

2 CROATIA: GACKA RIVER SPRINGS

2.1 Overview

The catchment of the Gacka River is situated in the western Croatia, within the Lika region. The Western half of Croatia is a part of the broader Dinaric karst area which spreads parallel to the eastern Adriatic coast over the territories of several countries from Italian border across SW Slovenia, Croatia, W Bosnia and Herzegovina and Montenegro to the N Albania. The area is characterised by pronounced karst morphology, absence of surface water on elevated plateaus and mountains, and occurrences of large karstic springs at their foothills

Gacka river springs at four major and several smaller (intermittent and permanent) karstic springs situated along the SE border of the Gacko polje (lowland) area. The river naturally flows for aprox 30 km in NW direction across relatively flat karst polje surface. The river has branched into two main branches and sank completely in several sinkholes at the foothills of the karstic massif which separates the polje from the Adriatic sea.

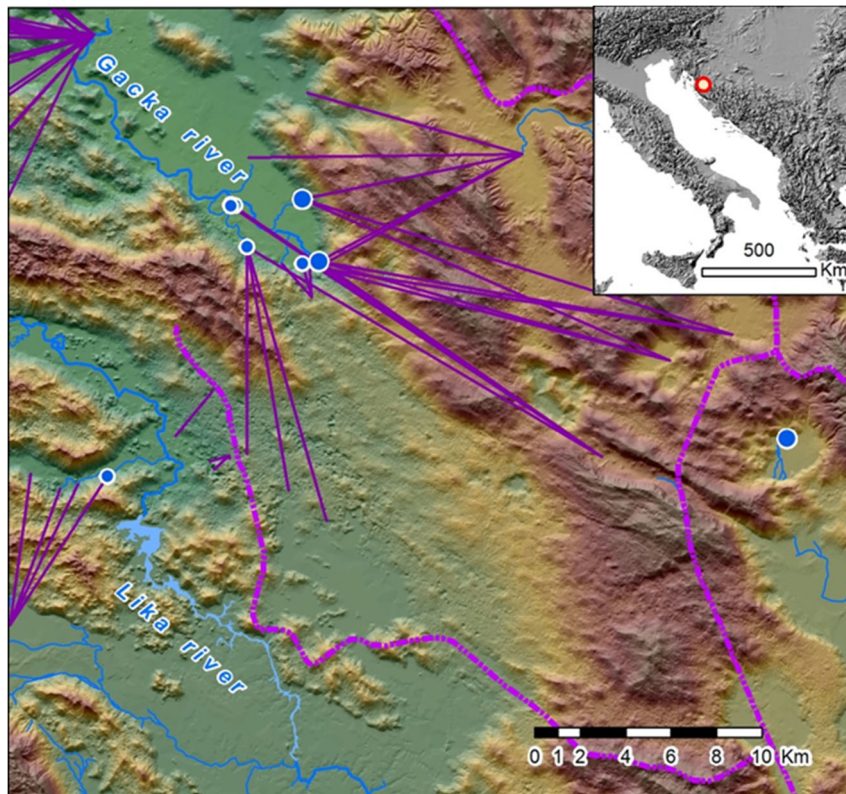


Figure 1: Gacka catchment area is located in the western part of Croatia within the broader Dinaric karst region (water tracing connections marked with solid lines; approx. catchment boundary with dashed line).

Nowadays Gacka River is utilized for electric power production, and the watercourse is diverted in the downstream part through a tunnel to the hydroelectric plant located on the sea coast. In present conditions natural sinkholes of the river are active only during extremely high waters, or during service works on the tunnel, on average only a few days a year.

Intake facility for the public water supply of the Gacko polje and its surroundings (approx. 10.000 inhabitants) is located on the one of the main Gacka springs. Mean yearly pumping rates



amounts approx. 50 l/s, which is negligible compared to minimum discharge of the spring (approx. 1000 l/s). However, Gacka springs are designated as a strategic water resource, and planned for future public water supply of the much broader area.

Beside energy production and public water supply, the Gacka River is important for tourism, especially trout fishing, and there are also fish farms located on the river. The Gacka River and its immediate surrounding is included and protected as an important bird habitat within Natura 2000 ecological network of the European Union.

The catchment of the Gacka springs (slightly over 500 km²) is very scarcely populated, with total number of inhabitants in the range at approx. 1500. There is no significant industrial activity within it, and the main economic activity is extensive cattle breeding, mainly sheep and cows. The majority of the area is covered with woods, and in lesser extent with the pastures, while only a fraction is cultivated lands. The majority of the catchment area is protected within sanitary protection zones for public water supply.

2.2 Geology

Various carbonate rocks, susceptible to karstification, underlie almost the entire catchment area of the Gacka river. Non-karstifiable Eocene marls appear only on a limited area (few km²) on the SE margin of the catchment. Dolomitic rocks of Jurassic age prevail in the NE part of the catchment. Cretaceous limestones and in less extent dolostones build up the central and SE parts of the catchment. SW and W part of the catchment, together with Gacko polje area on which Gacka river flows, is built of well-lithified and compact Tertiary carbonate (mostly limestone) breccias. These breccias are thought to originate from intensive rock fracturing during tectonically most active phases of structural formation of External Dinaride Mountains, most likely lasting from the end of Eocene to the beginning of Miocene period. The breccias are non-layered and less fractured compared to the older (Mesozoic) carbonate rocks. This results in pronounced solutional morphology of terrains built up of the breccias with scarce soil and debris cover on the surface. Soil cover is mostly continuous on dolomitic terrains, while on limestones it is usually discontinuous with numerous outcrops of the bedrock. Nevertheless, even on dolostones cover is usually thin, typically few tens of cm thick. Only in karst depressions, which appear more frequently on limestone terrains, soil cover could be few meters thick.

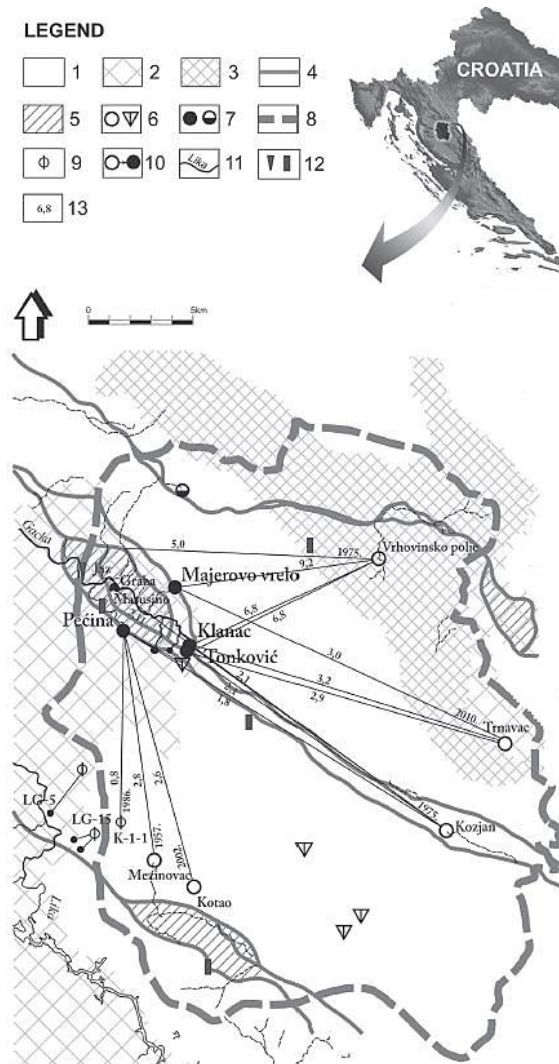


Figure 2: Schematic hydrogeological map of the study area.

1– prevailing limestone rocks, 2– carbonate breccia, 3–prevailing dolostone rocks, 4– most important faults, 5– extension zone, 6– swallow hole (ponor) and vertical cave (pit), 7– spring: permanent and intermittent, 8– groundwater divide, 9– borehole, 10– groundwater connection (tracer test), 11– river, 12– river and rain gauge stations, 13– groundwater velocity determined by tracing tests (cm/s) (modified from Lukač Reberski et al. 2013).

2.3 Geomorphology

The catchment area of the Gacka River can be described as a hilly karst area which surround large flattened surface of the Gacko polje on which the Gacka River flows. Mountainous area E and SE from the polje is the most elevated part of the catchment (1000-1200 m a.s.l.), while the lowest part is the Gacko polje which is on 450 m a.s.l. Karst plateau intersected with numerous dolines and with elevations mostly within 600-700 m a.s.l. forms S and SW parts of the catchment. Besade Gacko polje, there are a few much smaller karst poljes on higher elevations (600-800 m a.s.l.) on the E and S parts of the catchment. Watercourses in these poljes are not



permanent, i.e. dry up during dry periods of the year. Sinkholes of these watercourses were used to perform groundwater tracing tests, based on which the catchment boundaries are defined.

2.4 Climate

Mean annual temperatures within the catchment area are within 5-10 °C, while mean annual rainfall ranges 1200-1500 mm/y (www.meteo.hr). Locally, the relief plays a key role in the definition of climate conditions. Temperature is lowering and precipitation is generally higher with increasing elevation, so lowest temperatures characterize mountainous E part of the catchment. Minimum rainfall is usually in summer (July as the driest month average 70 mm of rainfall) and most intensive precipitation is during autumn (November precipitation average 170 mm). The climate is generally of continental type but modified by the maritime influence of the Mediterranean. Highest parts of the catchment characterise a mountain climate that differs primarily by lower air temperature and snow cover regime. Snow cover last 30-100 days in average, depending on the elevation.

2.5 Hydrogeology

The Gacka River catchment is a typical karstic system where water is flowing mainly through underground solution conduits, while permanent or intermittent surface watercourses are present only in areas of karst poljes. Surface elevations of karst poljes are typically within oscillation amplitude of groundwater level in surrounding area. Where and when surface elevation is below groundwater level karst springs appear, while where groundwater is below surface level sinkholes appear. Estavelles, spring-sinkhole features, which function depends on hydrological conditions, i.e. on the groundwater level in surrounding massif, are typical manifestation of surface water-groundwater interrelation on karst poljes.

The only permanent surface watercourse in the area is Gacka River, which is fed by four major and more minor springs situated along the SE borders of the polje. The river is flowing across the polje surface towards sinkholes located on the NW polje borders. Estavellas appear along the river course between the spring and the sinkhole areas. Formerly, in natural conditions the complete river sank in the sinkholes and reappeared on the surface at numerous coastal springs along Adriatic coast. Direct distance between the sinkholes and the coast is approx. 20 km, but the water sinking in sinkholes emerges on the springs spread across 70 km of coastline.

Two of the main springs (Majerovo and Pečina springs) have human enterable openings to the conduit network feeding them. Morphology of the explored conduits shows complex looping morphology with frequent channel branching and changes from horizontal to steeply inclined passages. Majerovo spring is explored to the maximum depth of -104 m below spring level, and total length of explored passages is 950 m (www.ddiskf.hr). This confirms that conduit network is developed to at least to 100-150 m below the polje level.

Springs and watercourses of a few higher elevated and much smaller karst poljes within the catchment are typically active only during wet periods. Tracing tests of the sinkhole located in these poljes defined the catchment boundaries. Apparent groundwater velocities of the injected tracers were mostly within 1-10 cm/s range, without obvious relation to the geology, i.e. limestones, dolostones or breccias building the area between the sinkholes and springs. That points to well-developed conduit networks in both limestone and dolomite rocks despite less pronounced surface karst morphology on dolomitic terrains. Transition from the zone of permanent springs to the zone of estavellas in the Gacko polje is abrupt and probably caused by barrier function of the major fault stretching along the W border of the polje (*Figure 1*).



Based on the catchment morphology and elevation of the springs, thickness of unsaturated zone ranges from 0 to approx. 800 m. Maximum depth of the hydrologically active conduits within the system is largely unknown, but based on the results of speleo-diving explorations in the wider area it should be presumed to be at least 200 m below low water levels. Geological boundary with non-karstic rocks is at much greater depth, so it is not relevant for estimation of the lower boundary of karstification.

There are neither deep wells nor piezometers within the Gacka catchment, so water levels within the system are estimated based on natural water occurrences, i.e. springs, estavellas, and sinkholes (ponors). An attempt to capture water through borehole in the (closer) hinterland of the Tonković and Klanac spring was a failure due to a very low yield of the borehole. This indicates very low effective porosity of rocks surrounding karst conduits, which is general characteristic of compact Mesozoic carbonate rocks of Dinaric karst.

Gacka springs generally have high water quality. Water quality is regularly monitored only on the public water supply spring, but some data for other main springs is also available (e.g. Matić et al. 2016). Rare events of increased turbidity, usually followed by increased bacterial content, present the only problem for water supply purposes. These events typically happen only during extremely high-water conditions, and last only for a few days. Turbidity and bacterial content increases in high water conditions are a natural phenomenon typical for karst springs, and they are not connected (directly) to the human activities within the catchment. There are no other contaminations documented for the Gacka springs.

2.6 Hydrodynamic characteristics of the springs (and river)

Mean annual discharge of the Gacka River downstream from the main springs amounts approx. 15 m³/s. Minimal recorded discharge is slightly above 2 m³/s while maximum recorded discharges are up to 70 m³/s. This points to relatively good regulation capacity of the karst system, compared to other big karst systems in Dinaric karst area where minimum/maximum discharge ratios are usually less favourable. On average lowest discharges are during summer (August and September), while highest are during autumn and spring (November, December and April). Minimum recorded discharges are related to the occasional draught periods that extended from summer to autumn months (October, November).

There is generally no reliable long-term discharge data for individual springs, except from Tonković spring (public water supply spring) on which hydrological station is located. However, some data is available based on monitoring and measurements carried through various former projects. Presently, there is ongoing project carried by Croatian Geological Survey which includes two-year monitoring of the main springs dynamics. Concerning individual spring dynamics, Majerovo spring and Tonković spring (captured for the public water supply) are the most abundant in draught periods, while other two major springs, Pečina and Klanac springs, dry up during most severe drought periods. The most pronounced discharge variations are typical for the Pečina spring, indicating lowest storage and regulation capacity of SW part of the catchment, largely built of carbonate breccias. Lukač et al. (2013) estimated that 29% of the total Gacka river discharge originates from the Tonković spring, 26% from the Klanac spring, 24% from the Majerovo spring, 15% from the Pečina spring, and 6% from all the other springs. The estimation was based on two-year monitoring period of individual springs during 2008-2010.



2.7 Data available for the project

1. Majerovo spring			
Data type	Time step	Monitoring period	Time period
Discharge	1 hour	1.5 year	05/2018-01/2019
Electrical conductivity	1 hour	1.5 year	05/2018-01/2019
Temperature	1 hour	1.5 year	05/2018-01/2019
Major anions/cations	1 month	1.5 year	05/2018-01/2019
O, H stable isotopes	1 month	1.5 year	05/2018-01/2019
TOC	1 month	1.5 year	05/2018-01/2019

*unreliable data

2. Tonkovića spring			
Data type	Time step	Monitoring period	Time period
Discharge	1 hour	1.5 year	05/2018-01/2019
*Discharge	1 day	>30 years	1982-2016
Electrical conductivity	1 hour	1.5 year	05/2018-01/2019
Temperature	1 hour	1.5 year	05/2018-01/2019
Major anions/cations	1 month	1.5 year	05/2018-01/2019
O, H stable isotopes	1 month	1.5 year	05/2018-01/2019
TOC	1 month	1.5 year	05/2018-01/2019

*unreliable data

3. Klanac spring			
Data type	Time step	Monitoring period	Time period
Discharge	1 hour	1.5 year	05/2018-01/2019
Electrical conductivity	1 hour	1.5 year	05/2018-01/2019
Temperature	1 hour	1.5 year	05/2018-01/2019
Major anions/cations	1 month	1.5 year	05/2018-01/2019
O, H stable isotopes	1 month	1.5 year	05/2018-01/2019
TOC	1 month	1.5 year	05/2018-01/2019

4. Pećina spring			
Data type	Time step	Monitoring period	Time period
Discharge	1 hour	1.5 year	05/2018-01/2019
*Discharge	1 day	20 years	1997-2016
Electrical conductivity	1 hour	1.5 year	05/2018-01/2019
Temperature	1 hour	1.5 year	05/2018-01/2019
Major anions/cations	1 month	1.5 year	05/2018-01/2019
O, H stable isotopes	1 month	1.5 year	05/2018-01/2019
TOC	1 month	1.5 year	05/2018-01/2019

*unreliable data

5. Grab spring			
Data type	Time step	Monitoring period	Time period

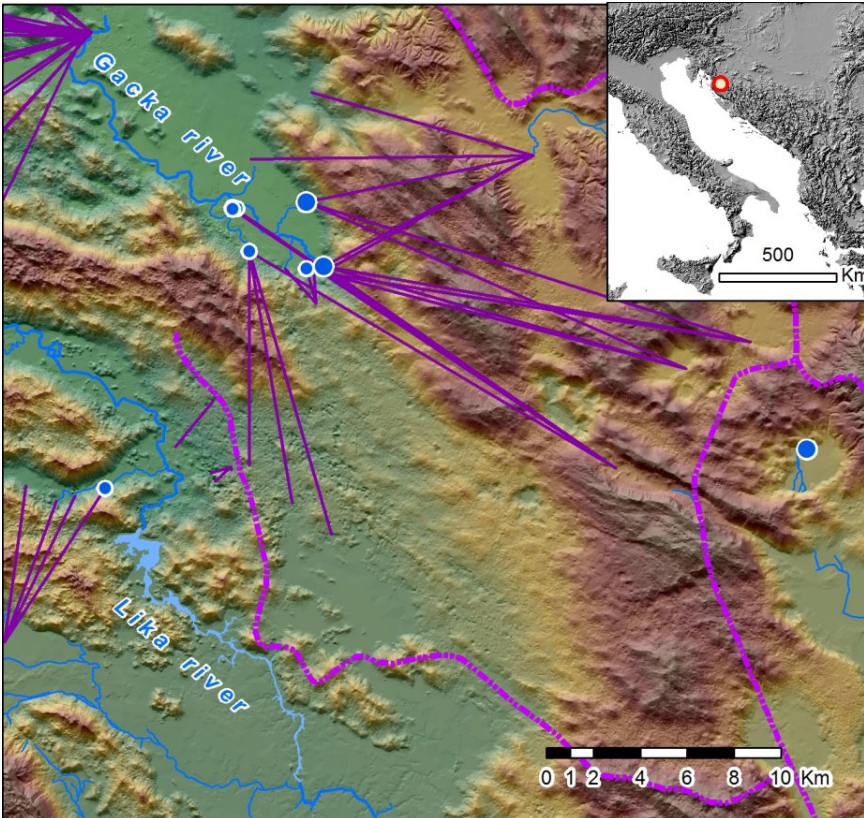


Discharge	1 hour	1.5 year	05/2018-01/2019
Electrical conductivity	1 hour	1.5 year	05/2018-01/2019
Temperature	1 hour	1.5 year	05/2018-01/2019
Major anions/cations	1 month	1.5 year	05/2018-01/2019
O, H stable isotopes	1 month	1.5 year	05/2018-01/2019
TOC	1 month	1.5 year	05/2018-01/2019

5. Gacka river (joint discharge of all spring)			
Data type	Time step	Monitoring period	Time period
Discharge	1 day	>20 year	1995-2016



2.9 Summary

Pilot name	GACKA RIVER SPRINGS		
Country	Croatia	EU-region	Mountain areas
Area (km ²)	515	Lithology	Limestone & dolomite
Short description: Karst springs of the Gacka sinking river are situated in western part of Croatia within broader Dinaric karst region, There are four major and several smaller springs with a total discharge ranging 2-70 m ³ /s, Catchment area of springs is situated within well karstified and scarcely populated mountainous area (450-1300 m a.s.l.). Complete catchment is composed exclusively of karst rocks: limestones and dolomites.			
Monitored objects	River; springs (five)		
Monitored data	Discharge, temperature, EC, chemistry, isotopes		
Contact person	Andrej Stroj (astroj@hgi-cgs.hr)		

2.10 References

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