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ASSESSMENT AND MODELING THE INFLUENCE OF NITROGEN INPUT IN THE SOIL ON GROUNDWATER NITRATE POLLUTION: PLAIN OF UPPER- CHELIFF (NORTH ALGERIA)

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ABSTRACT

The present study associates groundwater nitrate pollution with agricultural activity in the Upper-Cheliff wich is known for intensive farming practices. The indicatory kriging method is used in order to elaborate a map of the spatial probability distribution of nitrate concentration that exceeds a threshold value of 50ppm during high watering period for the year 2012. The obtained results show that the areas exceeding nitrate concentrations of 50 ppm, occupy more than 80% of the Upper-Cheliff aquifer area. It appears, from this map, the most affected areas are those for which the level of intensification of the N-fertilizers is the strongest (zone of garden farming, potatoes in particular) throw condensed.These results are coherent with the experimental data, which show an average nitrate concentration value of 75 ppm, significantly higher than the World Health Organization (WHO)'S standards.

In this study, the total nitrogen brought to the soils of the Upper-Cheliff is estimated at 247 kg ha^{-1} for this year, and compared to the results of New Computer models such as PILOTEN used to analyze alternative management practices together with soil, plant, and climate characteristics to determine the amount of nitrogen leached under the potatoes crops. The result of this model show that 60% of nitrogen input is leaching under potato crops which is relevant to the map showing the spatial evolution of nitrate. Nitrate pollution in the groundwater of the Upper-Cheliff appears to be significant and driven by the application of both inorganic fertilizer and land use.

Keywords: fertilizers, indicatory kriging, Nleaching, nitrate pollution, modeling, PILOTES, potatoes

1. Introduction

Groundwater nitrate (NO_3^-) contamination is increasing rapidly with the ever-increasing massive industrialization, urbanization, and the agricultural expansion with its associated activities that pose high pressure on groundwater resources (Wallis et al., 2011). Previous studies on different aquifers in Algeria (e.g. Kettab, 2005; Hadjouj, 2008) have identified the overuse of nitrogen (N) fertilizer to be one of the main sources for groundwater nitrate. It is often associated with intensive farming. (Bettahar *et al.*, 2009).

In the plain of Upper-Cheliff located in the North of Algeria Algerian where the main activity revolves around agriculture, the nitrate pollution threatens water resources. With a total annual volume of agricultural production around 1.5 million tons, agriculture is certainly the main practice of excellence in the region. Potato, covered nearly half (48%) of the total agricultural production of Upper-Cheliff and provides more than 40 % of the national production of potato, which is a major consumer of nitrogen fertilizer.

This work aims to visualize the extent of the pollution and to determine its origin and the main mechanisms that govern it. For this, we conducted a measurement campaign in May 2011 on a set of 53 water points (wells and drilling) irregularly distributed, showing the spatial evolution of nitrate through a map established by indicatory kriging method in periods of high waters. A field investigation was carried out in parallel to estimate the total contribution of nitrogen present on soils of the Upper-Cheliff It is supposed to estimate nitrogen brought by N-fertilizers used extensively in garden farming, potatoes in particular.

Due to the complexity of the nitrogen cycle in water-soil-plant systems, the PILOTEN model was selected to calculate the nitrogen balance and simulate N leaching from a potato cropping.

2. Materials and Methods

2.1. Study area

The study area is located in the north-west of Algeria. It is bordered to the south by the foothills of the Ouarsenis chain and north by the mountains of Zaccar, east and west.respectivelly by the massives of Gantas and Doui It occupies a territory of 370 km^2 approximately in the basin of Cheliff (Fig.1).

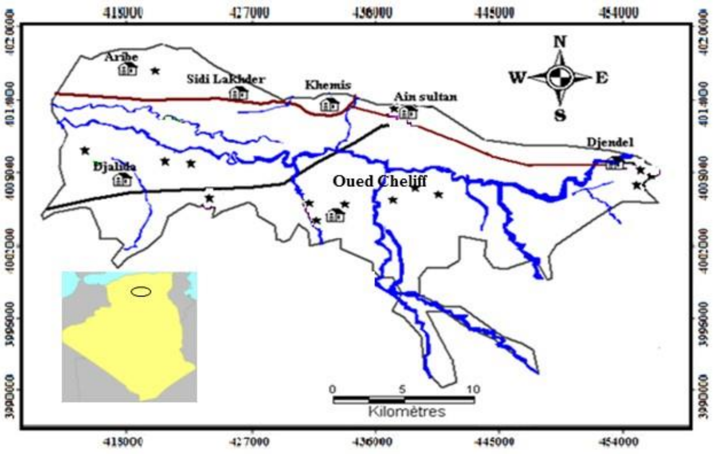


Figure 1. Location map of study area

This area has a typical Mediterranean semi-arid climate with long hot summer and short warm, winter. The considerable difference between the monthly maximum temperature ranging from (46 ° C) in July to (0 °C) in January, reflects a marked continental aspect, despite its proximity to the sea because the massive of Zaccar isolates the Upper-Cheliff from the influence of the Mediterranean.

The water balance established in 2011 (station of Harraza) indicates a relatively high evapo-transpiration and water deficit with 923.38 mm and 562.58 mm respectively. The infiltration deduced from the surplus water constitutes 5% (25 mm) of total rainfall (203 mm)

2.2. Hydrogeological context

Quaternary is an alluvial aquifer forming the embankment of the plain including sand, gravel or clay and sandstone with a maximum depth of 120 m. It is exploited with an annual average volume of approximately 19.4 hm^3 (ABH, 2011), It is used for drinking water supply (32%), irrigation (61%) and industry (7%). (Perrodon, 1957;Mattauer, 1958).

In the study area, Lithologic descriptions (ANRH, 2011) indicate that the alluvial sequence is made of gravels and sands with interbedded clay layers of the plain of recent Quaternary. These layers are located in the north and south of the valley with average thicknesses between 8 and 10 m. To the north and west there is a thick clay profile that offers low permeability. Instead, on the edges of the valley, more permeable layers are the unsaturated zone.

The monitoring network with 49 wells and four piezometers enable study of the chemical changes in the water mass and groundwater levels. Water samples were collected in the period from late May to early June, 2011.

The piezometric map established for this period shows closed curves in the center of the plain and open to the edges (Fig.02). Generally, the groundwater flows from east to west. The piezometric level is high in the east of the plain an became weakely to the west. Depressions are observed in the east of the plain due to the effect of intensive pumping for agricultural purposes.

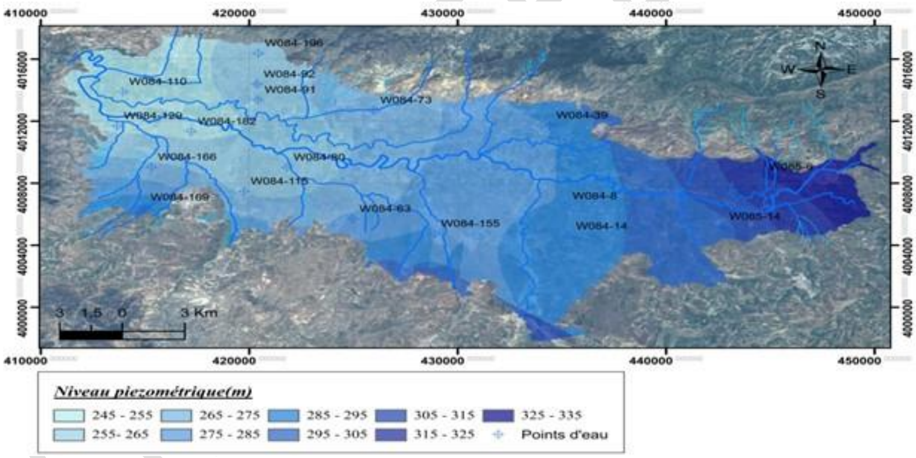


Figure 2. Hydrogeological context of the Upper-Cheliff

In addition to the meteoric water, the aquifer gets a significant piezometric level in the north from the Jurassic limestone manifested by a strong gradient (0.9%) in a northeasterly direction. It receives another lower supply from the Cheliff river and tributaries (Deurdeur, Souffay, Boutane), with a gradient (0.7%).

2.3. Soil context

The soil studies related to the Cheliff Valley which is an alluvial plain with high agricultural potential are numerous (Boulaine, 1957b; Daoud, 1993), soils often have a structure of average to poor stability (Haddaj, 1970; Derdourn, 1983).

These soils are poorly differentiated, more or less calcareous with variable textures, sometimes with local hydromorphism aspects, also the presence of vertic soils. (Boulaine, 1956; Daoud, 1993).

There are two big classes of soils:

- piedmont Soils only observed on the borders of the valley, with a balanced texture (40% sand, 35% silt, 25% clay), well structured and having therefore a very good permeability. The high permeability of these soils results in the quick transport of water infiltration into the deeper layers. The dwelling time of water in the surface layers is very short, so that nitrates are leached faster than the speed of biological processes.
- Soils of the plain (alluvial) have generally locally variable clay texture. Heavy soils (≥ 40% clay on average) are important in the most recent alluvial formations such as plain Djellida and the left bank of the plain of El Khemis they may show signs of water logging and salinity (conductivity between 2 and 72 dS m^{-1}) related to a local deficient internal drainage, causing the decline in already low permeability.

Table 1. Soil characteristics (surface horizon: 0--30 cm)

	pH	C.E (dS m^{-1})	$CaCO_3$ (%)	Organic matter (%)	Clay (%)	Silt (%)	Sand (grittiness) (%)
0-30 cm Soil layer	7,7	1,4	3,17	2,3	32	43	25

2.4. Land Use

The information collected from the department of the agricultural services of Ain Defla reports that 18% of the agricultural land areas are actually irrigated. Garden farming is the most profitable, concentrated throughout the valley and especially in the west side. Wells and drillings (boreholes) in the area and releases from dams Ghrib, Deurdeur and Harraza are used for irrigation. The annual average concentrations of nitrates in the waters of the dams are low (<20 mg l^{-1}) (ANRH, 2011) and can act as diluents.

Covering a total area of 5636 ha, garden farming is the main culture in the Upper Cheliff (Fig. 3) and is located mainly near the edges of the valley (the Aribs, Djendel Sidi lakhder, Djelida), their irrigation is provided by individual wells (ONID, 2012).

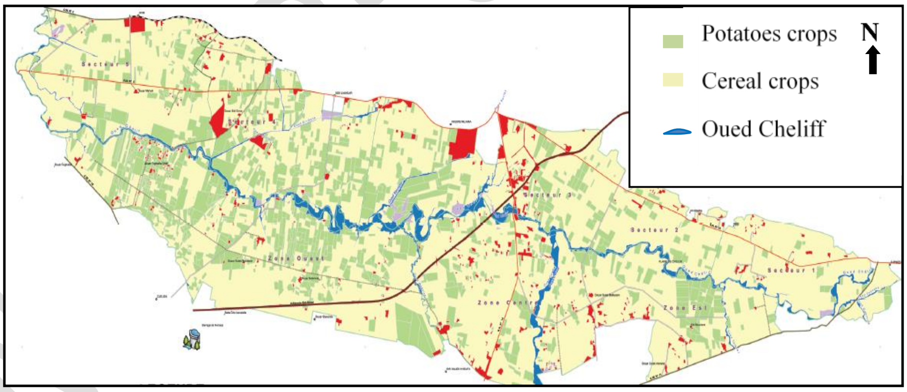


Figure 3. Plan of the land use in the Upper-Cheliff plain

2.5. Sampling and analytical methods

A total of 53 groundwater samples irregularly distributed in the area were collected from shallow wells (mostly <120 m deep) during campaigns carried out in May 2011 .

A piezometric campaign and chemical analysis were carried out after application of large amounts of nitrogen fertilizer, especially fertilizers used extensively in garden farming. Water depths in the wells ranged from 4 to 40 m with an average oscillating around 18 m.

Samples of water filtered at 0.45 microns using syringe filters (Sartorius) are taken in Stoppard plastic (polyethylene), previously rinsed with filtered water sample, and immediately stored to keep temperature below at 4 °C until arrival at the laboratory.

In the laboratory, they are placed in the refrigerator and analyzed within 24 hours of collection. The physico-chemical parameters (T, pH, conductivity) were in situ measured using a multi-parameter WTW Universal Conductivity Meter Multi-Line P4 set and probes.

The analysis of chemical elements was performed by the following methods (Rodier, 1996): the calcium, hardness (TH), magnesium, chloride and bicarbonate by titration, sodium and potassium were determined by the spectrophotometer flame emission (brand JENWAY PFPZ) on the wavelengths of 589 and 766.5 mm in. Sulfates and nitrates were determined by a spectrophotometer HACH DR/4000 brand, model 48000) on the wavelengths 420 and 415 nm, the estimated absolute error of the various chemical and physico-chemical parameters are identified in Table II. According to different analyses the ionic balance is less than 5%.

The ordinary and indicator kriging with semi-variogram modeling implemented in the geostatistical analyst of the ArcGIS9.3 package was then used to produce spatial maps of the measured and estimated spatial evolution of nitrate in groundwater.

For modeling the effects of potato crop agricultural practices on nitrate leaching in groundwater, we selected the PILOTEN model.

2.6. Spatial prediction of Nitrate (Geostatistical modeling)

The characterization of groundwater quality by geostatistical methods has been achieved in problems related to the simulation of the hydrogeological spatial variables (Delhomme, 1978; Goovaerts *et al*., 2005; Stigter *et al*., 2006), which estimate and characterize groundwater quality. (Adhikary *et al*., 2010; Antunes & Albuquerque, 2013; Baalousha, 2010; Dash *et al*., 2010; Lee *et al*., 2008; Liu *et al*., 2004; Mendes & Ribeiro,2010; Mario *et al*., 2014)

The indicator kriging helps in mapping the probabilities of different threshold levels for retained nitrate and the average probability of nitrates by calculating their mathematical expectation.

The indicator kriging is a nonparametric method based on a prior transformation of the studied variable indicator taking the value 0 and 1 according to the variable thresholds chosen (Bierkens and Burrough, 1993; Douaoui, 2005). Spatial analysis of this method of kriging is not done with the variable itself, but on the transformed variable by binary coding called indicator function. The threshold values depend, in our case, on the limits of nuisance or toxicity (drinking water standards).

The calculation of the indicator variogram functions of the given threshold determines the spatial structure.

$$\gamma^*(h,c) = \frac{1}{2N}(h)\sum_{i=1}^{N(h)}[I(x_i,c) - I(x_i + h \pm \Delta h, c]^2 \qquad (1)$$

Where: N (h) is the number of pairs of remote observations of h ± Δh

Ordinary Kriging at a point (x_0) of I (xi, c) is done according to the equation:

$$I^*(x_0,c) = \sum_{i=1}^{n}\lambda_i I(x_i,c) \qquad (2)$$

n: the number of data points included in the estimate

λ i: the weight assigned to the experimental points

The difference between the estimates of indicator functions for two consecutive threshold values is used to calculate the corresponding probability at any point:

Probability (X = c) = Probability (X ≥ Z_c) - Probability (X ≥ Z_{c+1})

Z_c and Z_{c+1} are the two threshold values

The mathematical expectation is calculated according to the different used probabilities:

$$E(Z) = Z_c + 2\, Z_{c+1} + 3\, Z_{c+2} + ... \quad (3)$$

2.7 PILOTEN Modeling

PILOTEN model was selected for simulating the effects of agricultural practices on nitrate leaching, in the Upper-Cheliff. PILOTEN is a model developed by Irstea whose principles are specified in particular in Articles of Mailhol *et al*.(1997); Khaledian *et al*.(2009).

It requires daily weather data: Rainfalls, initial evapotranspiration (ET0), global radiation and mean temperature. It also requires information on the plant (planting date, root growth, physiological status,) and soil (initial water reserve, volumetric water content at field capacity and wilting point)

Associated with climate data (rainfall, average temperature, evapotranspiration, global radiation) the period over which the simulation is done, the combination of two modules provides for a crop and soil characteristics data, an estimate of yield and water consumption required to achieve this performance (inputs other than irrigation are assumed to be non limiting).

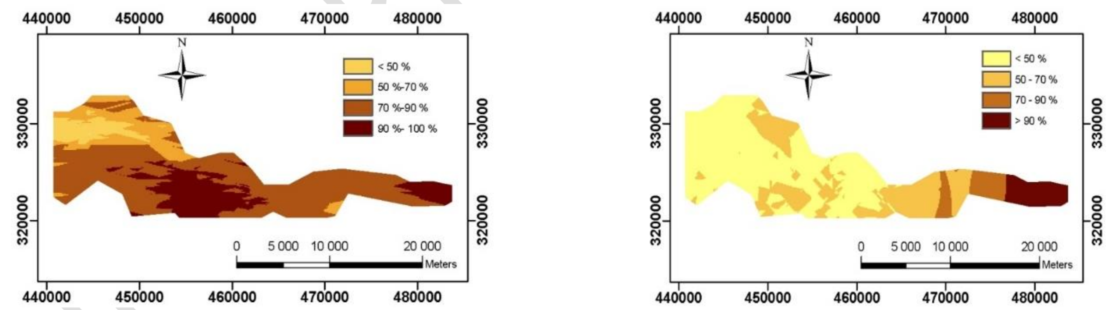
The calibrated and validated PILOTEN model was applied to field experiments in a Mediterranean area (Morocco, Spain, France) where potato cropping systems under common local agricultural management practices were implemented.

PILOTEN performs a complete nitrogen balance in a simulation period. (Mailhol *et al*., 2011) The software also evaluates the N draining and N leaching. It is a well-known code that has been used to estimate the leaching of nitrogen.

3. Results and Discussion

3.1. Nitrate mapping

Two threshold values were used: the first corresponds to greater than 50 mg l^{-1} which is the maximum limit set by the WHO levels: the second value equals to 80 mg l^{-1}. It is chosen taking into account the distribution of data and a limit beyond which the water consumption is very dangerous.



(a) (b)

Figure 4. Maps of the probabilities estimated by indicator kriging thresholds 50 mg.l^{-1} (a) and 80 mg.l^{-1} (b)

The average variogram (omnidirectional) calculated for the mathematical expectation of nitrate shows a good spatial structure with a range equal to 11900 m. The latter expresses that good spatial continuity and also shows a pattern in the spatial variability of nitrates in view of the high ratio between the address which is equal to 0.26 (mg $l^{-1})^2$ and the nugget effect equal to 0.04 (mg $l^{-1})^2$ (fig.7).

The indicator kriging was used to model the spatial variability of nitrate pollution in ground-water of the Upper-Cheliff. The map established by Indicator Kriging (IK) method Map of the mathematical expectation of nitrate is established to map (Fig.7). It appears from this map that the most affected zones (NO_3 > 65 mg l^{-1}) are those for which the level of intensification of the N-fertilization (zones of garden farming) are the strongest (Bettahar *et al.*, 2009).

It is in the east of the plain where the old alluvial soils and non-claly foothills are characterized by the highest permeabilities (Xu *et al*., 2013). The sensitivity of the soil to nitrate leaching is therefore very high. In these same areas, the exploitation of the breeding is more intensive.

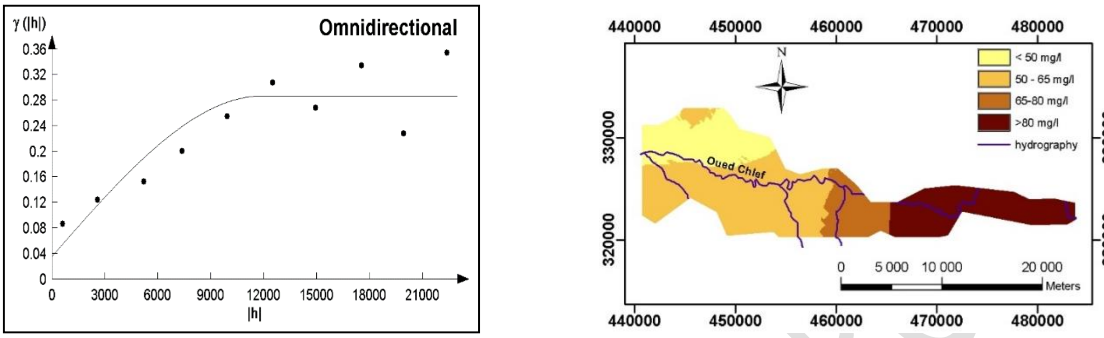


Figure 5. Variogram and Map of nitrate concentrations estimated by indicator kriging

As to the southwest extension, it contains a high nitrate levels (NO_3 > 50 mg l^{-1}) despite the very fine texture of the soil, due to the accumulation of pollution in the direction of water flow from upstream to downstream. With the exception of a zone located in the extreme north, the weak values of nitrate concentration are located in the northwest of the plain and do not exceed 50 mg l^{-1}. In this area, fine texture of the soil reduces significantly the spread of nitrates in depth due to the low permeability (Cheloufi & Jacquin, 2000).

3.2. Quantification of total nitrogen inputs in the study area

The estimate of the total nitrogen input can be given by the following equation:

∑ ENTRIES = Natural Contributions + non natural contributions

With

Natural contributions =Atmospheric nitrogen contributions + Contributions by mineralization

Non natural contributions = N-fertilizers + water of irrigation + breeding + municipal wastewater

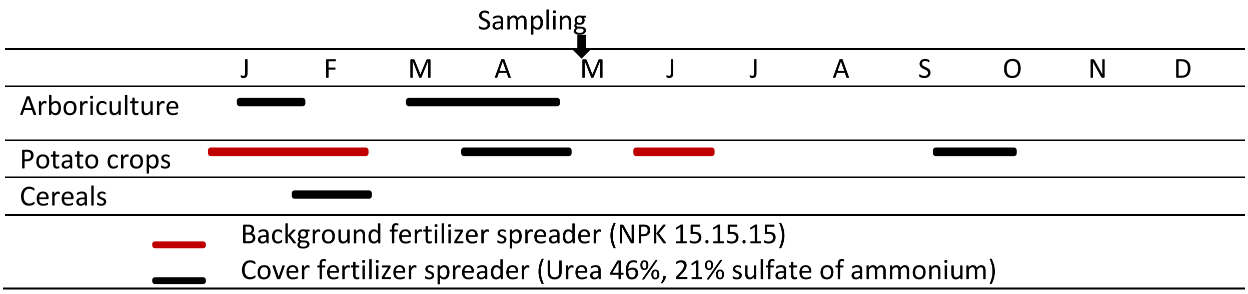
The nitrogenous balance method suggested by the COMIFER (1996) and the CORPEN (1988), permits the nitrogenous excess calculation.

In this work we are interested in calculating the nitrogen input from the non natural sources. During the year 2011, they are estimated at 5633 t year $^{-1}$ brought on the soils of the Upper-Cheliff plain. Nitrogen brought by agriculture (fertilizers and irrigation) equals to 62% of the total nitrogen applied to the soils of the region. 90% of the latter is attributed to nitrogen fertilizer intensively used in garden farming, potatoes in particular. Extrapolated to the total irrigated area, this contribution (related to fertilizers) was estimated at 247 kg ha^{-1} for this year.

3.3. Contribution from fertilizers

A field investigation from 350 agricultural exploitations has allowed us to develop a calendar of cultural practices (dates, fertilization) and estimate, therefore, nitrogen inputs for each type of land use (Table II). The industrial chemical fertilizers, especially, 15.15.15 NPK are predominating in almost all of the exploitations with annual average doses of 2000 kg ha^{-1} for potato, used as background fertilizer. Other fertilizers such as urea (46%) are used as cover fertilizer. The amount of nitrogen obtained for each crop type is deducted from the product of the fertilizer dose with the corresponding area of application.

Table 2. Results of the investigation into the agricultural practices in the Upper-Cheliff



3.4. Contribution from the water of irrigation

Garden farming and cereals surfaces are irrigated from groundwater of which nitrate concentrations, for the majority, exceed the critical value for drinking water set by World Health Organization (50 mg l^{-1}) (Bettahar & Douaoui, 2007). Referring to the potability standard (50 mg l^{-1}), we can estimate the amount of nitrogen in this water using the formula below: (Martin, 2003; Bettahar, 2012)

$$x_n = \frac{[NO_3^-] \times Qirrig}{4,43 \times 10^2}$$

X_N is the annual amount of nitrogen applied by irrigation water (kg N ha^{-1} an^{-1}), [NO^{-3}] is the concentration of nitrate in well water (mg l^{-1}) Qirrig and the annual amount of irrigation water (mm an^{-1}). The 4.43 figure is the ratio of molar masses NO_3 N^{-1}.

The total quantity of nitrogen brought by the water of irrigation in the year 2011 was 344.58 t $year^{-1}$ (Fig.6) which represents only 10% of the one produced by the nitrogen fertilizers (3139.65 t $year^{-1}$).

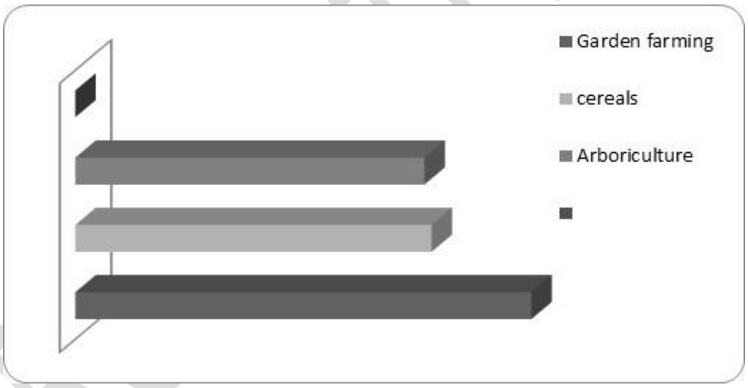


Figure 6. Results of the investigation into the agricultural practices in the Upper-Cheliff

3.5. Contribution from breeding

The calculation of the yearly total quantities of organic nitrogen generated by the set of each animal category for the year 2011 is based on the values of nitrogen produced annually per head for each species proposed by the (CORPEN 1988, 1999 and 2001). The results that we obtained show that the majority of this organic nitrogen is produced by cows (1515.7 t $year^{-1}$).

3.6. Domestic and industrial inputs

Organic nitrogen estimated for Individual septic tank systems constitutes only 23% of the one generated by the breeding.

The estimate of the yearly total quantities of organic nitrogen produced by domestic sewage is based on the nitrogen content of the volume of domestic wastewater produced by populations not connected to the sewage network..

The nitrogen produced by nitrogen fertilizers is estimated to 56% of the total nitrogen input added to the soil of the plain of the Upper-Cheliff for 2011.The contribution from breeding and domestic wastewater assessed represents about 38% of the total nitrogen (5633.13 t) brought on the soils of the plain of the Upper-Cheliff during that year.

The dumps, often seen on permeable soils, can also convey important quantities of nitrates in depth that is difficult to quantify at this stage of study.

3.7. Modeling results of N leaching under potato crops

Simulated amounts of infiltrated water and N leached past 0.9 m depth for each potato crop period are shown in graphs. As encountered by other authors (Doltra & Mu˜noz, 2010), the days when N leaching occurs correspond to the days of heavy rains or irrigation period (Table 3).

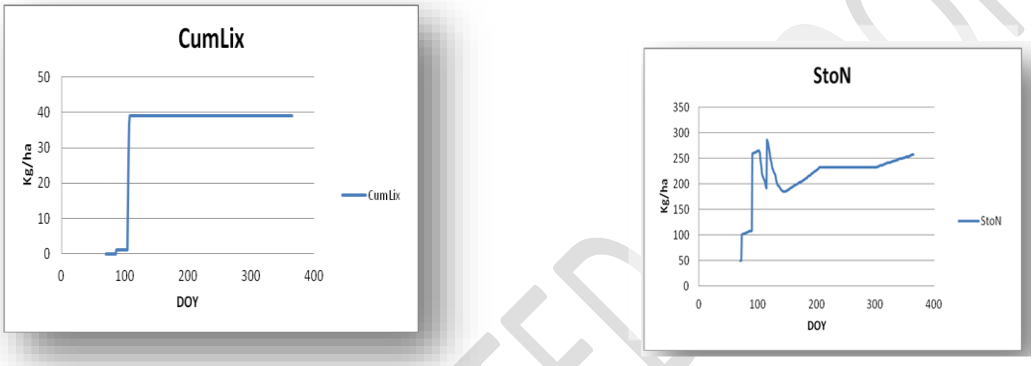


Figure 7. Cumulative nitrogen leached and cumulative nitrogen stock in the soil

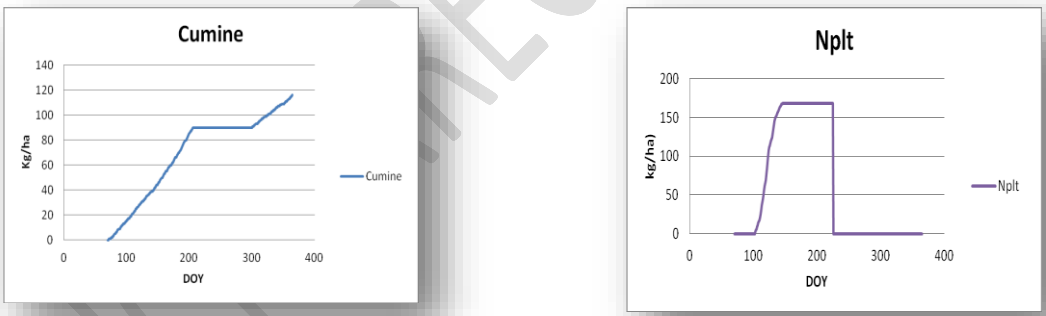


Figure 8. Cumulative nitrogen mineralization and cumulative nitrogen absorbed by theplant

With regard to nitrate leaching, the main difference between rainfall and the application of irrigation water is the nitrate concentration it holds. The average nitrate concentration in rainwater over the whole studied period was in the order of 6 mg l^{-1}, whilst in irrigation water pumped from the Mio-Plio-quaternary aquifer the nitrate concentration oscillated between 80 and 300 mg l^{-1}. Irrigation water alone accounted for an input of 344 t $year^{-1}$ for the 2011.

The period of leaching N coincides with fertilizer applications and irrigation groundwater. Over this period there was a 134 mm increase in drained water, which transported 143 kg N ha^{-1}. The total N leached for the 2011 crops was 148 kg N ha^{-1} (Table III).

This implies that the intensification of fertilizer and irrigation frequent applications played an important role in the total N leached increasing, especially under potatoes crops.

Table 3. Simulation results of the nitrogen balance established by PILOTEN

Total rain (mm)	Evaporation soil	Drainage	N lessives kg ha^{-1}	Mineralization kg ha^{-1}	Denitrification kg ha^{-1}	Stock Final N soil kg ha^{-1}
336	341	134	148	234	0	568

The nitrogen produced by fertilizers is estimated at about 56% (154 kg N ha^{-1}) of the total nitrogen input added to the soil of the plain of the Upper-Cheliff for 2011. The model of simulation has shown that 95% of N lixiviation was from the potatoes crops.

This lixiviation under the potato crops coincides with the same zone of high nitrate concentrations (NO_3 > 50 mg l^{-1}) located to the map of nitrate established by indicator kriging.

With this final stock of N, we tried to make a simulation of nitrgen balance for wheat crops planted just after potao.

In this scenario it would be interesting to grow wheat just after potato without nitrogen brought, it consume the available nitrogen in the soil,which could be from this model reduced the amount of N leached 0 kg h^{-1}.

4. Conclusions

The spatial relationship between NO_3^- concentrations in well waters and the N leaching under potato crops were studied in the Upper-Cheliff plain. Nitrate pollution in aquifers of the Upper-Cheliff in semi-arid climate. appears, important, with high levels of nitrogen (5500 T), brought annually to the soils of Upper-Cheliff by different practices (agriculture, breeding), don't reach the aquifer because of the climate and the soil characteristics. We also found that the indicator kriging method, correctly reflects the potential risk of nitrate pollution exceeding the maximum allowable value for drinking water, and is a suitable tool for the assessment of uncertainty in local estimation. From the results, the standard error maps portrayed the suitable reliability of the prediction map, although extra sampling points are suggested for monitoring, especially near the boundaries to reduce the estimation error in a non-sampled region.

It has also been shown that land use plays an important role on the water quality change, such as potato corps, where we found high nitrate concentration. Therefore, integrated aquifer management strategies can be designed, when water quality analyses are complimented with land use. PILOTEN was able to predict water content at different depths and nitrate concentration in drained water past 0.9 m depth with reasonable accuracy providing good predictions compared to field observations. This model simulates the amount of water drained and N leached below the root zone. Also, the adopted approach of comparing total nitrogen input content in soil of Upper-Cheliff to the N leaching under potato crops (the main culture in the region) and simulated data at 0.9 m depth with reasonable accuracy providing good predictions compared to field observations. The model simulated the amount of water drained and N leached below the root zone. This extra N input to the system from irrigation water should be considered in the N budget when designing fertilizer applications following crop requirements. Planned measures to reduce the impact of fertilizers and irrigation on the aquifer need to be taken by the agricultural and water sectors. However, these options should rely on technical and socioeconomic requirements.

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