Spatial and temporal distribution of nitrate contents in the Mancha Oriental Hydro-geological System, SE Spain: 1998–2003

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Abstract

This project determines the nitrate content as well as spatial and temporal distribution in the water supply wells which extract groundwater from the Mancha Oriental System (MOS). The underground resources of the system are used in maintaining approximately 80,000 hectares of irrigation and are the water supply for a total population of 275,000 inhabitants. The average nitrate contents show a heterogeneous spatial distribution, varying between 0.1 mg l^{-1} and 125 mg l^{-1}. The highest levels are associated with areas with large areas of irrigated crops. However, there are also points that are not found to be spatially linked to this type of farming in which nitrate has been detected in significant quantities. The presence of nitrate in these areas can be explained considering other sources of pollution or transport of the pollutant from contaminated areas through groundwater flow. In general, average nitrate values show a growing tendency during the period 1998 and 2003.
Keywords: nitrate, irrigated crops, groundwater, Mancha Oriental System, SE Spain.

1 Introduction

The natural quality of groundwater can be observed as altered by the presence of nitrate proceeding from farming and livestock activities. In fact, the excessive application of fertilizers has been admitted as the main cause of nitrate and other

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pollutants appearing in groundwater, [1–3]. In the European Union, Directives 91/676/CEE, 2000/60/CE, and 2006/118/CE consider polluted groundwater with nitrate content higher than 50 mg l^{-1}.

Over the last 30 years, farming activities have grown significantly due to the extraction of water from the MOS: Irrigated crops have risen from 20,000 ha in 1982 to nearly 80,000 ha in the year 2003, according to Calera and Martín [4]. The representative crops grown in the area are corn, barley, wheat, sunflowers and alfalfa. These crops require high quantities of fertilizer and water to maintain elevated agricultural yield. In addition, groundwater within this system also represents the only resource supplying a total of 275,000 inhabitants spread throughout the provinces of Albacete and Cuenca.

The regional dependence on groundwater resources justifies undertaking studies on the origin, behavior and evolution of nitrate content found. In the MOS, De las Heras *et al* [5], study nitrate pollution in groundwater within the MOS during the years 1998 and 1999 and indicate a high presence of nitrate in irrigation water and the public water supply. The study concludes that certain irrigation practices linked to high output crops could be responsible for the high nitrate content found in several areas of the MOS.

In this study, groundwater used for the urban water supply has been sampled and the nitrate content has been determined along with spatial and temporal distribution for the years 1998, 1999, 2001 and 2003. Although, in general, the highest nitrogen content is associated with large irrigated areas, there are other points where the nitrate levels could be related to other sources of contamination. In addition, the nitrate present could have been transported from production areas through groundwater flow.

2 Study area

The MOS is located in the south east of the Region of Castilla-La Mancha, within the hydrographic catchment of the Júcar River Basin. This hydrogeological system comprises an area of 7,260 km^2, Sanz *et al* [6].

Considering hydrogeology, the MOS can be considered a multiple-layered aquifer formed by the superposition of nine hydrogeological units (HU). The layers are of a diverse nature, belonging to the Triassic, Jurassic, Cretaceous, and Miocene period. The MOS is divided into six hydrogeological domains: Septentrional Domain (DS), Central Domain (DC), Salobral-Los Llanos Domain (DSL), Moro-Nevazos Domain (DMN), Pozo Cañada Domain (DPC), and Montearagón-Carcelén Domain (DMC), see Sanz *et al* [6] for further details.

The groundwater type within the study area is Calcium Bicarbonate (Table 1). This composition is related to the dissolution of the carbonate lithologies that are predominant in the aquifer HU.

The area climate is continental, semi-arid, with extreme temperatures in summer as well as winter. Average annual temperatures vary between 13ºC and 14.5ºC. Precipitation is between 300 mm in the south and 550 mm in the northern MOS.

Table 1: General characteristics of groundwater (782 samples, years 1998, 1999, 2001 and 2003).

Variable	Average	Min.	Max.	S.D.
NO^{3-} (mg l^{-1})	24.1	2.6	116.2	18.7
HCO^{3-}(mg l^{-1})	321.4	130.9	603.6	75.7
Cl-(mg l^{-1})	39.1	5.2	171.4	30.4
SO^{4-}(mg l^{-1})	127.5	4.3	634.1	121.4
Ca^{2+}(mg l^{-1})	96.5	24.0	218.0	32.7
Mg^{2+}(mg l^{-1})	47.3	4.0	145.0	25.9
Na^{+}(mg l^{-1})	15.4	1.8	122.5	16.0
K^{+}(mg l^{-1})	1.7	0.1	15.1	2.4

The largest river crossing the hydrogeological area is the Júcar River. The Valdemembra, Arroyo Ledaña and Cabriel Rivers are affluents of the Júcar on the left side.

3 Methodology

A total of 782 groundwater samples were collected in 57 sampling events from urban water supplies located throughout the three hydrogeological domains of the MOS (Fig. 1). Each point has been sampled every trimester during the years 1998, 1999, 2001 and 2003. Data is not available in the DS for 1998. In this domain only one sample point was analyzed in 1999. The nitrate content in each sample was determined using the ionic chromatography technique APHA [7].

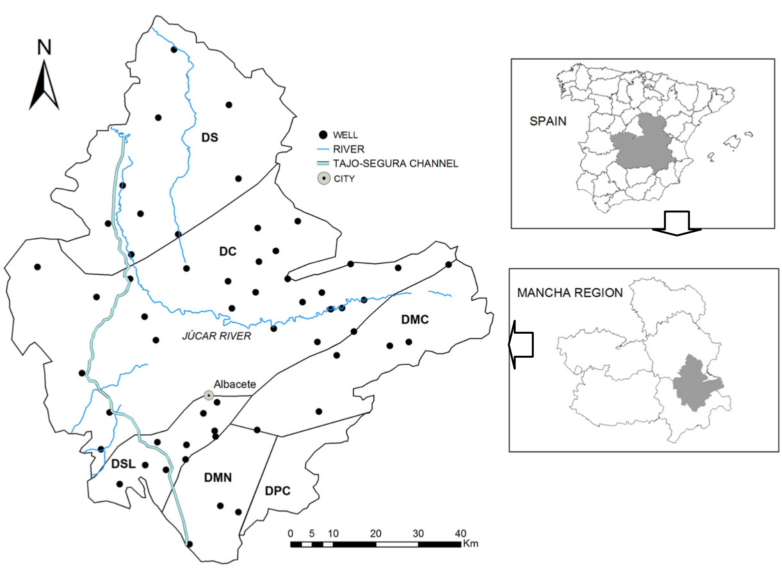

Figure 1: Study area and location of the sampled wells.

The maps of nitrate distribution and irrigated surfaces were obtained using the ArcMap 8.2 software (ESRI). The data on irrigated areas come from the GIS and Teledetection Group from the IDR at UCLM. In order to obtain the spatial distribution of nitrate content (Fig. 2), the method "inverse distance weighted" (IDW) was used.

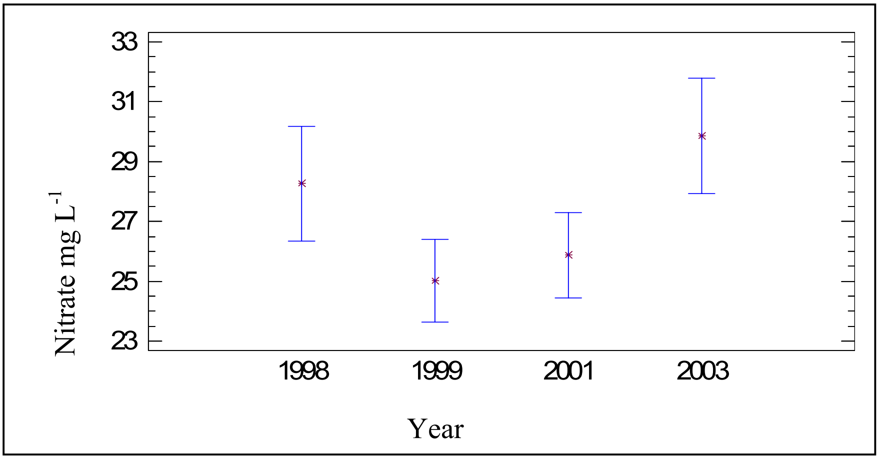

Figure 2: Nitrate content means and 95% intervals LCD.

4 Nitrate contents in groundwater

Analytical results indicate significant differences in average nitrate concentration depending on the domain considered, although none exceed the admissible maximum quantity (50 mg l^{-1}). The highest average content is found in DC and DSL. In DC, nitrate concentrations are between 0.1 mg l^{-1} and 125 mg l^{-1} (Mean value: 29.7 mg l^{-1}) (Fig. 3; Table 2). In DSL, nitrate concentration values vary between 11.7 mg l^{-1} and 61.4 mg l^{-1} (Mean value: 26.3 mg l^{-1}). The domains DS (Mean value: 15.2 mg l^{-1}), DPC (Mean value: 17.8 mg l^{-1}), DMN (Mean value: 18.6 mg l^{-1}), and DMC (Mean value: 22.3 mg l^{-1}) have lower values present (Fig. 3; Table 2).

The analysis of the temporal evolution of values yields results indicating a decrease between 1998 and 1999 in average nitrate concentration in all domains considered. This tendency was also found in the study by De las Heras *et al* [5]. However, after 1999 a progressive increase in nitrate presence was found in groundwater.

Figure 3: Distribution of the mean annual nitrate content in groundwater. A) 1998, B) 1999, C) 2001, and D) 2003.

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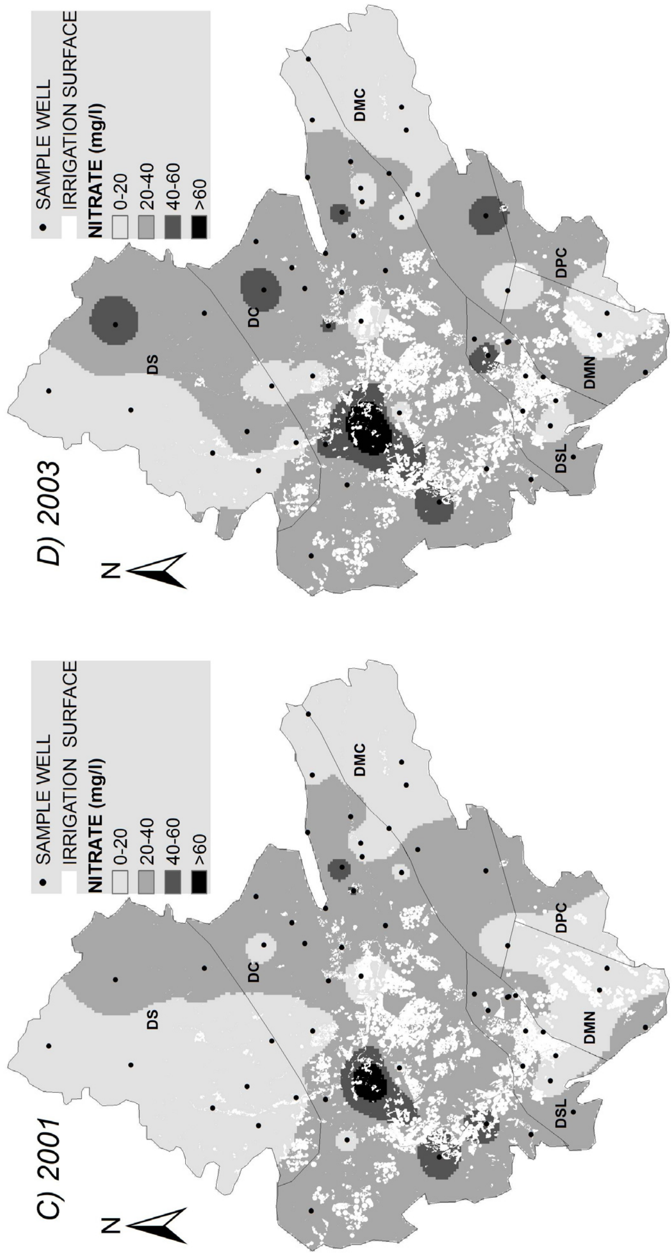

Figure 3: (cont.)

Table 2: Basic statistics of the nitrate contents (n=number of samples).

	n	Mean	Minimum	Maximum	S.D.
Septentrional Domain					
2001	16	13.2	9.1	29.4	5.7
2003	30	16.3	6.8	61.9	12.6
Total	47	15.2			
Central Domain					
1998	74	31.1	1.5	125.0	19.3
1999	133	26.9	0.9	122.0	16.6
2001	168	28.4	0.1	107.1	17.4
2003	73	36.8	5.6	124.1	21.6
Total	448	29.7			
Montearagón-Carcelén Domain					
1998	5	30.7	5.0	42.0	15.3
1999	16	19.8	4.3	43.2	14.1
2001	22	21.5	0.4	56.2	17.7
2003	11	28.2	2.6	52.4	18.9
Total	54	22.3			
Pozo Cañada Domain					
1998	5	19.8	16.4	22.9	3.1
1999	9	16.8	14.4	20.4	2.2
Total	14	17.8			
Moro-Nevazos Domain					
1998	8	20.6	14.1	26.4	3.9
1999	18	14.7	10.3	24.9	3.9
2001	18	20.6	9.9	34.1	8.6
2003	6	22.00	10.4	33.1	10.7
Total	50	18.6			
Salobral-Los Llanos Domain					
1998	45	26.8	14.0	49.4	8.9
1999	88	26.3	12.4	48.1	9.4
2001	21	24.7	12.8	41.5	9.1
2003	15	27.4	11.7	61.4	11.9
Total	169	26.3			

5 Spatial and temporal distribution of nitrate contents in the MOS

Nitrate content in groundwater is distributed in a heterogeneous fashion throughout the MOS (Fig. 3). The areas of highest annual means of nitrate concentrations are associated with the DC and DSL domains, which both sustain large areas of irrigated cultivation. Agricultural activities have been admitted to be potential sources of nitrate pollution due to extensive application of inorganic fertilizers [8–11].

Nevertheless, some samples in the DS and DMC domains with nitrate concentrations higher than the permitted levels are not spatially associated with irrigated crops (Fig. 3). This fact suggests that the origin of nitrate could be associated with sources other than farming, such as urban or industrial waste, or waste from livestock activities. Another possible explanation would be that groundwater can transport nitrate from point sources of pollution to other areas of the MOS where potential polluting activities are nonexistent. In order to collect data supporting this hypothesis, additional studies are required to further investigate the spatial and temporal evolution of nitrate concentrations and the relationship with the flow regime of the hydrogeological system (e.g. aquifer-river relation).

6 Conclusions

The MOS groundwater presents elevated nitrate content, which can reach maximum values of 125 mg l^{-1}. Significant differences have been found within the different domains considered. The average maximum values were detected in DC (29.7 mg l^{-1}) and DSL (26.3 mg l^{-1}). The minimum values were found in DS (15.2 mg l^{-1}). Nitrate presence in the MOS groundwater decreases within the period 1998–1999 and increases within the period 1999 and 2003.

The maximum values correspond to the most extensive irrigated farmed areas (DC and DSL). The source of nitrate in these domains can be associated with the use of inorganic fertilizers applied to irrigated crops. Nevertheless, there are areas where the irrigated area is practically zero, as in DS and DMC, where average nitrate content was also relatively high. In these areas, the nitrate present could be related to other inputs or may have been transported from the source of pollution by groundwater flow.

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