Nitrate contamination in a shallow gabbro hard rock aquifer (Beja – South Portugal)

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ABSTRACT: The gabbro of Beja aquifer system are a very important regional hard rock aquifer. The high grade of fracturing associated to gabbro weathering allows to high permeability. This aquifer is very shallow where the high productivity levels are around the twenty to thirty metres deep. An important feature is the high yield capacity when compared to another neibour aquifers, and are able to supply many irrigation farming lands and cattle breeding farms. In towns and some rural villages it was the only source of water for human supply. The groundwater quality is the major concern in the gabbro of Beja aquifer system. The rise of nitrate concentrations along the last years in groundwater is a result of the agricultural activities increase and start to be a serious problem that are assuming a high risk to human health. The occurrence of nitrate concentrations above 50 mg/L is very common. The first rain plays an important role in the nitrate contamination. It was collected 66 groundwater samples in the region on large wells, springs and deep wells. The results shows that 60 % of groundwater samples are above the Maximum Admissible Value (MAV) permitted by the Portuguese law.

1 INTRODUCTION

Nitrogen is one of the most important structural elements for life on earth. It is a component of the proteins, nucleic acids and other important cell content materials of living organisms. The nitrogen compounds which can be taken up by plants are ammonium and nitrate. The agriculture activities are the main responsible for the increase of nitrate in groundwater (Hamilton & Helsel 1995).

The nitrogen compounds are applied in form of mineral fertilizers or manure effluents or solid manure. In order to ensure maximum yields, crops are usually supplied with large quantities of nitrogen compounds at every stage of plant growth. Unfortunately, for economic reasons in current agricultural practices, more nitrogen is often added to the soil when harvesting the crops. The excess nitrogen not taken up by plants largely remains in the soil in the form of nitrate (NO_3^-).

Nitrate is the most common groundwater contaminant and, because of growing anthropogenic sources, nitrate pollution is increasing (Frezze and Cherry 1979, Gascho et al. 1998, Geng et al. 1996).

Nitrate is a stable nitrogen (N) species under certain natural conditions and forms compounds that are highly soluble. These peculiar features allow NO_3^- to be transported and widespread in some groundwater systems to environments where it can be converted to N species that either promote surface water eutrophication or are hazardous to humans, livestock, and the environment (Korom 1992, Bulger et al. 1990).

The occurrence of high nitrate concentrations, due to intensive agriculture, is a major problem concerning groundwater in the Gabbro of Beja Aquifer System (GBAS) (Duque 1997, Duque and Almeida 1997). This paper is a preliminary approach to the investigation made on this aquifer in order to develop a regional flow and transport model.

2 HYDGEOLOGICAL FEATURES OF GBAS

The GBAS is the most important hard rock aquifer in south of Portugal and covers 347 km^2 of area (Fig 1). The main rocks are gabbro, amphibolites and serpentinites which are very weathered and fractured. The groundwater yields are very high when compared with the aquifers around and have an average yields of 5 l/s, till a maximum of 36 l/s. At this system is a free type shallow aquifer with 30 to 50 m of thickness in a porous and fractured media. The principal productivity levels are around 20 to 30 m deep. The transmissivity values obtained through 62 aquifer tests are between 58 to 450 m^2/day. The GBAS are in equilibrium where recharge deficits are reposed in the rainy years and the overflows are discharged by runoff and by some natural springs. The recharge came directly from precipitation. Duque (1997) estimated the recharge at 4 % of precipitation corresponding to $7.7x10^6$ m^3/year for all aquifer. The flow system are made through independent and impermeable blocks giving raise to a very anisotropic flow with differentiated heads.

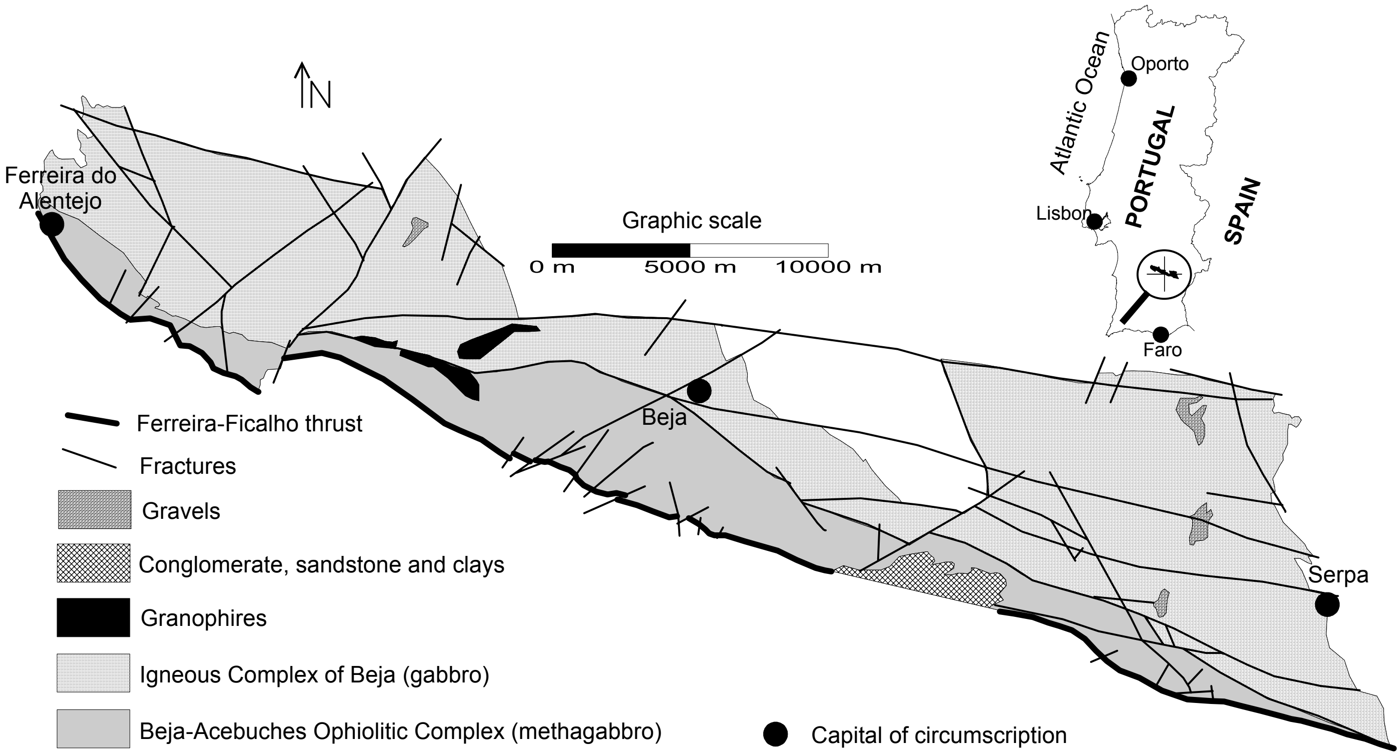

Figure 1. Map of the Gabbro of Beja Aquifer System (GBAS) and their geological features.

Globally the GBAS has three sectors: the west sector Beja-Ferreira do Alentejo; the middle sector Beja-Guadiana river; the east sector Serpa-Guadiana river (Duque 1997).

Nowadays GBAS supplies almost agriculture and cattle breeding. The human supplies in most rural villages also depends on GBAS groundwater. Till some years ago this aquifer supply the city of Beja (about 30.000 inhabitants) but the increase of nitrate concentrations in groundwater implied the change of water sources.

3 AGRICULTURE AND NITRATES IN GBAS

Since the prehistoric times the Beja region was a preferential zone for human occupation. The principal reason for human colonization was the high fertility of the the soils. The Romans, Phoenicians, Arabs occupied the region and started to develop agriculture activities. Nowadays still thousands of ancient Arabic wells are to be seen, some of them still irrigating little farms.

Today the agriculture tradition still keep up people and the principal crops are extensive dry cereals such as wheat, rye and barley. In the beginning of the century the political solution for the Portuguese cereal self satisfaction led to enlarge farming land, clearing uncultivated lands and farming the oak groves. The fertilization of this new farming areas was made with massive introduction of chemical fertilizers. In 1898 the chemical fertilizers applied in Alentejo region was 23000 tons, in 1901 45000 tons, in 1906 100000 tons and in 1910 152000. In these times 60 % of the Portuguese imported chemical fertilizes was applied in Alentejo. In 1928 and 1938 the Wheat Campaign promoted the occupation of virgin lands and the reduction of fallow lands time. In Beja region the wheat area was extended 293 %. Since 1936 the wheat production started to crash, in spite of applying more and more chemical fertilizers (Nitrate of Chile). These features has driven the farmers to ruin and promoted the Portuguese immigration in the 50's and 60's. After the Portuguese revolution in 1974, the political agriculture solutions and the strategic errors, for Alentejo region, was the same, implying the fertility loss and human and natural desertification.

Today the water changed the agriculture. The GBAS groundwater supplies almost all agriculture. Nowadays the farming land irrigation is a new source of income, allowing more and different type of crops, so the first farmers investment is searching water. The water run also promoted the development of the Alqueva Dam project, which will irrigate large areas of farming land inside and outside of GBAS.

Duque in 1997 made an inventory to define and identify: all possible areas of irrigated crops; the crops irrigation dotations; the ratios of used fertilizers as sources of contaminant loads of nitrate. Table 1 shows the areas and irrigation dotations for irrigated crops. Table 2 shows the standard amounts of fertilizers applied in dry cereals (DC), orchards/vineyards/olive-yards (OVO) and in

irrigated crops (IC). Table 3 corresponds to the partial and totals of nitrogen applied in DC, OVO and IC.

Table 1. The areas and irrigation dotations for irrigated crops in GBAS.

Irrigated crops	Real Irrigation dotation *m^3/ha/yr*	Effective irrigation dotation *m^3/ha/yr*	Irrigation efficiency *M^3/ha/yr*	Area *Hectare (ha)*
Wheat	5067	3040	0.6	662
Soybean	5583	3350	0.6	528
Orchard/vineyard	3267	1960	0.6	323.5
Lettuce	2520	1890	0.75	130
Melon	7000	5250	0.75	106
Green fodder	4200	3150	0.75	64.5
Maize	4200	3150	0.75	53
Tomato	3920	2940	0.75	21
Pasture	3500	2625	0.75	6.5

Table 2. The standard amounts of fertilizers applied in the GBAS agriculture areas. (For example the notation 18.46.0 means the rate of nitrogen/phosphorus/potassium).

Crops	Deep fertilization	Cover fertilization	2º Cover fertilization
All dry cereal crops (DC)	18.46.0 - 200 kg/ha or 20.20.0 - 300 kg/ha or 14.36.10 - 250 kg/ha	Urea a 46 % - 120 to 150 kg/ha + Nitro-ammoniacal at 26 % - 200 kg/ha	Urea at 46 % -80 kg/ha
Orchard/vineyard/olive-yard (OVO)	15.15.15 or 10.10.10 - 400 kg/ha or 7.21.21 - 300 kg/ha	Nitro-ammoniacal at 26 % - 150-200 kg/ha	Uncommon application
All irrigated crops (IC)	Like (DC)	Urea a 46 % - 200 kg/ha	Urea at 46 % 100 kg/ha

Table 3. Totals of nitrogen applied on DC, OVO and IC in GBAS.

Crops	Standard fertilization	Partial of nitrogen kg/ha/yr	Totals of nitrogen kg/ha/yr	Totals of nitrogen g/ha/day
DC	200 kg of 18.46.0 210 kg of Urea at 56% N_2H_4CO 300 kg of Nitro-ammoniacal at 26%	36 37.5 39	112.5	308.22
OVO	300 kg of 7.21.21 170 kg of Nitro-ammoniacal at 26%	21 43.2	64.2	175.89
IC	200 kg of 18.46.0 300 kg of Urea at 46% N_2H_4CO	36 89.5	89.5	245.21

Custódio (1982), Thierny & Seguin (1985) and Almeida & Silva (1987) considered that about 20 % of nitrogen applied in the agricultural soils usually reach the groundwater level. Assuming these criteria, the nitrate applied in 336.18 km^2 of the GBAS farming area, and after reaching the groundwater level it was about 2430 ton/yr or an average of 6.7 ton/day.

In order to evaluate the groundwater nitrate content it was collected and analysed 66 groundwater samples during the Summer of 1996, which corresponds to 26 large wells, 5 springs and 35 wells. These groundwater samples are very well distributed and representative of all the farming activities made in GBAS top soils.

Considering the European Community and the Portuguese legislation for human drinking water, the value of 25 mg/L corresponds to the Maximum Recommendable Value (MRV) and 50 mg/L corresponds to the Maximum Admissible Value (MAV), so the figure 2 represents the nitrate distribution and magnitude in GBAS taking in account the groundwater quality limits used for human drinking.

The table 4 shows the univariate statistics for nitrate in GBAS, and the figure 3 shows the histogram of the data set.

Almost 61 % of GBAS groundwater samples were above 50 mg/L (MAV) till a maximum of 143.3 mg/L. The mean is 63 mg/L and the median is 56 mg/L and the minimum is 4 mg/L.

Table 4. Univariate statistics for nitrate in GBAS (66 samples)

Parameter	Value
Mean	63 mg/L
Median	55.5 mg/L
Minimum	4.1 mg/L
Maximum	143.3 mg/L
1. Quartile	39.5 mg/L
3. Quartile	77.9 mg/L
Variance coeficient	51.15 %

Standard deviation	31.7 mg/L
Asymmetry	3.54 mg/L

The low values of nitrate in the west area corresponds to the a uncultivated zone in the aquifer.

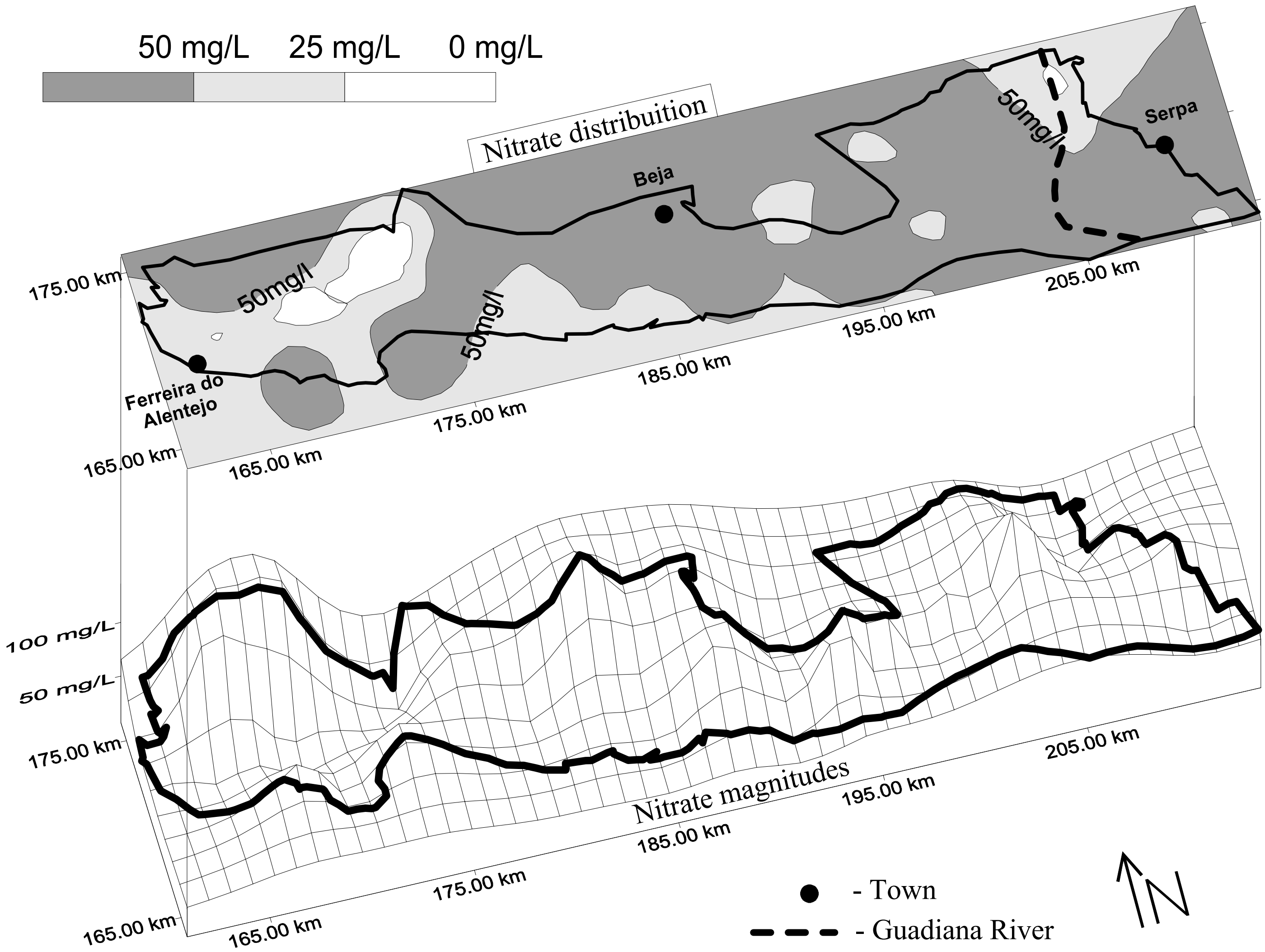

Figure 2. Distribution and magnitude of nitrates in GBAS groundwater considering the standards limits for human drinking (25 mg/L - Maximum Recommendable Value; 50 mg/L - Maximum Admissible Value).

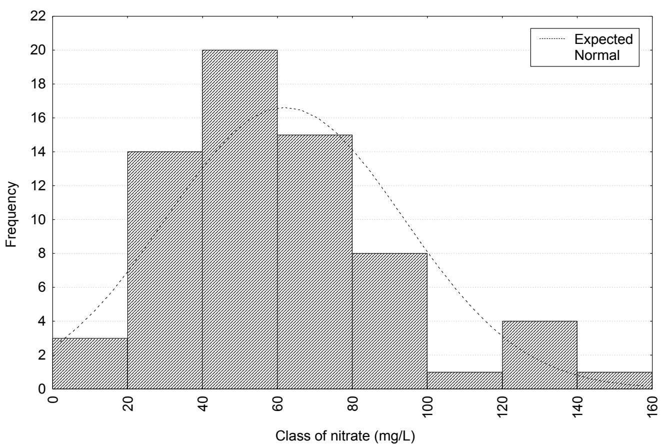

Figure 3. Histogram of the data set.

The results seems to show that the fate of some nitrate applied in the top soil reach the groundwater promoting high concentrations all over the aquifer.

However, in spite of being uncultivated, also the region of the Guadiana valley has high concentrations of nitrate, corresponding to an evident trend of contaminant transport through groundwater flow.

Almost GBAS has nitrate concentrations above 50 mg/L.

This situation has a great significance for human supply. Almost human supplies for little villages or private farms are based on groundwater of GBAS, and the agriculture and consequently the nitrate contamination still remains a problem. Due to this problem Beja changed the water supply to superficial water.

Many people drink water with nitrate with more than 100 mg/L. Unfortunately this problem could increase due the Alqueva Dam improvement. In few years this dam will supply almost irrigation, and the agriculture will be more intensive and extented.

The common groundwater annual renovation due to abstraction/ rain infiltration could run low and the aquifer would becomes in a contaminant agricultural reservoir.

4 CONCLUSIONS

The GBAS is one of the most important hard rock aquifer in south Portugal. The top soil is extremely productive and the farming activities are a unique source of income.

Diffuse contaminations are related to intensively irrigated crops as well as dry crops which demands large amounts of fertilizers like nitrate. The use of cheap azotised fertilizers, such as urea, implies high widespread due to their high mobility in soil and groundwater.

The standards of groundwater quality for human supply for nitrate concentration are overpassed; about 61 % of groundwater samples exceed 50 mg/L.

The nitrate contamination is a real problem in this area. Almost all human water supplies (public and private) are contaminated but the use of this water is still unquestionable and sometimes cause conflicts between public authorities and private interests.

Further works will be focused in flow and transport modelling, and research on desnitrification processes and water-rock interactions.

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REFERENCES

Almeida, C. C. & Silva, M. L. 1987. Incidence of agriculture on water quality at Campina de Faro (South Portugal), In Proc. *IV Simpósio de Hidrogeologia AEHS-GTH*. 5-9 Out. Palma de Maiorca, 1987: 249-257

Bulger, P. R., Kehew, A. E. & Nelson, R. A. 1990. Dissimilatory nitrate reduction in a waste-water contaminated aquifer. *Ground Water* 27(5): 664-671

Custódio, E. 1982. Nitrate build-up in Catalonia costal aquifers, In *Memories of International Symposium On Impact of Agriculture on ground water*: Vol. XVI. Part 1: 171-181

Gascho, G. J., Wauchope, R. D., Davis, J. G., Truman, C. C., Dowler, C. C., Hook, J. E., Sumner, H. R. & Johnson, A. W. 1998. Nitrate-Nitrogen soluble and bioavailability phosphorous runoff from simulated rainfall after fertilizer application. *Soil Sci. Soc. American Journal* 62: 1711-1718

Geng, Q. Z., Girard, G. & Ledoux, E. 1996. Modeling of nitrogen cycle and nitrate transfer in regional hydrogeologic systems. *Ground Water* 34(2): 293-304

Duque, J. & Almeida, C. 1998. Caracterização hidroquímica do sistema aquífero dos gabros de Beja. *4º Congresso da Água*. FIL. Lisboa: CD-164

Duque, J. 1997. *Caracterização hidrogeológica e modelação matemática do aquífero dos gabros de Beja.* Master Thesis. Lisboa. Faculdade de Ciências da Universidade de Lisboa.

Freeze, R. A. & Cherry, J. A. 1979. *Groundwater*. New York: Prentice-Hall Inc.

Korom, S. F. 1992. Natural denitrification in the saturated zone: A review. *Water Resources Research*, 28 (6): 1657-1668

Hamilton, P. A. & Helsel, D. R. 1995. Effects of agriculture on ground-water quality in five regions on the United States. *Ground Water* 33 (2): 217-226

Thiery, D. & Segin, J. J. 1985. First model of nitrate transfer over a river basin with a lumped model. In Memories of the 18th Congress of IAH - *Hydrogeology in the Service of Man*. Part III: 188-198