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TEMPORAL EVOLUTION OF RIOFRIO NITRATE CONTENT (SIERRA GORDA, GRANADA)

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ABSTRACT

An explanation and analysis of the temporal evolution (1974-1989) of the nitrate content of Riofrio, near the principal springs of the karst system of the Sierra Gorda is presented. The origin of the nitrates is related to agricultural practiceses in certain karstic poljes (essentially the polje of Zafarraya) and to a much lesser extent, to the manure from extensive pasturing of goats and sheep. The mean nitrate concentration for the series studied was 6.7 mg/l. The fluctuations detected in the concentration were within a narrow margin, generally between 2 and 14 mg/l. On an intra-annual scale, the maximum values were obtained from February to April, and the minimums from August to October. Inter-annually, a close direct relationship was found between the nitrate concentration and rainfall level; from this aleatory heterogeneity, emerged a clear trend towards a moderate temporal increase in the concentrations. For the entire series studied, the average annual increase was 7 %, with an increase in average annual values of 3.7 mg/l in 19784-75 at 9 mg/l in 1988 to 1989.

INTRODUCTION

Nitrates, resulting mainly from fertilizers, have in recent years stirred numerous studies which examine, from diverse standpoints, the sanitary, hydrological, agricultural, and ecological implications. The nitrate concentration in water has been steadily increasing since the 1960s, almost parallel to the rise in the dosage of fertilizers applied in agriculture (Dominguez, 1978; Young, 1982, OCDE, 1986; Canter, 1987; Angle et al., 1992). In many cases, isotope studies can help identify the origin of the nitrates (Sanchis, 1991; Komor and Anderson, 1993; Aravena et al., 1993).

Despite the attention given to nitrates elsewhere, studies in Spain attempting to quantify this rise have been few, perhaps due to the scarcity of reliable historical records (ITGE, 1989; Sanchis, 1991; Pulido-Bosch et al., 1992). The present work seeks to explain and analyse the data of the temporal evolution detected on a monthly level in the Riofrio station (Fig. 1), from October 1974 (the oldest record available) to September 1989. The

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concentration values are contrasted with those of the discharge of the same station, and with the pluviometric values of the nearby town of Loja.

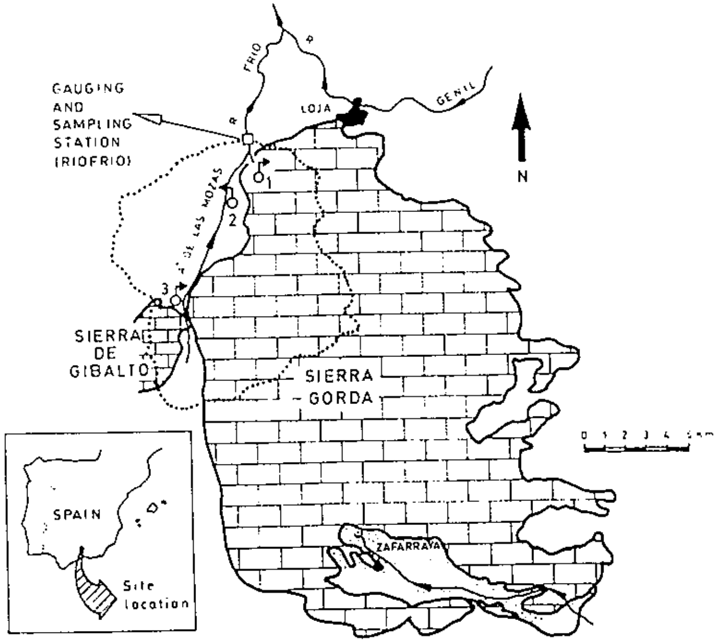

Figure 1.- Location of the gauging and the hydrochemical control point of the Riofrio station, showing the catchment basin and its relationship with the principal karstic aquifers. 1, 2, 3: springs (Riofrio, La Tajea, El Charcon, respectively)·

The present work provides information about the evolution of nitrates in a karstic aquifer. In general, karstic aquifers are slight affected by the increase of nitrates, not being used for agriculture in the Mediterranean area. In the case studied, however, the nitrates originate from fertilizers applied in certain depressions in the karstic aquifer, specially in the polje of Zafarraya (Fig. 1), where there is intense agriculture. The extensive pasturing in the area results in nitrate values of little importance. The fact that nitrates can be used to trace the flow of water provides complementary information about the hydrodynamic behaviour and about the infiltration and recharge processes of the karstic aquifer of the Sierra Gorda.

An analysis of the hydrogeochemical variables obtained in a previous multi-disciplinary study, concerning the waters of the region (University of Granada, 1990), indicated the interest of the temporal evolution of the nitrate content in the water of Frio River, in relation to the other analytical parameters (Castillo and Lopez Chicano, 1992). In

addition to this evidence, the available historical data on nitrates and discharge for Riofrio station (N° 88) were requested from the Confederación Hidrográfica del Guadalquivir (CHG), which graciously provided the analytical values taken monthly over 15 years - between October 1974 and September 1989- and these data constitute the basis for the present work.

HYDROLOGICAL FRAMEWORK

The Frio River is a left-bank tributary of the Genil River and originates near the town of the same name (province of Granada), from several springs which represent the principal discharge of the karstic aquifer of the Sierra Gorda (Lopez Chicano, 1992). After a short distance, the river is joined, on its left bank by the flow of Arroyo de Las Mozas, also called Arroyo Salado. This last waterway can be considered a permanent fluvial course, beginning near the Sierra de Gibalto, where it receives groundwater from the gallery spring of Charcon (Fig. 1). Before its confluence with the Frio River, and at the site of the Tajea, Arroyo de las Moras acquires large amounts of groundwater from the Sierra Gorda aquifer.

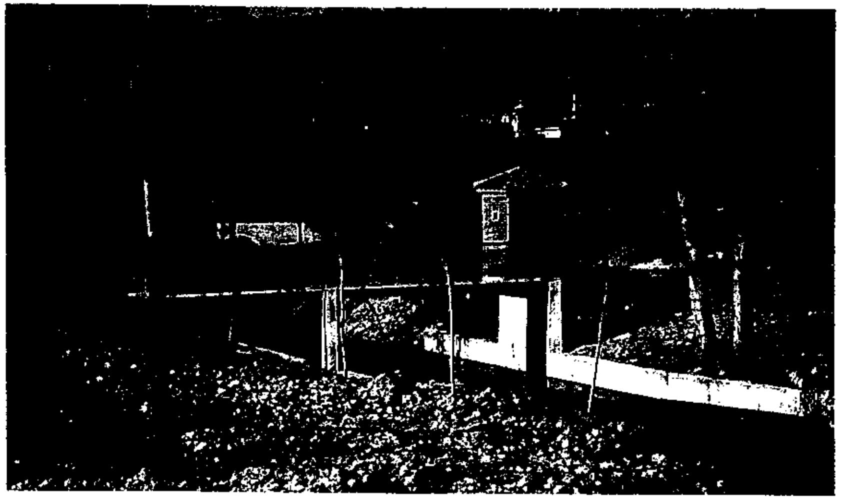

Photo 1.- Riofrio gauging station. (Photo by A. Pulido-Bosch)

The gauging and quality-control station used is located immediately downstream of the confluence of the Frio River with Arroyo de las Mozas. The catchment basin at this point

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has a surface area of 101 km^2, of which more than 60 % are composed of carbonate materials (Fig. 1). The average water flow for the period when the station is operating is an estimated 57 hm^3/year. The runoff coefficient is 0.85, a very high value, which illustrates the importance of groundwater from other basins. The relationship between the average low-water and high-water flow is 54 %, implying a moderate natural regulation, according to the classification of Gavrilov (1965).

The influence of the groundwater draining the Sierra Gorda karst is clearly regulated in this basin, in the sense that the flow diminishes during the high-water and increases during the low-water season. The different direct measurements of the springs -gauged out by the ITGE (Instituto Tecnologico GeoMinero de España) since 1974, and by the present authors in the last few years- enable us to calculate that 91 % of the total water circulating through the Riofrio station comes from the Sierra Gorda aquifer. On the average, 6 % is runoff from the basin, and the rest is discharged from the Sierra de Gibalto aquifer and other minor sources of groundwater.

THE TEMPORAL EVOLUTION OF THE NITRATE CONTENT

Inter-annual analysis

Figure 2 shows the evolution of the nitrate concentration for the temporal series studied (from October 1974 to September 1989) as well as the monthly flow -daily averages- in the same station and the rainfall in the neighbouring rainfall gauge in Loja. Within the normal intra-annual fluctuations, we find, in general, a certain cyclic annual regularity, with the nitrate concentration showing a trend to increase over time. This clearly parallels the evolution of the three variables mentioned; the direct correlation is evident between nitrate content and flow values, and in turn, flow values and rainfall (Lopez Chicano et al., 1992).

The average annual nitrate concentration, obtained from the series of values available, was 6.7 mg/l, and the minimum and maximum monthly values were 2.4 and 13.6 mg/l, respectively. The coefficient of variation was 32 %, somehow less than the one obtained for the flow (43 %), for which the average annual rate was 1.7 m^3/s, based on data from the study period.

Most noteworthy with respect to the inter-annual evolution represented in Figure 2 is the gradual and moderate increase in the nitrate content of the water, particularly in the first period, in which the values rise slightly to an inter-annual level, until the beginning of the 12-month period of 1978-79; from this point there is an abrupt jump, and a marked trend in the inter-annual concentration to increase moderately until the end of the series studied.

This tendency is not repeated in the flow or rainfall series, implying that the profile of the nitrates follows the evolution of the cultivated areas and thus the dosages of fertilizer applied in agricultural areas related to the karstic Sierra Gorda aquifer.

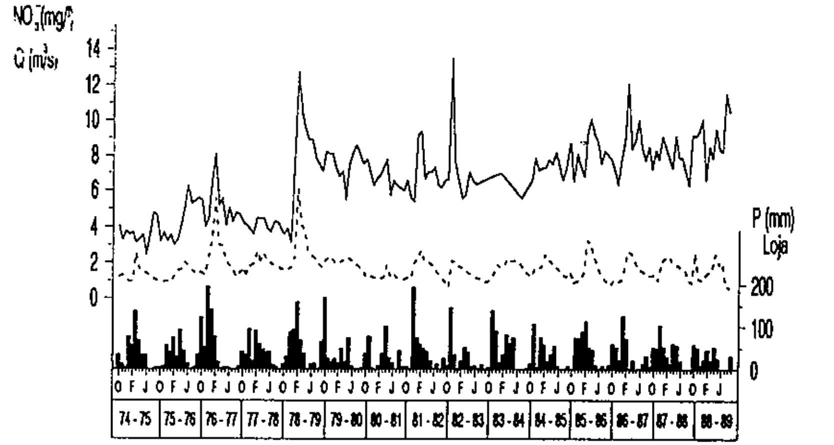

Figure 2.- Time series of nitrate concentration (solid line), flow at the sampling point (broken line), and rainfall in Loja.

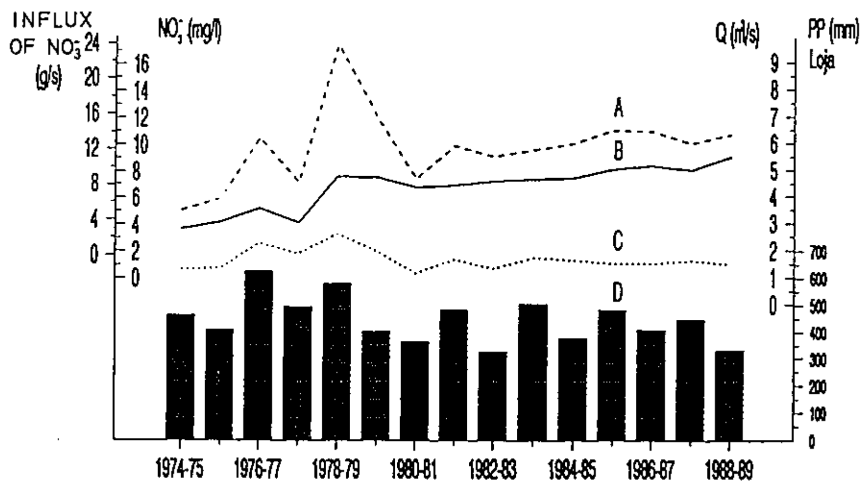

Figure 3.- Inter-annual evolution in Riofrío of: A, average annual influx of nitrates; B, average annual concentration of nitrates; C, average annual flow; and D, annual rainfall recorded in Loja.

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Figure 3 presents the average annual values for the concentration and influx of nitrates, and for the water flow, as well as the total annual rainfall in Loja, showing the increase in the average annual concentrations from 3.7 NO_3^- mg/l in the 1974-75 9 mg/l in 1988-89, the last season of the series. The average annual increase has been 7 %. In the period studied, the years 1976-77 and 1978-79 (the wettest of the series) stand out for their nitrate influx, whereas 1977-78 and 1980-81 are notable for the opposite reason. In the first year of the series (1974-75), the annual influx of nitrates was 150 t, and 430 t for the last (1988-89). The average value of nitrate influx for the entire period was 385 t (as NO_3^-).

The average specific influx obtained was 3.8 t NO_3^-/year/km^2, an appreciably overestimated value for a catchment basin which is much smaller than the hydrogeological one. In consideration of the surface area of the latter, (near 169 km^2) the specific-influx value should be less than 2.4 t NO_3^-/year/km^2.

Intra-annual analysis

For the series available, Figure 4 gives the average monthly evolution rainfall in Loja, of the flow, and of the concentration and influx of nitrates. The average monthly hyetogram (D) shows that the wettest month was December, followed by November and January; a secondary maximum usually appeared in February for the highest areas towards the south and southeast of the study area. The minimum rainfall values were recorded, as is normal in the region, during July and August.

The average monthly hydrogram (C) reflects a notable shift in the months with the greatest flow (February, March and April) with respect to months with the greatest rainfall. The average monthly minimums in the flow occurred in September. The greatest probability of flow maximums within the year were in February, while minimums occurred in August and September.

The distribution of the average monthly values for nitrate concentration (B) followed a more irregular rate than the one of the flows, perhaps due in part to the fact that the means for flow values were obtained from daily records. Nevertheless, it should be mentioned that the average monthly nitrate content fluctuated within very narrow margins: between something more than 6 mg/l and less than 8 mg/l. The highest values appeared in February and April, with a relative minimum in March. February also offered the best probability of maximum annual concentrations in nitrates. The lowest concentrations occured in summer and autumn, although the absolute minimums were in December, with a small peak in November. The influx of nitrates (A) reached a maximum in February and April, with an average of more than 40 t NO_3^-/month, and a minimum between August and October.

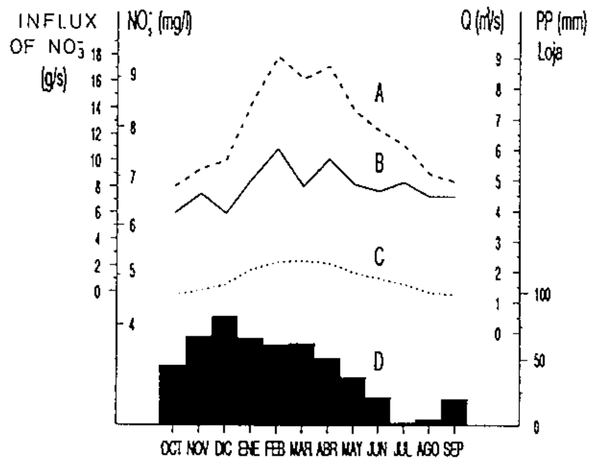

Figure 4.- Intra-annual evolution in Riofrio of: A, average monthly influx of nitrates; B, average monthly concentration of nitrates; C, average monthly flow; and D, monthly rainfall recorded in Loja.

Photo 2.- A view of a ponor of Zafarraya polje. (Photo by A. Pulido-Bosch)

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SOURCES OF NITRATES

The principal source of the nitrates infiltrating the aquifer of the Sierra Gorda is the fertilizer applied to the Zafarraya sector, where there is an important closed karstic depression, which area is 22 km^2 approximately. The detrital fill of the polje of Zafarraya constitutes an aquifer of intergranular porosity which feeds the Sierra Gorda and which has less hydraulic head. The connection of the Zafarraya area with the springs of Riofrio was demonstrated by water-tracing experiences, carried out by the SGOP (Servicio Geológico de Obras Publicas) (Hidalgo, 1974).

In the groundwater of this area Ollero and Garcia (1984) observed nitrate contents of up to 140 mg/l, resulting from the high organic and inorganic fertilizer dosages, which are applied to late vegetable crops. The great profitability of these crops in the polje of Zafarraya has brought about a gradual transformation from traditional dry crops, with irrigation today covering some 1.500 ha. In addition, there are possible influxes of fertilizers from the agricultural areas in the karstic depressions of La Dona (7 km^2) and of Pilas Dedil (3 km^2).

Another source of nitrates infiltrating of the Sierra Gorda aquifer is the pasturing of some 62,000 goats and sheep, mainly in the spring and summer, in pasture lands covering near 30,000 ha. A secondary source in the area is the urban waste water from 1500 inhabitants scattered in hamlets and isolated farmhouses both in the polje of Zafarraya and in nearby areas. Finally, part of the nitrates circulating through the Riofrío station may originate in the trout hatchery immediately upstream.

DISCUSSION AND CONCLUSION

The monitoring of these potentially polluting activities, together with the recording of nitrate concentrations since 1974-75, reveals that the principal source of nitrate influx is the fertilizer applied in the polje of Zafarraya. The progressive increase in the nitrate content of the water of the Frio River is produced mainly by the gradual and steady increase of the surface area placed under irrigation in the polje of Zafarraya, and by the increase in fertilizer dosages. The practice of fertilizing in Zafarraya consists in strong dosages at seeding in April and a steady application of large dosages until harvest in September. Livestock raising has remained constant, and has even decreased, during the last few years, revealing that the nitrate influx from pasturing has a little effect on the karstic aquifers, or at least in those which have several hundred metres of unsaturated thickness. From 1974 to 1978, although livestock farming was intense, the nitrate content of the Riofrio station was less than 4 mg/l.

The average intra-annual evolution of the nitrate content in the Frio River (Fig. 4) offers the following interpretation. A maximum concentration (February and April) coincides roughly with the months of maximum flow (February, March and April). During these months, the aquifer of the Sierra Gorda, and therefore the flow in the Frio River, begins to respond, slowly, to the pluviometric excitation; in general, the autumn rains have little influence on the discharge of the springs, which maintain their low-water levels until November. In February the maximum concentration of nitrates in the water occurs, coinciding with the greatest infiltration into the aquifer and with the discharge peaks. These discharge peaks carry nitrates stored in the soil from the end of the previous spring. It is possible that the maximum nitrate concentration registered in April coincides with an important leaching of fertilizer applied at seeding in the polje of Zafarraya during the same period. With the discharge of nitrates stored in the soil at the end of the previous hydrological cycle, the discharge and nitrate concentration diminish, reaching minimum values in the autumn.

The secondary peak in November, with respect to the mean nitrate concentration, might be explained by the surface leaching of fertilizers and the soil erosion of olive orchards and cereal fields located in the zones closest to the discharge area being studied, following the more normal behaviour of the flow in the streams (Casey, 1977).

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