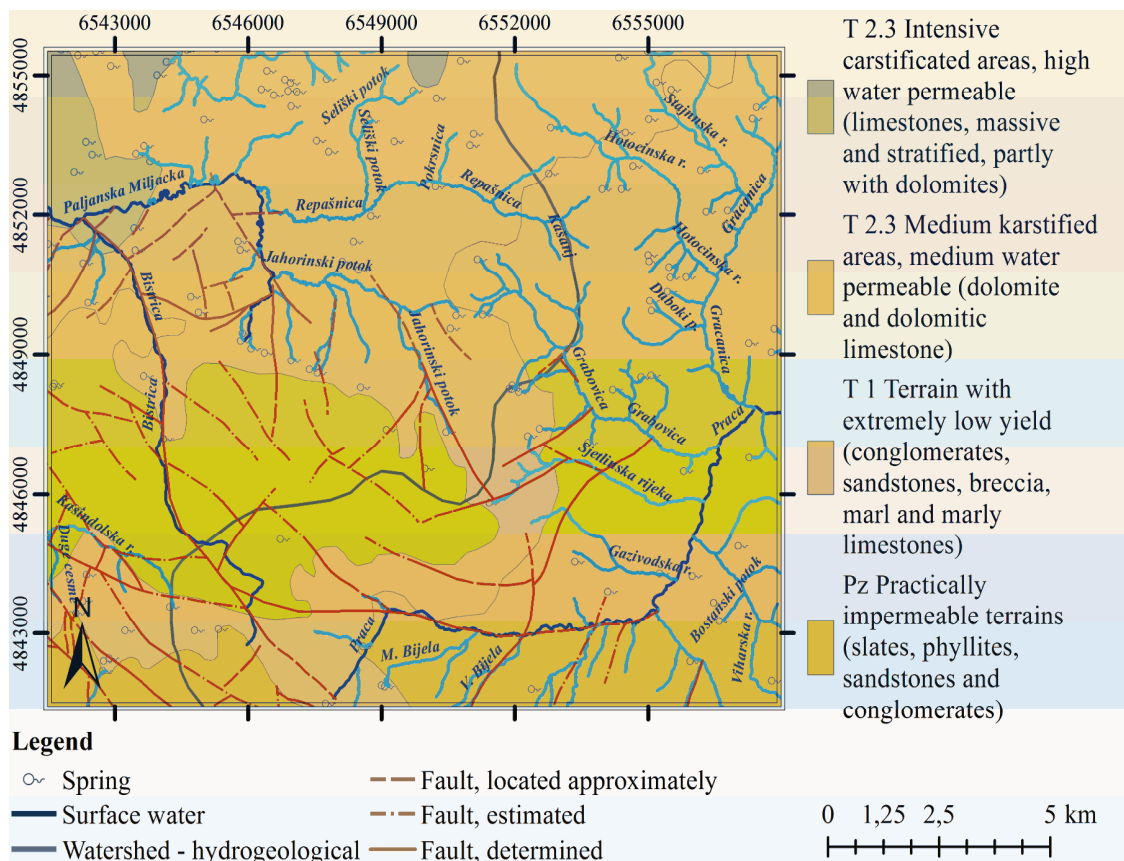


Figure 2 Hydrogeological map of the studied area

Hydrogeological complexes

Hydrogeological complexes are different lithological complexes where in studied area expose complexes with prevailing function of permeable rocks, and it is represented by the sedimentary polyfacial complexes with usually prevail limestones and clastic bonded rocks of Triassic carbonate composition, i.e. complex dominated by permeable rocks. This category corresponds banked and massive limestones, breccia limestones and marl limestones, breccia, conglomerates and sandstones, clay, marl and clayey marl of upper Cretaceous flysch [7]. This alternation of rocks with different hydrogeological functions cause accumulation of water in limestone rocks, which in shape of smaller or larger springs flows at various altitude levels.

Rocks with function of hydrogeological barrier

They are presented by Paleozoic shale with low level of crystallinity. At surface areas over these rocks are loose covering of different thicknesses which accumulate small amounts of infiltrate water, who

then play a significant role in occurrence and development of exogenous geological processes. Beside of Palaeozoic shales, function of hydrogeological barrier has polyfacial complexes of werfenian and, in lesser extent, volcanogenic-sedimentary formations of middle Triassic [7].

UNDERGROUND WATER AND SPRINGS

All of groundwater in studied area are vadose type, i.e. water formed from precipitation sinking through ground or cracks in rocks. The formation of underground waters is going on whole area, especially on karst plateau where there are no surface flows due to high karstification and cracking of limestone. In this area, according to the spatial estimation, coefficient of underground flow is greater than surface flow, where high forest covered of terrain on Ravna Mountain plays a significant role.

Due to the complicated tectonic relations in this morphological unit, hydrogeological situation is not quite clear. The fact is that the total capacity of springs: Prača, Paljanska Miljacka, Hladenac, Mandra, Studenac, Leletva, Tilavsko, Stansko and other springs, exceeds the accumulating area from the limestone surface, so it is assumed that there exists system of feeding along tectonic zones [8]. In the northeastern part of Ravna Mountain surface has ascertained remains of overthrust of clastics in whose basement are Anisian limestones. In these terrains made of clastics, is formed a normal aquifer, on whose presence indicate springs in boundary of the overthrust, in slope locations of topographic surface. Draining of these area is done by surface collectors of river Bistrica and Repašnica in valley of Paljanska Miljacka. Terrains formed by Anisian limestone, with developed karst process, shows up scattered karst aquifer system in relation with fissure system. Speleological research at Ravna Mountain, has determined that most of underground karst forms are in permanent dry zone, through which rainfalls infiltrate to lower levels [9].

Springs and wells in study area are conditioned by the arrangement of groundwater, and thus are dependent on precipitation pattern. They belong to a group of gravitational drain (feed from aquifers in clastics) and karst springs (feed by karst groundwater). In addition to the dominant karst springs Paljanska Miljacka, Jahorinski Potok and Bistrica, on slopes of Ravna Mountain are springs of Grabovica, Sjetlinska River and Gazivodska River, a larger springs which occurs: Libarevo well, Hajdučko well, Ždrebanovo well, Dubovičko well, Saračevo well, Studenac etc.

Yield and quality of water springs

Water springs have a variable yield during year, and water circulates through water pipes that make water supply system of Sarajevo, Pale, Podgrab and Jahorina. The necessary amount of water for these settlements are being provided from largest mountain springs in study area (Table 1).

Table 1 Capacity of springs in studied area

No.	Spring/well name	Capacity of springs by water supply systems (l/sec.)			Total
		Pale	Jahorina	Podgrab	
1	Stansko	5,31	12,39	-	17,7
2	Prača	27,20	53,8	-	81
3	Bistrica	9,63	22,47	-	32,1
4	Vlahovići	13	-	-	13
5	Paljanska Miljacka	45	-	-	45
6	Sjetlinsko	-	-	12	12
Total		100,14	88,66	12	200,8

According to Pale municipal water supply company (JP „Vodovod i kanalizacija”) [10], the total capacity of springs meets needs for all categories of users in time of medium yield of springs. In periods of minimum yield, when yield of some springs fall by more than 35%, the supply of

consumers in areas covered by water supply systems of Pale and Podgrad, is carried out with restriction of consumption. The physical properties of water springs and wells, except temperature, do not differ mutually. Water wells and springs under study, are characterized by a high level of transparency, without colors, smell and taste.

VULNERABILITY OF GROUNDWATER

In this area, we have a watershed between two major rivers – Bosna and Drina. In hydrological terms, studied area is divided into the basin of Miljacka which drained ground in river Bosna, and the basin of Prača, a left tributary of Drina river (Figure 3). Watershed of these flows are determined by topographic, using DEM, a map, in addition to topographic definition of watershed, on map is shown watershed according to hydrogeological map of Bosnia and Herzegovina 1: 500.000.

In complex geological conditions, characteristic for karst terrain, watershed often depends not only on topography, but primarily of geological and hydrogeological conditions [11]. Although the hydrogeological defining of watershed is significantly more reliable, we have applied topographic determination due lack of precise hydrogeological parameters whose scale should be sufficiently reliable for smaller coverage. Similar models have been used in previous studies in this area [12]. Hydrogeological map of Bosnia and Herzegovina in the scale 1: 500.000 did not give sufficiently precise information for a clear definition of the watershed in the studied area, and process of determination of watershed hydrological boundaries represents a delicate, complex, extremely long and expensive process, which is beyond limits of this paper.

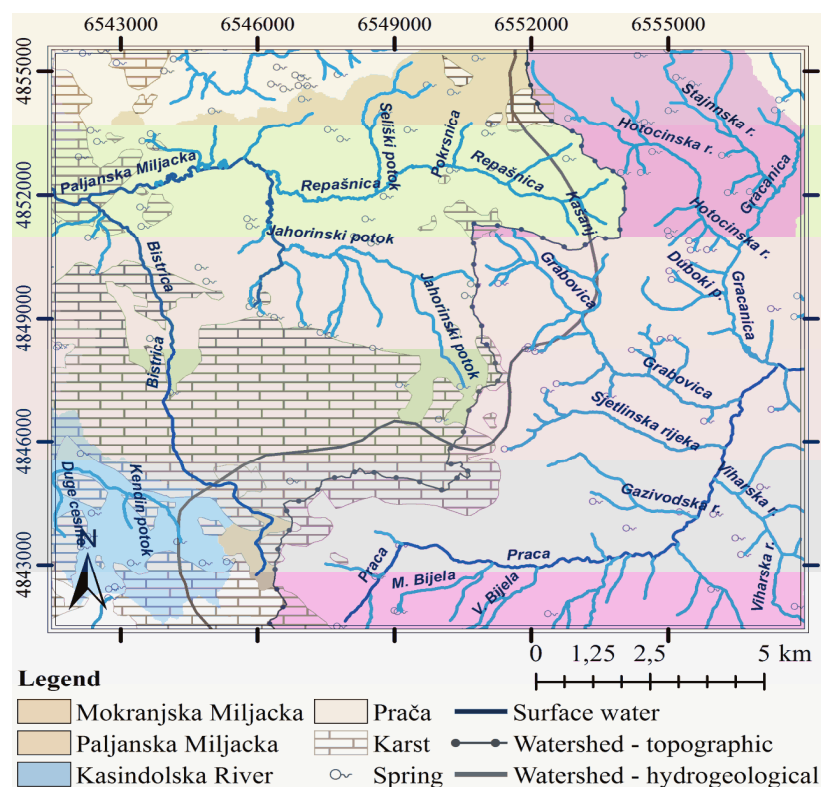


Figure 3 Watershed in the studied area

Considering that groundwater collecting area of Jahorina which supplies population of Sarejevo and East Sarajevo is dominantly karst, and that in this mountain terrains are built many infrastructure facilities, especially those adapted to the needs of tourism, vulnerability groundwater therefore is much higher. The analysis included the vulnerability of water flow Paljanska Miljacka and Bistrica as well of these flows supply the highest percentage of the population of Pale and Sarajevo, and

according to the topographical definition of watershed, the highest percentage of groundwater in karst of Ravna Mountain flows into two rivers.

To more clearly analyze possible threats to Jahorina groundwater, we started with defining of groundwater depth (Figure 4). The depth of groundwater is determined by the hydrogeological characteristics of the terrain [4] and proximity of hydrographic objects – springs, permanent water flows etc. Based on vectored layers (maps) of water objects (springs and flows), first we made map that shows how far certain point on area is from any sources or permanent flows. When point is closer to the water, it is more likely that the level of ground water is closer to the surface and vice versa [13]. In correlation of these maps with hydrogeological map, according to the relations shown in the table (Table 2) [14], ie. overlapping of these layers obtained is a map that shows the estimated depth to groundwater levels in studied area. The frequency of the springs is determined also by using GIS, which found that in the studied area, exists three categories of spring and wells frequency (0 pcs/km²; 1-5 pcs/km² and 6-10 pcs/km²) [15].

By analyzing the map of depth to groundwater we found that in the study area are presented all types of springs. In karst area in highest percentage is presented aquifer with estimated location at a depth of over 30 meters. In contrast, the karst aquifer at shallow depths (9-15 m) is presented in the lowest percentage and is located along flows and springs on karst plateau. These springs are mainly located in northeast and north karst plateau and directly below it, where under debris material which is mechanically slide from karst plateau, there appears a series of wells and springs in the contact limestone debris layer and degraded quartz-micas sandstone, clay and marl. These springs are fed by gravity, along the lines of fossil flows (dry valley) that were active in the geological past, and are relatively most vulnerable. Abundant spring of this zone is spring of Paljanska Miljacka which is used to supply with drinking water population of Pale.

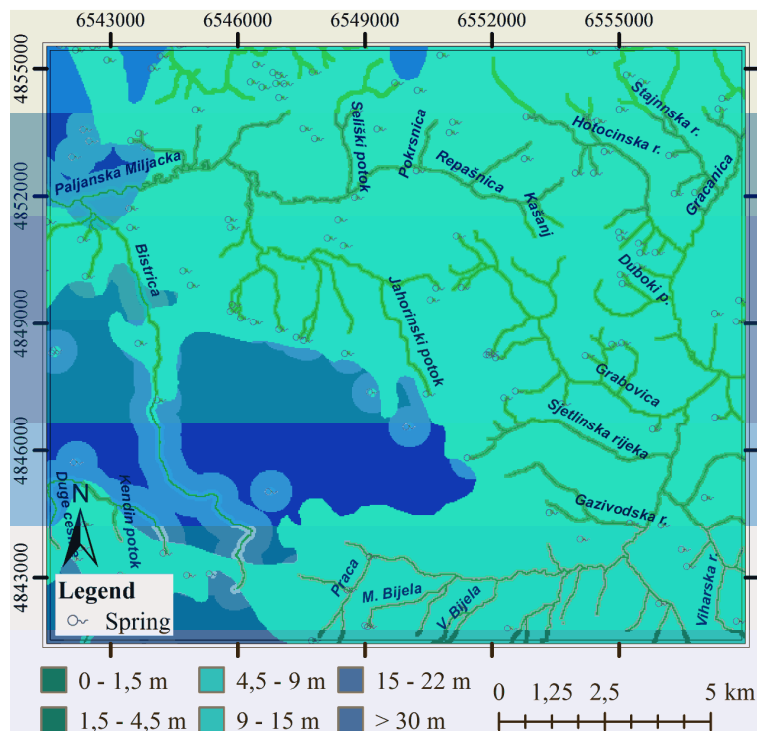


Figure 4 Depth to groundwater

Table 2 Calculation chart for assessing depth to do groundwater levels

Type of aquifer	Distance from spr. and water flow (m)	The depth to groundwater (m)
Dense	0 – 20	0,0 – 1,5
	> 20	1,5 – 4,5
Karst	0 – 20	0,0 – 1,5
	20 – 100	9,0 – 15
	100 – 500	15 – 22
	> 500	> 30
Fissure and cond. waterless	0 – 20	0,0 – 1,5
	20 – 50	1,5 – 4,5
	> 50	4,5 – 9,0

In the southwest, stands out spring and stream of Bistrica, whose aquifer is also at lower depths, and feeds with water that in highest percentage comes from karst of Gola Jahorina, and Ravna Mountain. Spring of Bistrica is located at an altitude of about 1601 m, at the contact of limestone and clastic rocks. In the period of high and very high water levels of groundwater, springs Bistrica yield increases

on account of Paljanska Miljacka spring, and at time of low and lower water levels of groundwater we have reverse process [15]. This spring is tapped for water supply needs of city Sarajevo.

A map showing the infrastructure facilities and zones in the studied area clearly illustrates areas where the groundwater in karst is more vulnerable. This problem is further complicated by intense uncontrolled construction and the exploitation of area, which is especially intensified in the post-war period. These phenomena are triggered by the development of tourism and mostly are present in touristic areas of Gola Jahorina, but also recently is intensified in area of Ravna Mountain [16]. It is planned and already being implemented renovation of prewar and construction of new cottages and other tourist facilities in Ravna Mountain, especially at the location of karst uvala Saračevo field, located in the northeastern part, near the springs and numerous cave and shaft channels (Figure 5). The route of gondola „Jahorina Express” cuts the central karst plateau of Ravna Mountain. With this object in plan is to build interstation on Ravna Mountain, which will be followed by other tourist features and facilities. It should be noted that the positive side of building gondola is that it will significantly relieve area of Gola Jahorina in terms of concentration and problems with car parking space.

Built touristic complex and zone of weekend settlements without regulated sewerage network in area of Gola Jahorina, are located closely to spring of Bistrice. Also, the progressively destruction of the forest complex directly affects the changes in the amount and mode of groundwater recharge, therefore more frequently reduction of water usage in the summer. These and many other factors must be considered together, in order to rationally comprehend the problems and threats so we can mitigate the consequences that negatively effect on quality of groundwater in Jahorina karst.

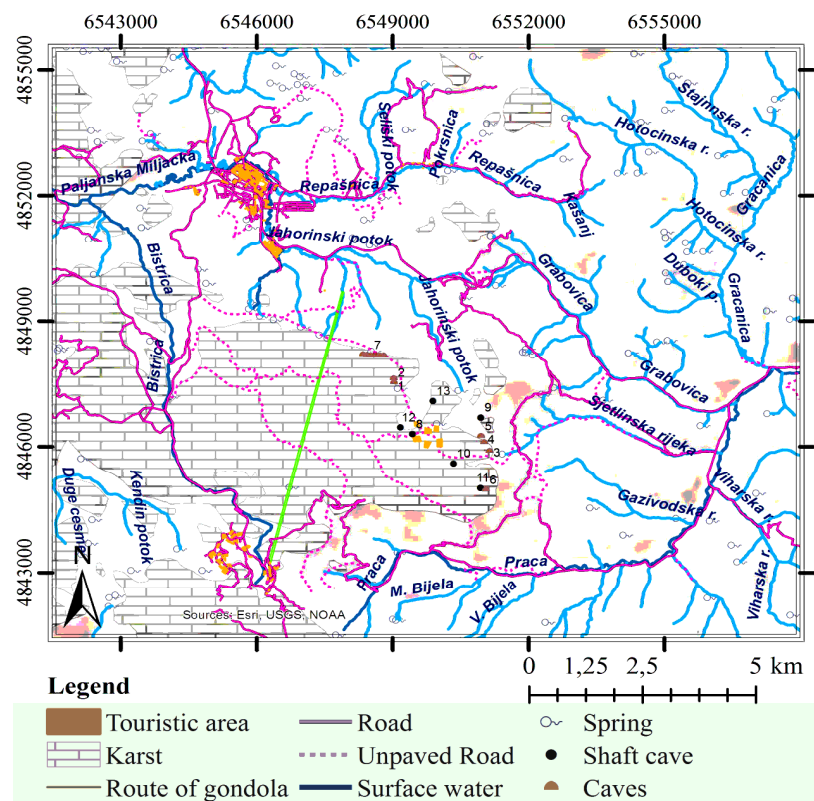


Figure 5 Infrastructure facilities and zones in area of Jahorina

CONCLUSION

The analysis covered area of Jahorina, its northern part Ravna Mountain, whose karst plateau represents the water storage area of Paljanska Miljacka and Bistrice. Wells of these flows are capped and supply with water population of Sarajevo and Pale. Intense demographic and urban changes in the

analyzed area have consequences on karst, ie. affect on quality and general vulnerability of groundwater.

Since that physical components are limiting factors of spatial planning (they have a key role in planning of area purpose), it imposes conclusion for particular need for rational use of natural potential and generally to work according to the principles of sustainable development. Due to uncontrolled construction and the exploitation of area, which is especially intensified in post-war period, where protection of area is not yet established in more or less regulated system and it is not a priority, there are a series of problems that are permanently damaging environment and indirectly affect the underground water in this area, which still have high quality. On the other side, sustainable development followed by planning, protection and rational management of area has not yet been established and is not implemented in practice.

Studies have confirmed that vulnerability of karst groundwater on Jahorina exists, especially in areas that are more effected by tourist development and attraction. Hereby we give recommendations to mitigate the effects of possible groundwater contamination:

- Tourist accommodation facilities and restaurants build on non-karst surfaces, and base unit of karst plateau preserve from rapid construction and adapted to needs of recreational tourism (hiking and biking trails, adventure and amusement parks, educational parks and trails, etc.);
- Waste water from pre-existing facilities collect on an environmentally acceptable way to prevent discharge on karst areas;
- Preserve forest complexes and enrich them with new species, and species that have been dominant for ages in this area but are suppressed due to deforestation and destruction of forests of maple (greek and sycamore), by which mountain was named (Javor, serbian for maple - Javorina, later under influence by Turkish language Jahorina);
- Using GIS technology, in cooperation with experts from various fields, make maps of groundwater vulnerability of the whole karst area of Jahorina, ie. get precise information on natural groundwater vulnerability to contamination from the surface. Today it is a necessary procedure to achieve environmental and technical standards of countries that already apply this concept in planning and protection of area.

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