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"The influence of agricultural activities in the Polje of Zafarraya on the water quality of the karstic aquifer the Sierra Gorda (Southern Spain)"
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# The influence of agricultural activities in the Polje of Zafarraya on the water quality of the karstic aquifer of the Sierra Gorda (Southern Spain)

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mary A polje of more than 20 km$^2$ in area, and a catchmemt area of over 100 km$^2$, plays an extremely important role e hydrogeological functioning of the the Sierra Gorda karstic aquifer, which is composed essentially of Jurassic limestones er 1,000 m in thickness. In this polje a notable agricultural transformation is placing practically the entire surface area under ation. In relation with the detrital materials which fill the polje, there is a small perched aquifer, although in many places there irect connections between the unconsolidated aquifer and the karstic ones, as the limestone is immediately below, or across eries of ponors which absorb the surpluses from the irrigation. Despite that the unsaturated fringe of the limestone has a ness of more than 300 m, in the principal springs of the karstic aquifer are showing a steady rise in nitrate content, the ary cause of which appears to be the nitrogenous fertilizers used in the agricultural practices of the polje.

## RODUCTION

Polje de Zafarraya, with an area of approximately 22 km$^2$ uated in the southern area of the karstic system of the a Gorda. Due to its special microclimate, the polje has e last few years been converted into a zone of intense ulture dedicated essentially to the irrigated cultivation of eason vegetables. Until the beginning of the 70s, the ation demand was satisfied by numerous wells drilled in nconsolidated Quaternary aquifer of the polje, but at nt the exploitation includes the underlying carbonate er, which, connected to the alluvial aquifer, is of greater ulic potential.

ltaneously, the massive use of fertilizers and crop-nent products have polluted the alluvial aquifer, evident arily in the high nitrate content currently reaching ntrations of 300 mg/l, and the salination due to the rise lphate and bacteriological contamination (Hidalgo, 1). appearance of nitrates in the wells of the carbonate er, as well as in the principal springs of the system, ate a relationship between the agricultural activities and ow but progressive degradation of the water quality.

## LOGY AND HYDROGEOLOGY

geological and hydrogeological characteristics of the c massif of the Sierra Gorda have been exhaustively ed by Hidalgo (1), Ollero and Garcia (2), (3), Lopez-Chicano (4), (5), Lopez-Chicano and Pulido-Bosch (6), (7), (8) and continue to be an object of attention for the Grupo de Investigación de Recursos Hídricos y Geología Ambiental, of the University of Granada. In fact, the Sierra Gorda aquifer is a pilot area within the framework of the Action COST 65 of the EU (Hydrogeological aspects of groundwater protection in karstic areas) and in the AMB92-0211, project financed by the CICYT.

The karstic system of the Sierra Gorda constitutes a carbonate massif situated on the western edge of the province of Granada, with an area of approximately 295 km$^2$ (Fig. 1). The lithology is basically Jurassic limestone and dolomite belonging to two tectonic and stratigraphic units called Sierra Gorda and Zafarraya, the substratum of which is presumably composed of Triassic clay and evaporites (Keuper facies).

In the southern sector of the massif lies the Polje of Zafarraya, covering an area of about 22 km$^2$, with a length of 10 km and a maximum width of 3.5 km, on the central-western transverse. The maximum length is oriented N140E, coinciding with one of the preferential fracturing directions (Lopez-Chicano and Pulido-Bosch, 8). The fill, from the end of the Miocene to the Quaternary, is comprised of calcarenites at the bottom, with silt, marl and alluvial detrital material throughout the rest of the series. The maximum thickness of the Quaternary series is 60 m, in the central sector.

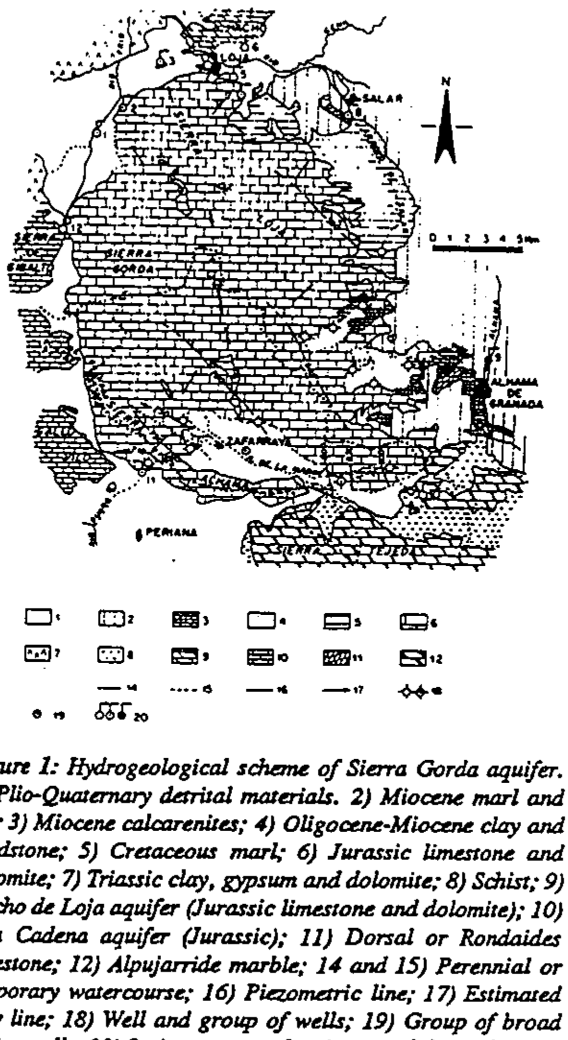

*Figure 1: Hydrogeological scheme of Sierra Gorda aquifer. 1) Plio-Quaternary detrital materials. 2) Miocene marl and silt; 3) Miocene calcarenites; 4) Oligocene-Miocene clay and sandstone; 5) Cretaceous marl; 6) Jurassic limestone and dolomite; 7) Triassic clay, gypsum and dolomite; 8) Schist; 9) Hacho de Loja aquifer (Jurassic limestone and dolomite); 10) Alta Cadena aquifer (Jurassic); 11) Dorsal or Rondaides limestone; 12) Alpujarride marble; 14 and 15) Perennial or temporary watercourse; 16) Piezometric line; 17) Estimated flow line; 18) Well and group of wells; 19) Group of broad radius wells; 20) Spring, group of springs, and thermalwaters spring. The spring cited in text is Riofrio.*

Hydrologically, the Quaternary fill of the polje constitutes a detrital fill with transmissivity of between 20 and 90 $m^2$/day (Hidalgo, 1) and a storage coefficient of up to 13 % (Ollero and García, 3). The hydraulic connection between the unconsolidated aquifer and the Jurassic carbonate rock is good, except in the central sector, where there is a separation by a level of low permeability (Upper Miocene).

This is the only functional polje of the system, with endorreic drainage, which receives water from a catchment basin of 150 $km^2$, of which 65 % is composed of carbonate rock of the Sierra Gorda. The average annual precipitation is around 950 mm. The polje is crossed longitudinally by the Arroyo de la Madre, a seasonal watercourse which under normal pluviometric conditions overflows the limestone at the headwaters. In wet periods, and especially after heavy storms, overflow reaches the western sector of the polje, where the principal ponors are situated, and, exceeding the infiltration capacity by more than 3 $m^3$/s, gives rise to partial flooding of the polje (Lopez-Chicano et al., 9). In Figure 2 a hydrogeological scheme of the polje presents piezometric lines and prevalent flow directions, showing the relationship between unconsolidated and karstic aquifers. The main ponors are also indicated.

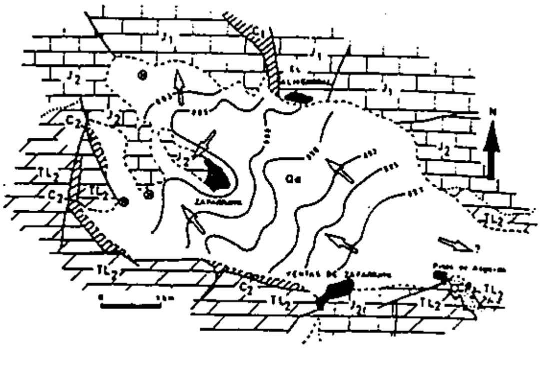

*Figure 2: Hydrogeological scheme of the polje of Zafarraya (central-western sector). TL) Triassic-Liassic dolomite; J) Jurassic limestone; C) Cretáceous-Palaeogene marl and marl-limestone. CCP) flysch. Aa) Quaternary alluvial. H) principal ponors of the polje. The isopiezes correspond to August 1968.*

The connection between the principal ponor and the more important discharge points of the system has been identified by fluorescein injection (Anguita and Fernandez-Montero, 10; Hidalgo, 1; IGME, 11). The preferential flow direction in the karstic aquifer is towards the north, discharging essentially through numerous springs located on the northern border of the massif (Riofrio-Loja-Salar sector), at an elevation of 500 m a.s.l.. The southern discharge is less, concentrated in zone of Guaro, which, for its higher elevation (700 m a.s.l.), acts in the overflow regime.

## AGRICULTURAL ACTIVITIES

Due to the peculiar microclimate and soil fertility, in the last few years agricultural activities have increased notably in the polje, until at present irrigation covers an area of nearly 1500 ha dedicated to intensive vegetable cultivation, principally tomatoes, lettuce, cabbage, cauliflower and greenbeans.

| Substance | Dosage (kg/ha/year) | Total (kg/year) |
|---|---|---|
| Manure | 60,000 | 10,740,000 |
| Calcium phosphate | 2,000 | 386,000 |
| Potassium sulphate | 1,000 | 133,000 |
| Ammonium nitrosulphate | 300 | 357,800 |
| Urea | 500 | 672,000 |

*Table 1: Fertilizers applied in the polje of Zafarraya.*

Currently, drip irrigation systems are used and the demand is met almost totally by the wells in the underlying carbonate aquifer, particularly in the western sector of the polje, where over 60 wells occupy an area of scarcely 3 $km^2$. In the alluvial aquifer the wells (over 300) are shallow and only occasionally used. The combined effect of the recharge and the pumping induce sharp fluctuations in the piezometric levels, for an estimated average of over 7 m per year in a large part of the unconsolidated aquifer. Fertilizers are normally applied in the months of April and October in the dosages listed in Table 1.

These dosages are double or more the recommended amounts for the crops grown. In addition, there is massive use of crop-treatment products for which little information is available. Various insecticides (nicotine, lindane, aldrin), fungicides and other pesticides are habitually used. In the next few years the entire surface of the polje of Zafarraya is expected to be covered with irrigated crops, as well as 1000 ha more in another 2 poljes of the Sierra Gorda (La Dona and Pilar Dedil) hydrogeologically similar to the polje of Zafarraya, although with superficial drainage.

## AFFECT ON WATER QUALITY

Information is scant on the degree of agricultural pollution in the karstic system of the Sierra Gorda, probably because only recently have the consequences of fertilizer use been detected. Nevertheless, in 1984 Ollero and García 2) demonstrated that the nitrate-ion content in the unconsolidated aquifer already exceeded 50 mg/l in a broad sector, and at certain points reached concentrations 140 mg/l. Recently our measurements gave values of 300 mg/l.

The data available on the nitrate pollution in the karstic aquifer are limited to several monthly assays which we have been conducting in the wells in the centre of the polje of Zafarraya and in the principal springs which drain the polje. In the *well water*, values were slightly lower than for the underlying unconsolidated aquifer, ranging between 15 and 25 mg/l from November 1993 to March 1994. For the same period the springs registered 10 and 20 mg/l, substantially lower than the wells because of the dilution by the total hydric mass stored in the aquifer.

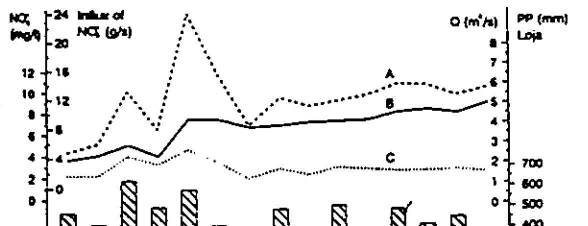


*Figure 3: Inter-annual evolution in Riofrío spring of: A) average annual influx of nitrates; B) average annual concentration of nitrates; C) average annual discharge; and annual rainfall recorded at Loja.*

Apart from our own information, a series of monthly measurements of nitrate concentrations is available for the Riofrío sector, the primary discharge area for the entire system (Fig. 3). Here, in the 1974-75 hydrological cycle, average monthly values of 3.7 mg/l rose to 9 mg/l in the 1988-89 cycle, for an average annual increase of 7 %. The average value for this 15-year period was relatively low, around 6.7 mg/l for nitrates, with extreme values at certain points reaching 2.4 and 13.6 mg/l (Castillo et al., 12). The highest values correlate well with the wettest periods (Fig. 3). The total weight ranged between 150 and 430 tonnes of nitrates/year, in this period and only in this sector, values reflecting the serious consequences of eutrophization of the Iznajar Reservoir situated immediately downstream from the preferential discharge area.

With respect to the unconsolidated aquifer (properly speaking, the polje), the most relevant data shows that the nitrate-ion concentrations reached values of nearly 300 mg/l in some sectors. A lack of information from 1984-1994 hinders our knowledge of the evolutionary mechanisms involved, but a substantial rise unquestionably took place, undoubtedly due to agricultural activity.

To understand the mechanisms of nitrate migration towards the unconsolidated aquifer through the unsaturated zone, we installed an experimental pilot equipped with a suction device made of porous porcelain for sampling to a depth of 2 m. The preliminary results indicate that during the rainy period there is a vigorous leaching of nitrates in the unsaturated zone and a subsequent fall in concentration at the shallowest levels of the aquifer, from initial concentrations of 200 mg/l to less than 100 mg/l.

Consequently, during the period of April to November (dry period) nitrates enter the system, and during the rest of the year (wet period) the rains provoke a strong rise in the piezometric level, from 7-8 m in depth to practically flooding the polje, this process being responsible for circulating the nitrate masses towards the karstic aquifer.

The connection between the karstic aquifer and the unconsolidated aquifer constituting the polje is established by a double mechanism: through ponors situated on the western edge of the polje or through the unsaturated zone in the sectors where the unconsolidated aquifer lies directly over the carbonate rock.

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## Glossary

*Polje*: large flat floored enclosed depression in karst terrains (from Slovene).

*Ponor:* place where a sinking stream goes underground (Slovene; more or less equivalent to the English term *swallow hole*). In this paper it is used like drainage points of Zafarraya polje.