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Effect of the Climate and Soil Characteristics on the Nitrogen Balance in the North of Algeria

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1. Introduction

The regular growth of the nitrate concentrations observed in the superficial and underground waters since the years 70 is a topic of preoccupation (Gomez, 2002). This general increase is largely imputed to the agricultural activities, which knew deep modifications.

The agricultural pollution is problematic because of its diffuse character. Of this fact, the solutions can be only preventive while reconciling effective agriculture (establishment of balance to assure the good management of nitrogen in soil) and quality of water using regimentations.

Numerous research elaborated methods of balances of the nourishing elements to develop a lasting agriculture (Parris, 1998). However, the principles that found these balances are very variable, so much to the level of the sought-after precision (choice of the fluxes and parameters took in account and simplifying hypotheses), of the scales of the study (country, exploitation, rotation, parcel), or the length of observation (season, year, etc.) (Van Bol, 2000).

The nitrogenous balance method permits the nitrogenous excess calculation that constitutes the quantity of available remaining nitrogen in soil, capable to be leached toward the aquifer. We have three predominant types of nitrogen contribution: the contributions bound to the mineral fertilizers and the irrigation (Benoît et al., 1997; Sivertun & Prange, 2003; Delgado & Shaffer, 2002), the contributions bound to the breeding and finally the contributions bound to the municipal waste water.

However, the fate of nitrogen in the middle depends on the type of soil, of the type of culture, of the bacterial activity in soil, of the out-flow of water in the matrix of soil and the environmental conditions (Pinheiro, 1995). There are strong interactions between these factors, but environmental conditions, as the temperature, the humidity, the pH, the dissolved oxygen, will play essential roles.

Large quantities of inorganic and organic N- fertilizers are applied each year in agricultural areas (Feng et al., 2005; Elmi et al., 2004; Sivertun et Prange, 2004; Delgado et Shaffer, 2002), which increases the threat from NO_3^- contamination in groundwater. Several processes can manage these quantities of nitrogen in the nature (Tremblay et al., 2001).

The losses of nitrogen are bound to the absorption by the culture that depends on the climate, of the nature of the cultures (Weier, 1992), their stage of growth (Haynes, 1986), the content of the other nourishing elements in soil and the availability of the soil water (Tremblay et al., 2001).

Machet et al., (1987) note that 40 to 60% of nitrogen absorbed by the plants come from the soil nitrogen. Tremblay et al., (2001) note also that even in the best conditions, the plants are not capable to absorb more than 80% of nitrogen contained in the fertilizer applied. The availability of water in soil encourages the absorption of water and nitrates by the plants, various process, either the volatilization, the denitrification and the leaching don't let the rest accessible.

The losses by volatilization depend on conditions of soil (pH, capacity of exchange, porosity, humidity) and of the climatic conditions (Sommer et al., 1991). At the time of mineral fertilizer's application, the losses are less important. The fertilizers which contain the urea entail the volatilization as well as the nitrate of ammonium, the diammonic sulphate and the chloride of ammonium. In this case, the losses can reach 40 to 50% of nitrogen applied in the conditions of chalky soil, of pH> 7.5 and of elevated temperature (Tremblay et al., 2001; Hargrove, 1988).

However, the urea remains the fertilizer that frees the strongest quantities of ammonia in the atmosphere, producing 72% of the quantities freed by the application of fertilizers (Environment Canada, 2000).

The denitrification occurs in soils poor in oxygen, as the swamps, the peaty soils and soils badly drained and is encouraged by elevated temperatures (> 15°C). It is inhibited for a temperature lower to 8°C, what explains the existence of the maximal nitrogen stock in winter (Payraudeau, 2002).

The denitrification is influenced by the environmental conditions as the temperature, the humidity, the content in organic matter of soil (Rassam et al., 2008; Addy et al., 1999), the availability in oxygen (Smith & Tiedje, 1979), the morphology of soil, the pH (Standford et al., 1975) or the activity of the microorganisms (Firestone, 1982). This process can be increased strongly in irrigated cultures that permit to gather several favorable conditions: the presence of fertilizers, the elevated humidity level, the organic product contribution at periods where the temperature is favorable to the microbial activity.

In Western middle Cheliff valley (North of Algeria), Agriculture is the dominant activity. The agricultural land surface constitutes 67% of the total and the main cultures are arboriculture and the garden farming. The alluvial aquifer situated in centre of this zone is exploited for the drinking water supply, the irrigation and industry. In this study, we try at first to show the spatial evolution of nitrate, through a map established by ordinary kriging method for the year 2004 in periods of high water.

Secondly, we try to estimate, for this year, the total contribution of nitrogen present on soils of the valley. It supposes to estimate nitrogen brought by N-fertilizers used extensively in garden farming, potatoes in particular, by water of irrigation from individual wells, by breeding and by municipal waste water.

2. Materials and methods

2.1 Characteristics of study area

The zone of study is located in North-Western Algeria, approximately 200 km to the west of Algiers, and 30 km away from the Mediterranean. It occupies a territory of 300 km^2 approximately in the basin of Western Middle-Cheliff (Fig. 1).

The area is characterized by a semi-arid climate. The infiltration deduced from the surplus water constitutes 7% (25 mm) of total rainfall (361 mm).

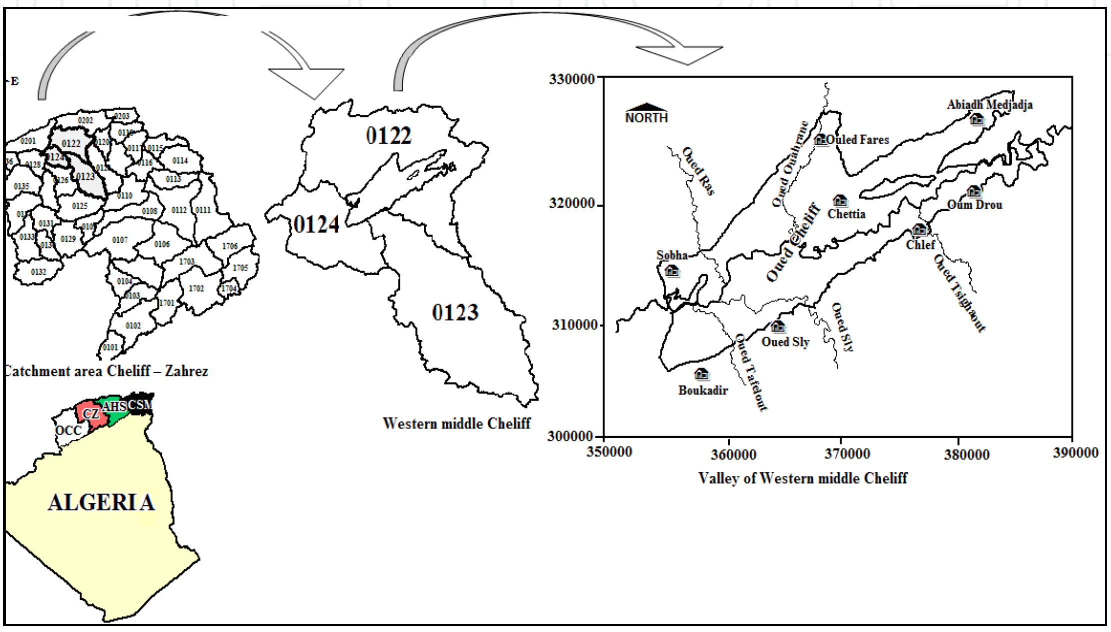


Fig. 1. Location map of study area

The alluvial aquifer situated in centre of this zone is formed by coarse alluvia of age Pliocene Quaternary forming the embankment of the valley (Fig. 2).

It is exploited for the drinking water supply, the irrigation and industry with an annual volume of 15 Million m^3. The depth of water varies between 4 and 65 m with an average oscillating around 22 m.

2.2 Types of soil

Two big wholes of soils are observed:

- Soils of the borders of the valley; They have a balanced texture (25% sand, 35% silt and 40% clay), are deep and structured and present high hydraulic conductivity with elevated pH (8) (Scet Agri, 1984).
- Soils of plain, alluvial, with variable texture, locally clayey. The heavy soils (> 40% of clay on average) are important on the more recent alluvial formations as the plain of Boukadir, northwest of Wadi Sly and southwest of Ech-Chettia. These soils are chalky (21% of $CaCO_3$) with a very high pH (8.3).

The C/N report for the two types of soil denotes a good mineralization, of a weak rate of nitrogen mineralizable bound to the weak content in organic matter.

The agricultural land surface constitutes 67% of the total of which 65%, either 11700 ha, are irrigated effectively. The main cultures are arboriculture and the garden farming; this last, located near the borders of area study, is a large consumer of N- fertilizers and irrigation relies mainly on groundwater.

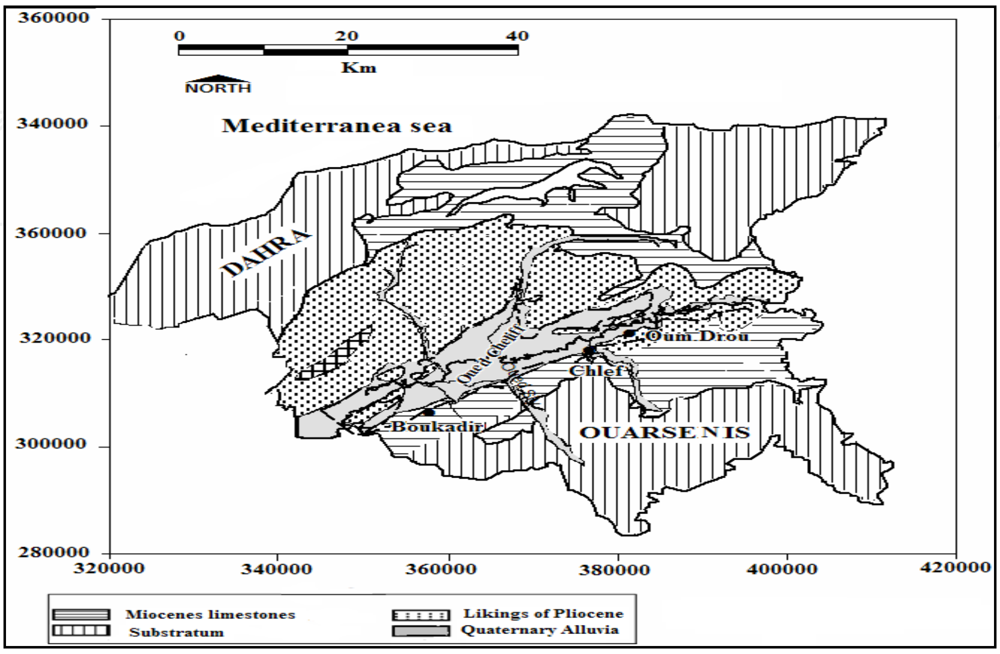


Fig. 2. Geological context of study area (Perrodon (1957) & Mattauer (1958))

3. Results and discussion

3.1 Space-time evolution of nitrates

3.1.1 Origin of the data

The study of the evolution of the contents nitrates was undertaken to highlight the former stages of enrichment of water of the studied aquifer which has ends in the current situation. We collected near the service of the National Agency of hydraulic resources the chemical analyses of the major elements corresponding to the taking away carried out on collecting belonging to the inspection network managed by this organism. The data are available for the years 1992, 1993, 1994, 1997, 1998, 1999, 2002, 2003, in addition to the results of analyses which we carried out to us even during the year 2004 in periods of high and low water.

3.1.2 Evolution of the nitrate concentrations groundwater between 1992 and 2004

Four classes of nitrate concentrations are distinguished for the campaigns previously described (Fig. 3):

- Lower than 25 mg/l (represented in blue): water of optimal quality to be consumed;
- Between 25 and 50 mg/l (represented in green): acceptable water of quality to be consumed;
- Between 50 and 100 mg/l (represented in orange): non-drinking water, disadvised for nourrissons and women enclosure, a treatment of potabilisation is necessary before distribution;

- Higher than 100 mg/l (represented in red): water disadvised for all the categories of population, the potabilisation is impossible.

It clearly appears, according to the figure 3, that at the beginning of the years nineteen, more half and until two thirds of the sampled wells offered water of optimal quality to acceptable for drinking. On the contrary, the percentage of well with which water is excessively charged of nitrates represent, with the average, just 9% of the whole of these wells. At the end of this decade, the percentages of well pertaining to the first two classes narrowed with the profit of the third classifies in particular (which represented more than 34% to the average) and in a less way of the last (12% approximately).

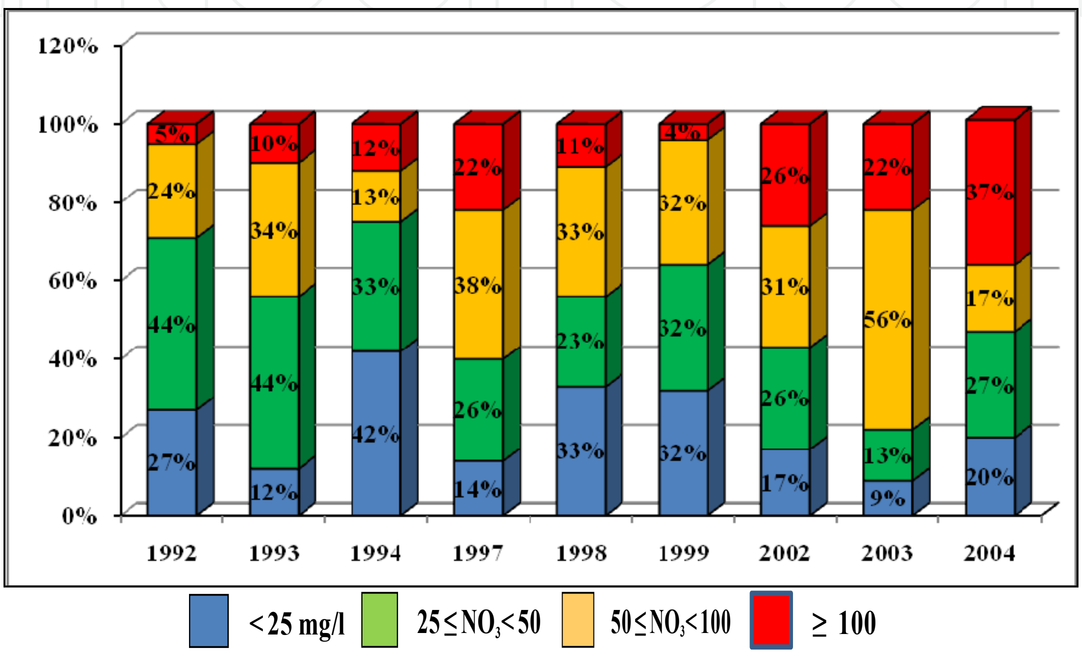


Fig. 3. Proportion of well per class of nitrate concentration

The contracting of the classes of good quality for drinking is accentuated more during the years 2000 to reveal clearly the class of contents nitrates higher than 100 mg/l with a percentage of rather significant well (around 28%).

The number of offering well of non-drinking waters (> 50 mg/l) is thus significant and rises to 63% of the whole of the sampled wells.

It is clear according to this report that the total tendency of the evolution of the nitrate concentrations of water of this aquifer represents a progressive temporal degradation of the quality of this water intended for drinking and/or the irrigation.

The description of the current state of the water quality of this aquifer proves also significant. This is why, a space distribution of the maximum contents nitrates is established for the year of study (between high and low waters of the year 2004).

3.1.3 Maximum contents nitrates of the year 2004

The maximum contents nitrates of the 34 wells to both campaigns of the year 2004 (high and low waters) are distributed in the following way (Fig. 4):

- The number of wells whose maximum content is higher than 25 mg/l is 28, that is to say 82%,
- The number of points whose maximum content is higher than 50 mg/l is of 19, that is to say 56%,
- The number of wells whose maximum content is higher than 100 mg/l is 11, that is to say 32%

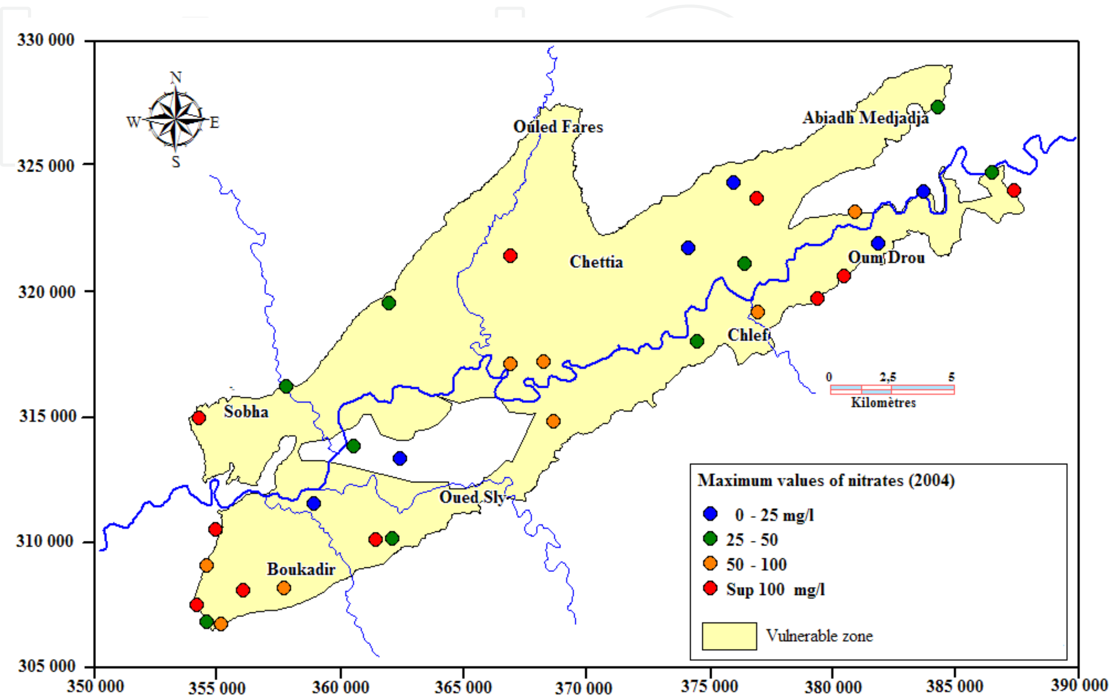


Fig. 4. Space distribution of the maximum contents nitrates (year 2004)

3.1.4 Evolution analysis of the contents nitrates from 1992 to 2004

The number of common wells whose respective contents are indicated is 20. From 1992 to 2004:

	A number of points whose evolution of the contents (Δ) is				
Variation of NO_3 (mg/l)	**in reduction**		**stable**	**in increase**	
	Δ≤-5	-5<Δ<-1	-1≤Δ≤+1	1<Δ<+5	+5≤Δ
Number of wells	7	1	0	0	12
	8		**0**	**12**	

Table 1.

- the number of wells whose nitrate content is higher or equal to 50 mg/l evolved from 30% to 45%.
- the evolutions of nitrate contents for the same 20 wells are distributed in the following way:

This highlights:

- A tendency to degradation on 12 wells (60 %) with increase of content higher than 1mg/l (Fig. 5),
- A tendency to the improvement on 8 wells (40 %) with a reduction of content least 1mg/l.

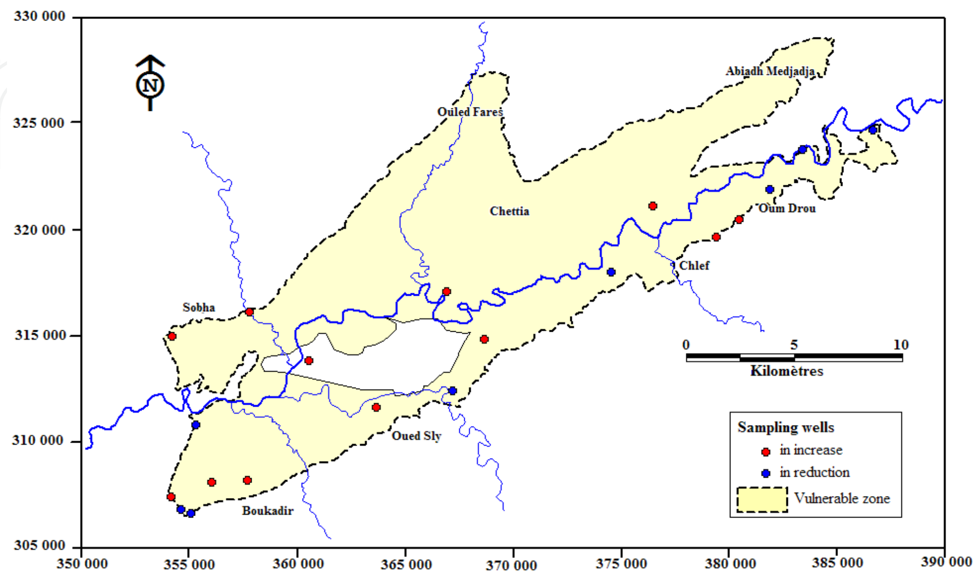


Fig. 5. Evolution of the contents from 1992 to 2004

The annual evolution of the average of the 12 wells in increase is of 3.16 mg/l per year, with like specific evolution between the two campaigns the contents of nitrates between 1992 and 2004 (Fig. 6):

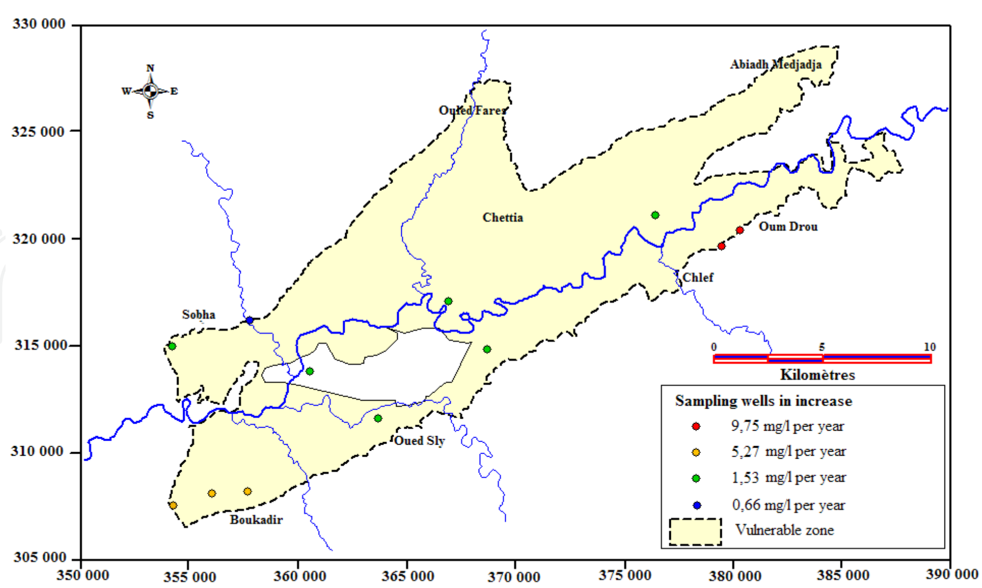


Fig. 6. Specific evolution of the contents nitrates wells in increase (1992-2004)

9.75 mg/l per year for 02 well, 5.27 mg/l per year for 03 wells, 1.53 mg/l per year for 06 wells, 0.66 mg/l per year for 01 well.

The excessive increases characterize Oum Drou (zone of horticulture) and the Boukadir downstream which coincides with the hydraulic downstream.

The global tendency of the evolution of the concentrations in nitrate of the waters of the alluvial aquifer of the middle western Cheliff translated a progressive temporal deterioration of the quality of these waters destined for the drinking and for the irrigation, since the percentage of well sampled during these last years offering non drinkable waters (> 50 mg/l) rose from 40% in the average to 63%.

3.1.5 Map of nitrates

Adjustment by a right of the points cloud between the measured values of nitrate and the residues (Fig. 7) show that the general tendency of the estimation is marked by a strong misjudgement of the values raised from NO_3; thus, all values that are superior or equal to 100 mg/l are underestimated systematically.

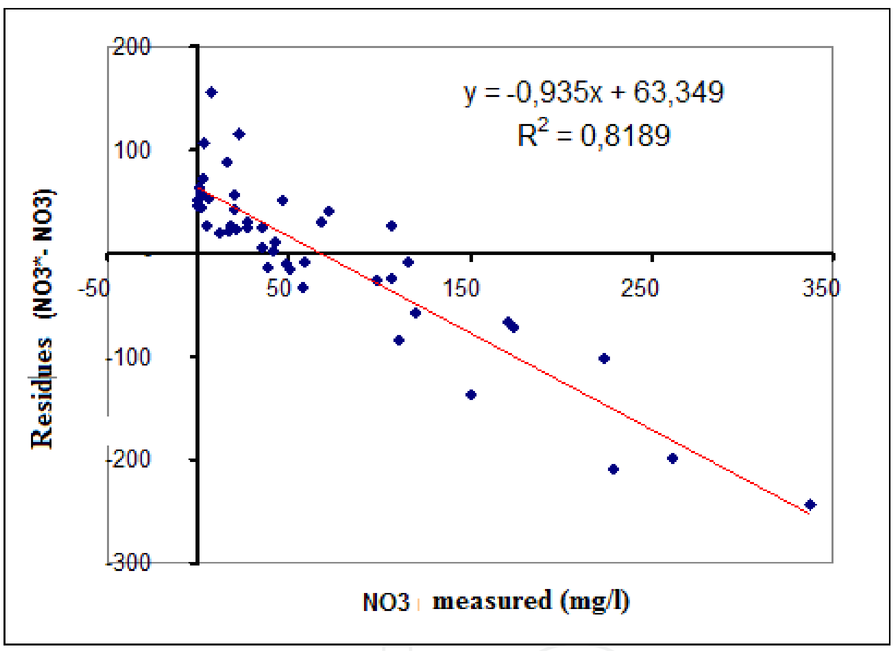


Fig. 7. Relation between NO_3 measured values and residues

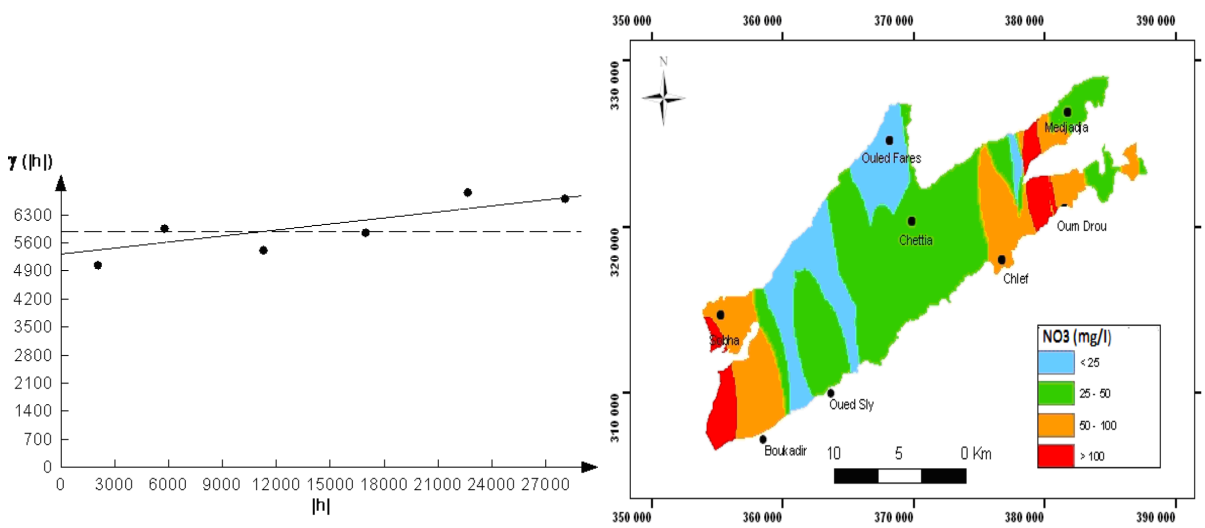
3.1.5.1 Ordinary kriging

The experimental middle variogram was calculated on a distance of 28000 m without reaching a range (Fig. 8a). This variogram was adjusted with a linear model of 5300 of nugget with the same order of magnitude as the variance, thus translating a very high local variability (Douaoui et al., 2006).

It appears according to the map of nitrate established by ordinary kriging (OK method) (Fig. 8b) that the most affected zones are those for which the level of intensification of the N-fertilization (zones of garden farming) are the strongest (township of Sobha, Boukadir downstream, the southeasterly extension (to the west of Oum Drou), the plain of Medjadja) under the old alluviums and soils of borders area study characterized by the strongest permeabilities (10 cm/h). This strong hydraulic conductivity has for consequence that the transportation of waters of infiltration toward the deep layers makes itself very quickly

(Rahman, 2008; Giroux, 2003) and the sensitivity of these soils to the phenomenon of washing of the nitrates is therefore very elevated. In these same zones, the practices of breeding are more intensive

The map shows also a general bottom lower to 50 mg/l characterizing the centre of the area study. Soils in this zone have fine texture and weak permeability varying between 0.5 and 2 cm/h. the thick clayey profile that surmounts the aquifer in this zone and the weak yearly infiltration (25 mm) recorded in general in the semi-arid zones, seem to play an important role in this sense (Bettahar et al., 2009). In this same part, arboriculture concentrated in this part of area study is irrigated from dams waters of which the concentrations in nitrate are weak.



(a) (b)

Fig. 8. Variogram and Map of nitrate concentrations estimated by Ordinary kriging (OK) method

3.1.5.2 Indicator kriging

The map established by Indicator Kriging (IK) method (Fig. 9) shows that the geographical distribution of the classes 50-100 and > 100 mg/l is generally the same that the one gotten by OK method. However, we observe an improvement in the elevated value surfaces (the class 50-100 mg/l) to the profit of those of the values excessively elevated (the class > 100 mg/l), weakly of the middle values (the class 25-50 mg/l) and even of the weak values (the class < 25 mg/l) in the low valley of the Ouahrane wadi. This zone is known by a strong agricultural activity (zone of garden farming, potato in particular benefitting from a phenomenal N-fertilization).

3.1.5.3 Comparison between the OK and IK methods

The quality of the estimation by the two types of kriging rests on the comparison between the surfaces estimated by every type (Fig. 10). The surfaces of the nitrate classes gotten by IK method compared to the OK show a reduction in the non contaminated surfaces and in the same way an increase of the surfaces very contaminated

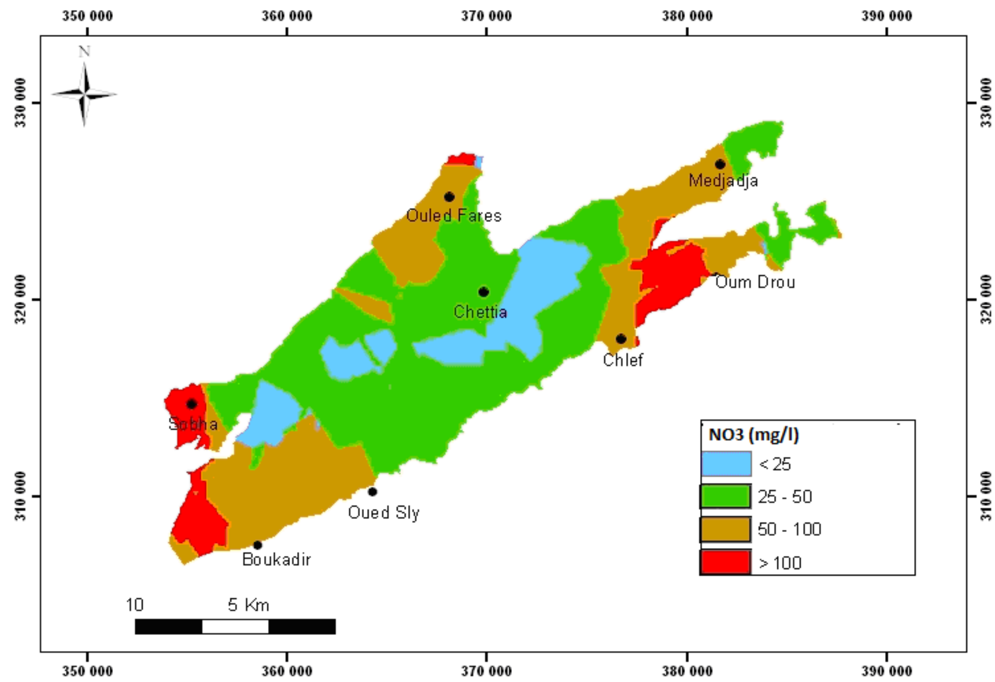


Fig. 9. Map of nitrate concentrations estimated by Indicator kriging (IK) method

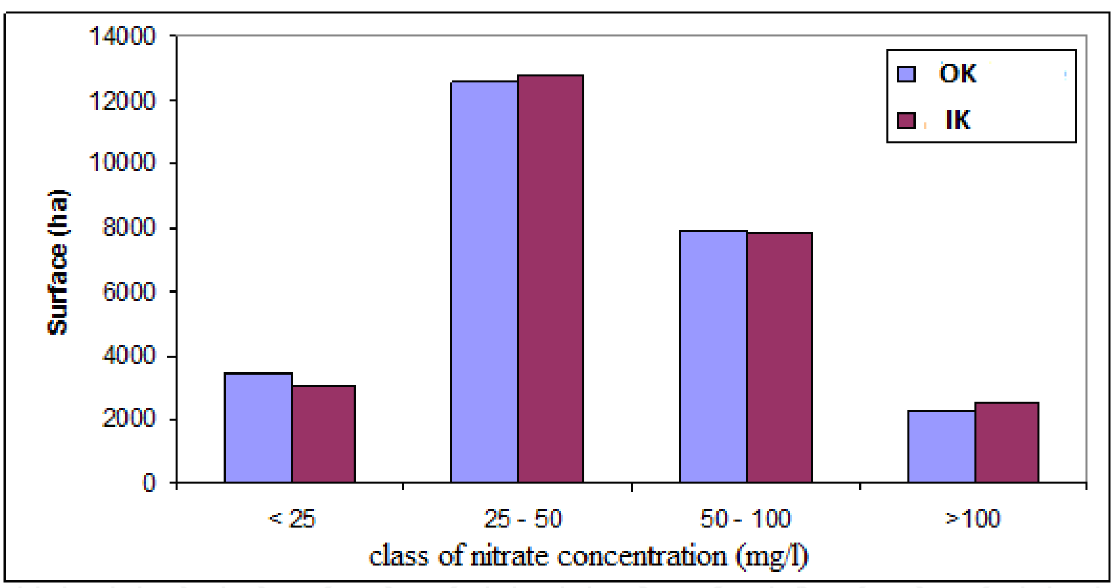


Fig. 10. Comparison between the surfaces of NO_3 classes gotten by OK and IK methods

3.2 Quantification of the nitrogen contributions

3.2.1 Contributions from N-fertilizers

The industrial chemical fertilizers, particularly, the NPK 15.15.15 is predominant for the quasi - totality of the exploitations with yearly middle doses of 500 kg ha^{-1} for arboriculture and until 1000 kg ha^{-1} for the potato.

The uses of other N-fertilizers as the urea (46%) and the sulphate of ammonium (21%) are estimated as high as 50-600 kg ha^{-1} for the cereals, arboriculture and the garden farming.

The quantity of nitrogen gotten for every type of culture (Fig. 11) is deducted of the product of the dose of fertilizer that it receives by the corresponding surface.

3.2.2 Contributions from the water of irrigation

The surfaces of the garden farming and cereals are irrigated from the waters of wells of which NO3--N concentrations exceed the potability standard of 50 mg/l (Martin, 2003).

The total quantity of nitrogen brought by the water of irrigation represents only 3% of the one produced by the N-fertilizers (Fig. 11).

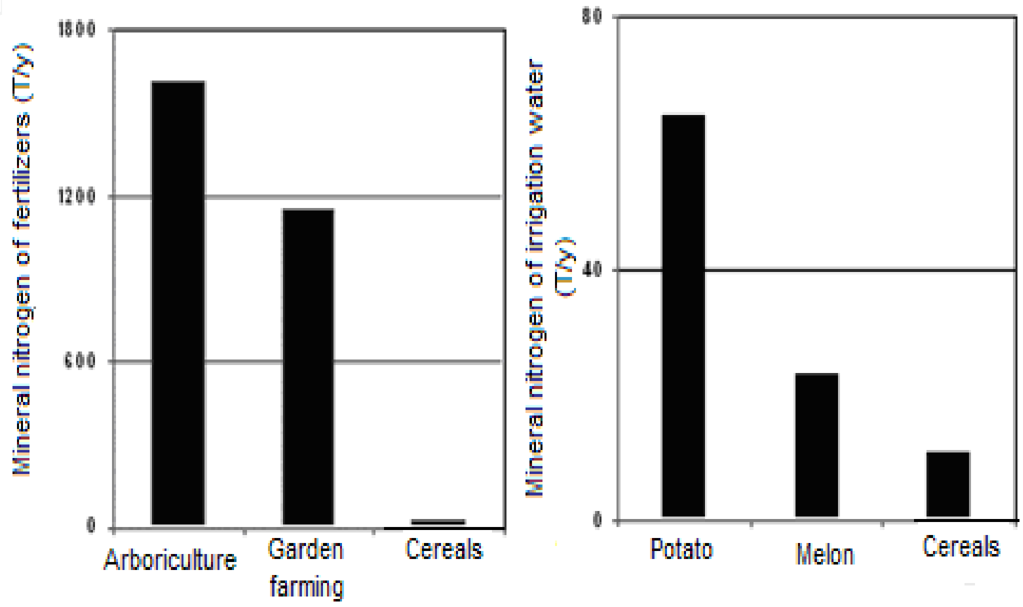


Fig. 11. Annual mineral nitrogen contribution

3.2.3 Contributions from breeding

The exploitations of the breeding for the different animal species (bovines, ovine, goats and poultries) are located in the borders of the valley (in the townships of Ouled fares, Abiadh Medjadja, Sobha and Boukadir). The calculation of the yearly total quantities of organic nitrogen generated by the set of every animal category is based on the values of nitrogen produces annually by head for every species, proposed by the CORPEN (Parris, 1998].

3.2.4 Contributions from municipal wastewater

Organic nitrogen estimated for Individual septic tank systems constitutes only 5% of the one generated by the breeding (Fig. 12).

3.2.5 Total contributions in nitrogen

Nitrogen brought by agriculture (fertilizers and water of irrigation) constitutes 86% of the total nitrogen brought to the soils of the valley. 97% of this last is attributed to nitrogenous fertilizers used extensively in garden farming, potatoes in particular. Extrapolated to the total irrigated area, this contribution is estimated at 238 kg ha^{-1} yr^{-1}.

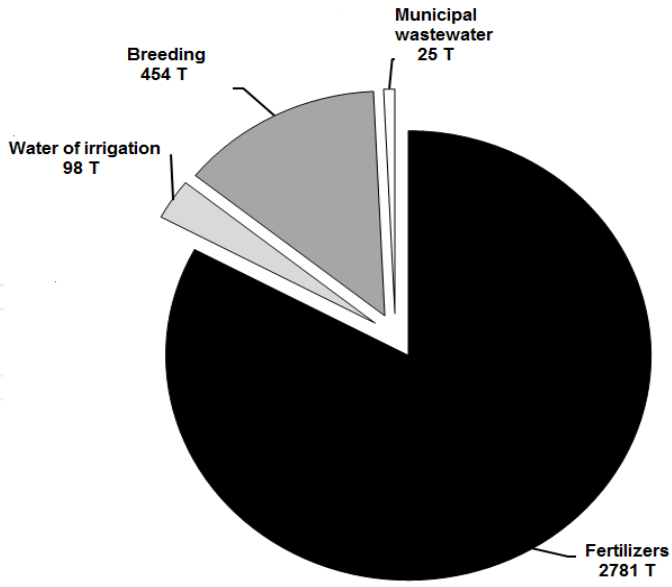


Fig. 12. Annual nitrogen contribution (mineral and organic)

3.3 Effect of the climate and soil characteristics on the nitrogen balance

The nitrogenous balance method proposed by the COMIFER (1996) and the CORPEN (1988), permits the nitrogenous excess calculation whose general formula can be given by the following equation:

$\sum$ *ENTRIES* - $\sum$ *EXITS* = natural Contributions + non natural contributions - A - V - D - L
With A=Absorption by the plants, V= volatilization, D=dénitrification and L = Leaching.

3.3.1 The entries

3.3.1.1 Natural contributions

a. Atmospheric nitrogen contributions: Nitrate concentration of the precipitations falling on the study area doesn't pass 2 mg/l (Ikhlef, 2008). This weak concentration doesn't seem to influence the entries.
b. Contributions by mineralization: The organic matter rate is very weak on the soils of the study area (< 2%); this last will continue to decrease in the time in parallel with an increase of the speed of mineralization by effect of the semi-arid climate. The two phenomena decrease the capacity of soil to provide nitrogen by mineralization.

3.3.1.2 Non natural contributions

They constitute the sum of contributions from N-fertilizers, the water of irrigation, the breeding and municipal wastewater. They are valued to 3358 T yr^{-1}.

3.3.2 The exits

3.3.2.1 Absorption by the plants

If we keep the lower doorstep of the absorption rate (60%) of nitrogen contained in fertilizers recognized by Tremblay et al., (2001), the quantities of nitrogen absorbed by the plants in study area from the different fertilizers applied would be the order of 1669 T yr^{-1}.

3.3.2.2 Volatilization

The losses by volatilization depend on conditions of soil (pH, capacity of exchange, porosity, humidity) and of the climatic conditions (Sommer et al., 1991).

The losses by volatilization at the time of the application can reach 40 to 50% of nitrogen applied in the conditions of chalky soil, of pH> 7.5 and of elevated temperature (Tremblay et al., 2001; Hargrove, 1988). However, the urea remains the fertilizer that frees the strongest quantities of ammonia in the atmosphere, producing 72% of the quantities freed by the fertilizers (Environnement Canada, 2000). In the study area, the quantity of nitrogen that could be volatilized from the urea, for a doorstep of 40%, would be the order of 307 T yr $^{-1}$, either about 11% of the total of nitrogen (2781 T).

3.3.2.3 Denitrification

The fraction of nitrogen lost by denitrifiocation given N_2O is located particularly on soils badly aired to basic pH, in the conditions of elevated temperature (> 15°C). For a middle doorstep of 20% advanced by the works of Trembley and al. (2001) the fraction of applied mineral nitrogen capable to be topic to the denitrification in the study area would be meadows of 556 T yr $^{-1}$.

3.3.3 Effect of the climate and soil characteristics in semi-arid regions

In the semi-arid regions with strong agricultural activity, it is necessary to take always into account some entries: nitrogen brought by fertilization, nitrogen brought by the water of irrigation whatever weakly (Bettahar et al., 2008). It is generally useless to include nitrogen coming from the precipitations or the mineralization.

In the same way, it is indispensable to take into account some exits in the calculation of the nitrogenous balance: the quantity of nitrogen absorbed by the culture, the denitrification and the volatilization. The stape of calculation of the nitrate quantity leached is not always essential since the infiltration is very weak in these regions.

The risks of nitrate pollution in aquifers of the valleys in semi-arid climate seem bound closely to the climatic conditions and soil characteristics. Indeed, important quantities of nitrogen brought annually to the soils of Western middle Cheliff valley by different practices (agriculture, breeding and municipal waste water), don't reach the aquifer because of the climate and the soil characteristics.

The contribution of nitrogen by mineralization is weak, because of the reduction in the time, of the organic matter of soil in parallel with an increase of the speed of mineralization by effect of the semi-arid climate. The quantities of nitrate leaching in the aquifer, deducted of the nitrogenous excess, remain weak because of the weak yearly refill of the aquifer (25 mm only), direct consequence of the semi-arid climate of the study area and to the nature of soils whose hydraulic conductivity is weak (0,2 - 0,5 cm/h) on big surfaces of the valley.

4. Conclusion

Some knowledges have been acquired on the answer of the soils of Western middle Cheliff valley to the contributions of nitrogen coming from different origins. Indeed, the soils of borders, show a vulnerability more raised to the leaching of the nitrates seen their elevated permeability and that oscillates around 10 cm/h. Indeed, the nitrate concentrations in the aquifer are there the most elevated (> 100 mg/l).

On the contrary, the soils of the plain (center of the valley) seem less vulnerable to the nitrate leaching; they have fine texture and weak permeability varying between 0.5 and 2 cm/h. It could attenuate the propagation of the nitrates strongly in depth. The thick clayey profile that surmounts the aquifer, in this part of the valley seems to play an important role also in this sense.

The chemical characteristics of the soils of the valley, notably the pH and the rate of limestone, can strongly encourage important losses of nitrogen through processes as the volatilization and the denitrification. These last can appear very increased seen the temperatures excessively elevated in the Cheliff plains in the months of August and September, period of irrigation of the garden farming very developed on the borders of the valley, potato in particular, by the well waters greatly loaded in nitrate.

In the semi-arid regions characterised by a strong agricultural activity, it is necessary to take always into account some entries: nitrogen brought by fertilization, nitrogen brought by the water of irrigation whatever weakly. It is generally useless to include nitrogen coming from the precipitations or the mineralization.

In the same way, it is necessary to take into account some exits in the calculation of the nitrogenous balance: the quantity of nitrogen absorbed by the culture, the denitrification and the volatilization particularly for the chalky soils with a basic pH. The calculation of the quantity of nitrates leaching is not always essential since the infiltration is very weak in these regions.

Although the risks of nitrate pollution in the aquifers of the valleys in semi-arid climate seem lessen, even with phenomenal contributions of nitrogen (3000 T annually in the case of the study area), because of the climate and of the physical and chemical characteristics of soil, these waters are not completely safe from nitrate contamination.

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