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title: **Characterizing aquifer behaviour of two karst systems from S Spain by hydrodynamic and hydrochemical data**

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ABSTRACT

The monitoring of karst springs provides data about hydrogeological functioning, water resources and their vulnerability to contamination, information that is essential for the appropriate management and exploitation of karst aquifers. Hydrochemical and hydrodynamic studies of the karst waters at the springs of El Burgo and Fuensanta (Málaga province, southern Spain), carried out during an 18-month sampling period, reveal the main hydrochemical processes and flow conditions within the Sierra Blanquilla and Sierra Hidalga aquifers.

Electrical conductivity (EC) time series and hydrochemical monitoring suggest that the karst aquifer network drained by the Fuensanta spring is more developed than that of El Burgo.

Discharge variations at La Fuensanta are faster, but less marked than at El Burgo (average discharge rates of 0.068 m^3/s and 1 m^3/s, respectively). The hydrochemical characteristics recorded at the two springs indicate different degrees of functional karstification: thus, the chemical components dissolved in the spring water at El Burgo present a lower variation than at Fuensanta. At El Burgo, EC varies in accordance with TAC, Ca^{2+}, Cl^- and TOC contents, while NO_3^-, SO_4^{2-} and Mg^{2+} vary inversely.

The Fuensanta spring water presents large variations in most chemical parameters, such as Ca^{2+}, TAC, SO_4^{2-}, Mg^{2+}, NO_3^- Cl^- and TOC. This spring presents a typical pattern of karstic functioning, with predominantly conduit flow during high water conditions.

INTRODUCTION

The growing demand for high-quality water, together with the scarcity of water resources, in an area such as the Mediterranean, characterised by considerable climatic variability, accounts for our interest in determining the hydrogeological functioning of carbonate aquifers, the volume of resources available and their vulnerability to contamination, all these factors being relevant to the appropriate management and exploitation of such aquifers. The present study presents two examples of karst springs in southern Spain, located within an area classified as a UNESCO Biosphere Reserve.

Karstic aquifers are differentiated from other types of aquifer by the development of secondary porosity through conduits and fissures that are enlarged by dissolution processes, thus enabling rapid groundwater flow (White, 2002; Ford, Williams, 2007). In karstic aquifers, infiltration takes place in diffuse form via fissures, and in a more concentrated way through karstic sinkholes.

In the absence of direct information (from prospective boreholes, speleological exploration, etc.), karst studies normally focus on the natural responses apparent at discharge points. Thus, the joint analysis of hydrodynamic responses (Mangin, 1975) and hydrothermic and hydrochemical responses (Bakalowicz, 1979; Mudry, 1987) enables us to characterise the functioning of a karstic aquifer.

The main aim of the present study is to characterise the hydrogeological functioning of the two most important springs draining the carbonate aquifers beneath Sierra Blanquilla and Sierra Hidalga (Fig. 1), in the eastern part of the Ronda mountains (Serranía de Ronda), in the province of Málaga (southern Spain).

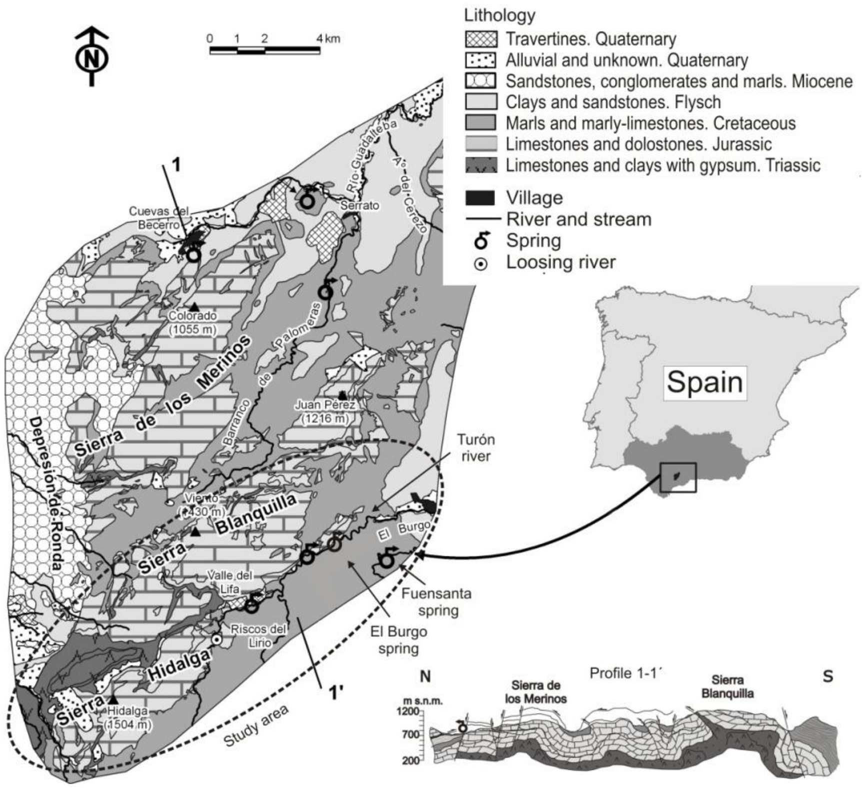

Figure 1. Location of the study site (dotted line ellipse). Geological and hydrogeological settings and geological structure (Profile 1-1´).

SITUATION

The study area is shown in figure 1 and it is located in NW of Málaga province. It has a surface area of approximately 90 km^2, and presents a varied, rugged relief, rising to altitudes exceeding 1500 m (the Hidalga summit is at 1505 m), although the upper parts of the massifs are rounded. The most important river in the area is the Turón, which receives both groundwater and surfacewater flows from the adjacent heights. The climate is of the Continental Mediterranean type, strongly influenced by Atlantic winds. There are two significant rainy periods, in winter and spring. Average precipitation values and mean annual temperatures in this part of Serranía de Ronda are 650 mm and 15ºC (Jiménez et al., 2007), respectively. During the study period (August 2007 – February 2009), the average annual precipitation was over 800 mm, and the mean air temperature was 14°C. Therefore, the study period was both wetter and colder than the historical average.

From a geological standpoint, three main lithological groups have been identified (Cruz Sanjulián, 1974; Martín Algarra, 1987): limestones, dolostones and clays with evaporites (Triassic age)at the bottom; these are overlain by a thickness of several hundred metres of carbonate rocks (Jurassic limestones and dolostones); and finally, a top formation constituted of Cretaceous-Paleogene marls and marly-limestones.

The geological structure is constituted of NE-SW oriented folds, tilting towards the NE (Martín Algarra, 1987). The folds are box-type, with flat hinges and subvertical flanks (Fig. 1; cross section 1-1´). All the fold structures are affected by fractures, which are preferentially oriented N50-70E and N150E (Fernández, 1980).

Sierra Hidalga and Sierra Blanquilla present significant karstic modelling in the Jurassic formations, with large extensions of karrenfields, dolines, uvalas and karstic sinkholes.

METHODOLOGY

Hydrodynamic, hydrothermic and hydrochemical parameters at the El Burgo and Fuensanta springs were monitored during the period August 2007 – February 2009. Water samples were taken at the two springs for chemical analysis, and in situ measurements obtained of electrical conductivity (EC), temperature, pH and water discharge. In addition, continuous (hourly) monitoring was taken of EC and temperature at both springs.

All the hydrochemical parameters considered were analysed at the Hydrogeological Centre at Málaga University. Total alkalinity (TAC) was determined by volumetry, the majority ions (Ca^{+2}, Mg^{+2}, Na^{+}, Cl^{-}, SO_4^{-2} and NO_3^{-}) by ionic chromatography, and total organic carbon (TOC) using a carbon analyser.

RESULTS AND DISCUSSION

In an initial consideration of the hydrochemical characterisation of the carbonate aquifers of Sierra Hidalga and Sierra Blanquilla, we examined the water mineralisation at the springs of El Burgo and Fuensanta, determined from measurements of electrical conductivity (EC) and the continuous records provided by the dataloggers installed at these springs (Fig. 2).

At El Burgo, the electrical conductivity ranged from 288-383 µS/cm. The shape of the frequency curve obtained reveals a distribution with a single clearly-defined mode value, around 320 µS/cm, and a frequency of 26%.

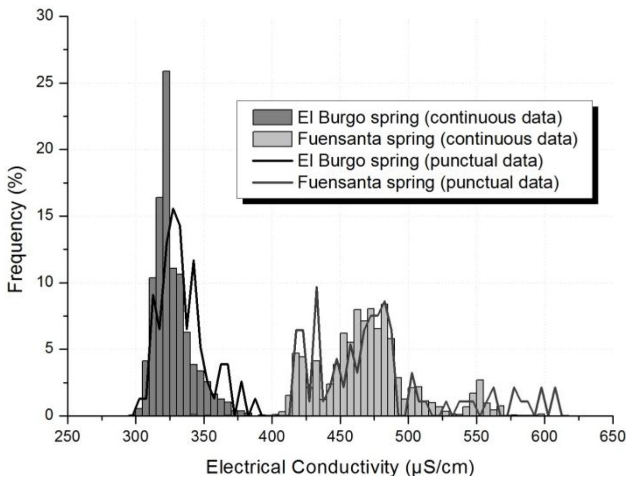

Figure 2. Frequency analysis of electrical conductivity (EC) at El Burgo and Fuensanta karstic springs (EC intervals are 5 µS/cm).

At the Fuensanta spring, EC ranged from 336-600 µS/cm. The frequency distribution presented a wide range, with low frequency values (in no case exceeding 10%). Multiple modes were visible; the curve, thus, was plurimodal.

The distribution of frequencies for the EC values at the two springs studied shows that water mineralisation presents greater variability at Fuensanta, due to the higher degree of development of the karstic conduits there.

The temporal evolution of the hydrochemical parameters registered at El Burgo (Fig. 3A) is shown together with the series of punctual discharge values recorded to the river Turón, which is the main drainage axis for Sierra Blanquilla. The mean net annual discharge from Sierra Blanquilla to the river Turón exceeds 1 m^3/s, with maximum values exceeding 5 m^3/s and minimum values of about 50 L/s during the summer.

The lag affecting the discharge from the spring at El Burgo, with respect to rainfall, is less than one day (Fig. 3A). The continuous recording equipment revealed short-term increases in EC of up to 50 µS/cm (Fig. 3A) during most high-water periods, followed by dilutions in which EC values returned to their initial levels. These episodes provide clear examples of the "piston" effect, by which each increase in discharge provokes a parallel increase in water mineralisation. The EC, temperature and all the chemical components dissolved in the aquifer water presented significant decreases in response to the inflow of less highly mineralised recharge water. In summer, once depletion is established, the increase in water mineralisation is slow but continuous.

The water temperature recorded at El Burgo spring ranged from 12 to 16°C, with a mean annual value of 14.4°C. Temperature variations occurred practically simultaneously with changes in EC, with slight increases, of just a few tenths of a degree, per point increase in EC. After each recharge event, the water temperature fell gradually. An average water temperature of 15.5°C was recorded during the summer and approximately 13°C during periods of heavy rainfall. Thus, the temporal evolution of the water temperature is equivalent to a seasonal curve, with higher values in the summer and lower ones in the winter.

Alkalinity is the main factor responsible for the mineralisation of the spring water at El Burgo, together with the content of Ca^{2+} (calcium bicarbonate facies). Increases in spring water discharge during recharge periods provoke the drainage of more highly mineralised water, with higher TAC values (Fig. 3A). This variation in concentration also affects the Ca^{2+} ion and, moreover, coincides with an increase in calcite saturation. Contents of the Mg^{2+} ion are low (mean value: 6.7 mg/L), and this concentration decreases during high water periods; nevertheless, these variations are of less magnitude than are those of alkalinity and of the Ca^{2+} ion.

Total organic carbon (TOC) responds rapidly to rainfall, with significant increases during spikes in spring water discharge. This is also the case with the ions NO_3^- and Cl^-, which present important increases following the first autumn rainfall. This was particularly so following the heavy rain of October 2008, when maximum levels of concentration of these ions were recorded.

These temporal evolution findings reflect the existence of rapid flows, with the participation of the soil and the unsaturated zone, especially during the recharge events at the beginning of the hydrologic year, because rapid infiltration tracers such as TOC and Cl^- are mobilised, and these become more highly concentrated with the arrival of the recharge water. This effect is in addition to the dilution of other parameters that are characteristic of the saturated zone, such as

SO_4^{2-} and Mg^{2+}, which suggests that the water stored in the saturated zone is becoming mixed with the recharge water, which contains a lower concentration of these components.

On the other hand, the Fuensanta spring (Fig. 3B) presented a mean discharge of 68 L/s during the study period, with maximum values of 325 L/s. During the summer, the discharge fell to barely 10 L/s, but the spring never became completely dry. The response time to rainfall, measured by spring water discharge and hydrochemical parameters, was minimal, at less than one day.

The evolution of EC at the Fuensanta spring presented rapid, important variations in response to the entry of rain water. Recharge events produced punctual increases in mineralisation, followed by reductions proportional to the intensity of the precipitation. The heavy rainfall in the spring and autumn of 2008 provoked a considerable decrease in EC, and this value remained low throughout practically the entire winter (Fig. 3B).

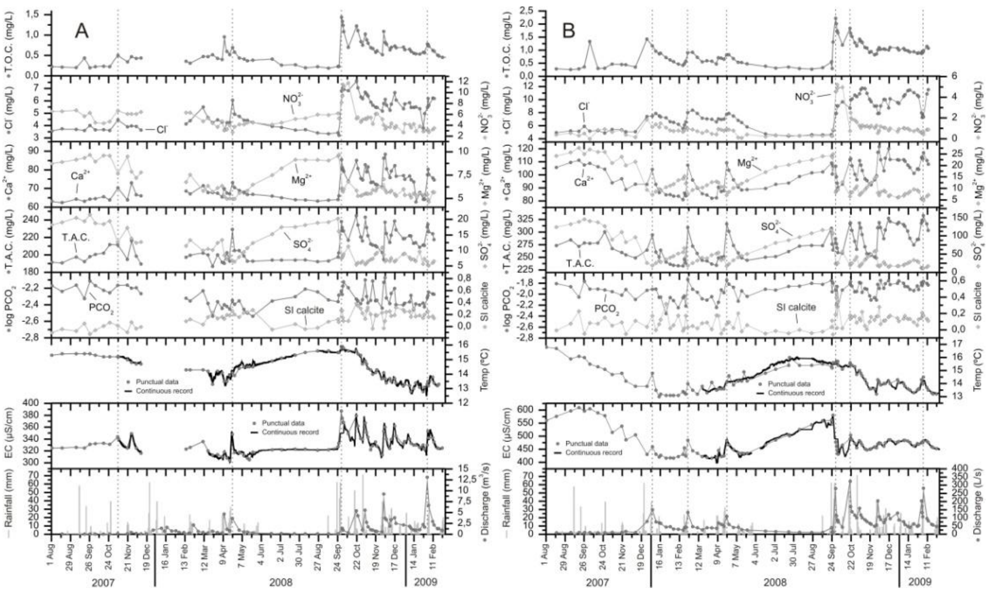

Figure 3. Temporal evolution of dissolved chemical parameters and discharge values at El Burgo (A) and Fuensanta (B) springs.

Water temperature at the spring ranged from 13-16.8°C, with an average value of 14.4°C. The temperature pattern corresponded to a sinusoidal curve, such that during high water periods, colder waters were drained, while during the summer, water temperatures were higher. The general evolution was interrupted by each recharge event, when the spring water underwent slight increases in temperature and in EC, related to increases in water discharge, and decreases in the values of chemical components such as SO_4^{2-} and Mg^{2+}.

The alkalinity and Ca^{2+} and SO_4^{2-} contents influenced the mineralisation of the water at Fuensanta spring. A significant finding was the considerable variability of certain hydrochemical parameters, such as TAC (233-332 mg/L), SO_4^{2-} (11-146 mg/L), and Ca^{2+} (81-122 mg/L). The content of Ca^{2+} and alkalinity varied in parallel, although the responses in the latter case presented greater magnitude. In both cases, the concentrations rose rapidly with higher discharge values (the “piston” effect). On the other hand, during low water periods, the increase in concentration was continuous but slow, due to the greater contact time with the rock and the kinetics of calcite dissolution.

The contents of SO_4^{2-} and Mg^{2+} varied following a similar pattern, with maximum values in summer, and lower concentrations during rainy periods.

In general, the values for NO_3^- and TOC behaved in a similar way (Fig. 3B), unlike EC and water temperature. The former values tended to be higher at the beginning of the hydrologic year (in the autumn), when the first rains fell, and decreased as less water reached the spring. During high water periods, the two parameters responded rapidly with slight increases, almost always associated with increases in discharge from the spring.

CONCLUSIONS

The application of different hydrogeological techniques to the data obtained in this study has enabled us to obtain a hydrochemical characterisation of the two springs, El Burgo and Fuensanta, that drain the carbonate aquifers beneath Sierra Blanquilla and Sierra Hidalga, respectively.

The discharge variations were found to be more rapid at Fuensanta, although of lesser magnitude (68 L/s versus 1 m^3/s).

The EC values recorded at the two springs reflected different degrees of functional karstification. Thus, the Fuensanta spring presented a high level of differentiation of flow types through the aquifer, a pattern that is typical of karstic springs, while El Burgo presented a less variable discharge pattern.

The hydrochemical variations at the two springs also differed significantly, indicating different degrees of functional karstification. El Burgo was characterised by a lower development of functional karstification (less hydrochemical variability with respect to Ca^{2+}, SO_4^{2-}, Mg^{2+} and TOC, although higher variability for NO_3^-), with rapid flows, sometimes reflecting a piston effect, in which each increase in discharge rate was reflected by a punctual increase in water mineralisation, involving some of the chemical components (TAC, Ca^{2+}, Cl^- and TOC). The remaining parameters (NO_3^-, SO_4^{2-} and Mg^{2+}) varied inversely, in accordance with the dilution of the volume of water stored in the aquifer.

Fuensanta is a typically karstic spring, with a well developed network of internal drainage, which is reflected in the considerable variation recorded for most of its chemical components (TAC, Ca^{2+}, SO_4^{2-}, Mg^{2+}, NO_3^- Cl^- and TOC).

REFERENCES

Bakalowicz M., 1979: *Contribution de la géochimie des eaux à la connissance de l´aquifère karstique et de la karstification*. Thèse Doct. Sci. Nat., Univ. P. et M. Curie, París-VI, Géol. Dyn.; 269 pp.

Batiot C., Emblanch C., Blavoux B., 2003: *Total Organic Carbon (TOC) and magnesium (Mg^{2+}): two complementary tracers of residence time in karstic systems*. Comptes Rendus Geoscience 335, pp 205-214.

Cruz Sanjulián J., 1974: *Estudio geológico del sector Cañete la Real-Teba-Osuna (Cordillera Bética, región occidental)*. Doctoral Thesis, Univ. of Granada, 431 pp.

Fernández R., 1980: *Investigaciones hidrogeológicas al Norte de Ronda (Málaga)*. Thesis, Univ. of Granada, 214 pp.

Ford D., Williams P., 2007: *Karst Hydrogeology and Geomorphology*. Edit. Wiley, Chichester (UK), 562 pp.

Jiménez P., Fernández R., y Jiménez Fernández P., 2007: *Sierras Hidalga-Merinos-Blanquilla (M.A.S. 060.043). Atlas hidrogeológico de la provincia de Málaga*, 2: 49-58. Diputación de Málaga-IGME-UMA.

Mangin A., 1975: *Contribution à l´etude hydrodynamique des aquifères karstiques*. Ann. Spéleol., 29 (3): 283-332, (4): 495-601, 30 (1): 21-124.

Mudry J., 1987: *Apport du traçage physico-chimice naturel à la connaissance hydrocinématique des aquifères carbonatés*. Thèse Sciences Naturalles, Université de Franche-Comté, Besançon, 378 pp.

Martín Algarra A., 1987: *Evolución geológica Alpina del contacto entre las Zonas Internas y las Zonas Externas de la Cordillera Bética (Sector Occidental)*. Doctoral Thesis, Univ. of Granada, 1171pp.

White W.B., 2002: *Karst hydrology: recent developments and open questions*. Ed. Elsevier. Engineering Geology 2016.

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