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# Impact of the urban and industrial waste water on surface and groundwater, in the region of Annaba, (Algeria)

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**Abstract**

"The characterization of a hydrologically complex contaminated site bordering the river of Meboudja (Annaba, Algeria) was" undertaken by investigating surface water and groundwater affected by Number of urban and industrial waste water have been established during the period 1999-2007 in El-Hadjar Industrial Development Area in the region of Annaba, North-East of Algeria. The treated and untreated effluents from the cities and industries are to be discharged in Meboudja river groundwater level and water quality monitoring was carried out during 1999 - 2007 in El-Hadjar and its surrounding areas. Surface water samples were also analyzed for the water quality. The groundwater shows a high electric conductivity (more than 560 $\mu Scm^{-1}$ with a maximum exceeding 20000 $\mu Scm^{-1}$), a high chloride content (with a maximum greater than 6000 $mgl^{-1}$), and a high sodium concentration (mean = 420 $mgl^{-1}$) are observed for the wells located down gradient and near industrial waste water. Also, high metallic concentrations (0.02-1.25 $mgl^{-1}$ in chromium) are observed in these wells. Meboudja is acting as a diffuse source of contaminations all along its course. Aquifer parameters were estimated by carrying out pumping test at a number of wells. Groundwater flow and mass transport models were prepared using visual MODFLOW software. The extent of contaminants migration from Meboudja and other streams has been assessed for 8 years (1999-2007). The stream-aquifer interaction was found to be responsible for faster migration of contaminants in the over-exploited area East of Seybous.


Selection and peer-review under responsibility of the Euro-Mediterranean Institute for Sustainable Development (EUMISD)

"*Keywords* : Pollution; Iron and Manganese; Urban and industrial waste water; Numerical modelling; Annaba (Algeria)"

## 1. Introduction

Increase of waste production is correlated with economical and demographical development. While life improvement expected, such development also leads to negative effects on the environment and economy of many countries. Demographical development and intensification of the economical activities in Algeria are accompanied by an increase in solid waste production (Kherici N, 1993; Djabri L, 1996; Debièche et al., 2003). [1, 2, 3]


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The considered zone, that is expected to be the third industrial node of Algeria, has experienced an intensification of demography (higher than 800000 inhabitants) (RGPH, 2001) and economy (higher than 150 industrial units). Environmental problems such as air and water pollution could seriously set back these economical and urban developments. Indeed, several hundreds of tons/day of solid and liquid wastes are dumped in environment lacking any treatment. This uncontrolled dumping has negative effects that are clearly identified such as nauseous smells, smoke generation, water and soil pollution (Debièche et al., 2003, Hani A, 2003 [4])

The industrial effluents contain appreciable amounts of both inorganic and organic chemicals and their bye-products. Most of industries are in small scale sector and are not having any sewer lines. Even today most of them don't have proper wastewater treatment plants and they discharge industrial effluents in unlined channels and streams and thereby causing enormous contamination of air, water and soil. As a result, the highly coloured and toxic chemical effluents join the river of Meboudja, which is a left-side tributary of Seybous river, polluting surface and groundwater.

The degree of contamination has been so intense that in some parts the environment has become unsuitable for human life. Traditionally, people of the lower Seybous plain are an agricultural community. None of the industrial units took any measures for safe disposal of industrial effluents till 2000. Indiscriminate dumping of wastes all over the place became a routine practice. Soon the levels of toxic elements in soil, water and air drastically exceeded the permissible limits. Crop production fell hugely and aquatic life in Seybous stream started perishes. Seybous has become extremely polluted. In fact, it no longer looks like a water body; what remains is dark, greasy, frothing mass of thick liquid in the summer. Annaba was no longer like 20 years ago. Experts attribute the present situation to both lack of planning and mindless sitting of industries (Japanese Agency of International Office of Survey for the Countryside Development, in Zenati, 1999 [5]).

In order to find out the impact of these effluents on the river water and groundwater quality, a monthly water monitoring chemistry was performed in the river and in the water catchment, situated lower Seybous plain.

In the present research, groundwater monitoring has been taken up for effective assessment through understanding of hydrogeology, geology and water-chemistry of the watershed. The collected basic data is used for the preparation of the groundwater flow and mass transport model for quantitative assessment of contaminant migration impact on the watershed. To find out the groundwater velocity distribution is used in order to analyze advectif and dispersive transport to settle on contaminant migration in the area.

## 2. Study Area

The studied area is situated in the lower Seybous plain (NE Algeria) upstream of Meboudja river, see Fig. 1. The northern limit of the zone is constituted by the metamorphic basement, whereas the other limits are open limits which are in continuity with the shallow aquifer of the low-lying Seybous plain.

River Meboudja is characterized by a permanent flow in winter. Its alimentation comes from rain waters, and drainage of the lake Fetzara (the discharge reaches 16 $m^3.s^{-1}$). During the summer, the water inflows are mainly the lake outputs (the flow rate ranges between 1 and 5 $m^3.s^{-1}$). The river receives also urban contributions upstream, such as domestic sewage waters. The aquifer reservoir is developed on a clayey substratum. The aquifer formations are represented by 70 loamy sand and 30 clays (Japanese Agency of International Office of Survey for the Countryside Development, in Zenati N, 1999). The average permeability ranges between $10^{-3}$ and $10^{-4}$ m $s^{-1}$.

The Mediterranean climate is of type with an annual rainfall of 650 mm, a mean temperature of 18°C and high atmospheric humidity. The dominating wind direction (Northwest-Southeast) blows from the studied area towards the region of Drean. The effective infiltration is about 15% of the total rainfall that is 100mm per year, which infiltrates through waste, soil and finally to the ground water (Hani A, 2003, Debièche T.H, 2002).

Some of the wells situated about 400-500 m away laterally from the z= 09m (Meboudja River) in El-Hadjar village are not presently in use because of the contamination. The total dissolved solid (TDS) concentration of groundwater has reached about 2000 mg.l-1. There is progressive deterioration of groundwater quality noticed over the last two decades and it is due to high permeability of alluvium along the (Meboudja River). The lateral spreading of contamination due to large scale pumping also promoted stream-aquifer interaction around the El-Hadjar village. Water quality and water level monitoring were carried out on 30 wells and 12 of them have also been selected for periodical monitoring since July 2006. The ground water contours of the region (June 2007) indicate that the groundwater flow follows the general topography of the area. The z = 8.5m is affluent around b: Sidi amar, c: Pont Bouchet villages and the region between the y = 399 and the x = 344, whereas the stream becomes influent around Pont bouchet and El-Hadjar villages in the downstream of the z = 6.5 m as a consequence of stream-aquifer interaction due to heavy pumping for irrigation. This is a very significant process that enhances transport of contamination in the region.

The ground water varies widely in the area. These first is at a shallow depth in the alluvium. The average depth to ground water is 3 m and increases away from the river z = 09m. Thus, it can be interpreted that the main source of ground water in the area is at the z = 5m. Some wells close to the z = 6m are seen oozing from the side of the z = 0.5m, which clearly indicate that the source of groundwater is nothing but surface water flow in the stream. Ground water in granitic terrain is varied between 5-11 m below ground level. The lift irrigation structures along Meboudja River were found spoiled because of the polluted water. Some of fertilizers used for growing the cultures may also enter the groundwater regime. But it seems that the nitrate concentrations are within the permissible limits. Mainly chlorides and sulphates have shown increased concentrations.

Meboudja River, while carrying effluent, contributes as diffuse source of contamination all along their courses up to the confluence with Seybous River. Because of the presence of alluvium on the banks; there is more infiltration of contaminants. These latter on reaching ground water through stream-aquifer interaction migrate in the aquifer system mostly through advectif dispersion. The resultant rate of motion and the scattering of the pollutants depend on the pressure gradient hydraulic and the underground water velocity as well.

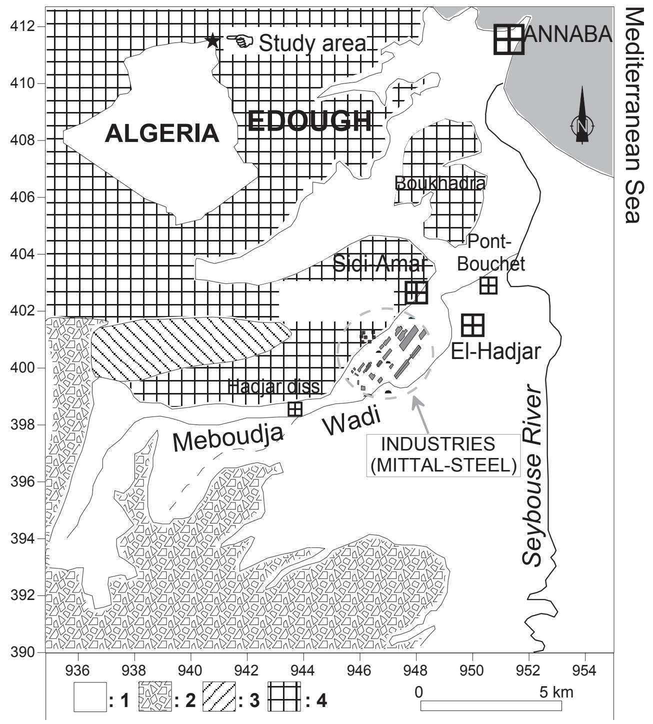


Fig. 1. Location map of study area: 1: Undifferentiated Quaternary, 2: Ancient alluvium, 3: Numidian sandstone or clay, 4: Metamorphic formation.

## 3. Material and Methods

Many monthly surveys of the piezometric level and geochemical analysis have been monitored. The analyses are carried out on a network of 30 wells in the plain of Meboudja, see Fig. 3. Some sampled wells are used by the neighboring population for daily drinking, irrigation and animal alimentation (case of P2). The grounds were taken according to a direction south-north.

The temperature (T), electrical conductivity (EC) and pH were measured in situ using a multiparameter WTW set (Multiline P3 PH/LF SET), an Ox meter (WTW) with an oxygen probe (Cell Ox 325) for the measurement of dissolved oxygen. The concentration of chloride ($Cl^-$), sulphate ($SO_4^{2-}$), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), carbonates ($HCO_3^-$), were determined using the volumetric method (AFNOR, 1987). Nitrate ($NO_3^-$) and ammonium ($NH_4^+$) were analysed by colorimetric method using spectrophotometer (Spectronic 20 D). The heavy metals (Fe, Zn, Mn, Cu, Cd, and Cr) were determined using atomic absorption spectrophotometer (Unicam 929 AA Spectrometer).

In the present study, groundwater monitoring has been taken up for effective assessment through understanding of hydrogeology, geology and water-chemistry of the watershed. The collected basic data is used for the preparation of the groundwater flow and mass transport model for quantitative assessment of impact of contaminant migration in the watershed. To determine the groundwater velocity distribution is used to analyze advectif and dispersive transport to determine contaminant migration in the area.

## 4. Results and Discussion

### *4.1 Water Chemistry*

Water samples collected from bore wells, dug wells and surface water bodies at 50 locations were analyzed for ionic concentration, pH and total dissolved solids (TDS). The observed surface water TDS in downstream is ranging from (4500 $mg.l^{-1}$) near El-Hadjar to (2970 $mg.l^{-1}$) in upward. The impact of pollution due to effluent discharge from industries located around El-Hadjar resulted in a decrease of TDS concentration of groundwater to (2180$mg.l^{-1}$). To put in evidence the impact of the interaction river water ground water on the quality of the underground waters one followed monthly EH; pH; Fe(T); $Mn^{2+}$ was realized on the set of the wells picking the alluvial ground water . The drawings out of water for analyses were also carried out on the waters of Meboudja river, see Fig. 2.

### *4.2 Origin of contents in iron and manganese in the waters of Meboudja river*

The carried out analyses on the industrial and urban rejections make existence in the iron and manganese appear it to elevated contents. Both elements of common origin, is the factory Mittal Steel Arcelor's acid rejections. The spatial evolution of the elements (Fe (T) $Mn^{2+}$) in the waters of the river was analyzed for the month of June, where the rushes are very weaklings, the values of pH (8, 82 - 8, 92) and EH (115 - 140 mV) are stable. The raise of the concentrations Iron And some Manganese at the level three stations (P1, P2 and River) are told the industrial rejections of wealthy Mittal-steel Arcelor elements ferric and manganese steel. The weak concentrations under shape dissolute, are told the basic middle conditions (pH 8, 82 at 8, 92). In this context, the ions precipitate sediments at the level under intricate shapes (hydroxides and carbonates.) The steadiness of the contents in iron and in manganese on the three stations, comes of the effect of the steadiness of pH (8, 82 at 8, 92) and EH (355 at 362 mV) pointing out that the iron and the manganese exist in identical to the level proportion of the three stations. No contribution in iron and in manganese is recorded at the level of the stations P1 and P2, situated however near of industrial perimeters.

At the confluence of the two rivers, the contents in iron and in manganese diminish brutally as a result of the collaborative effect of the dilution by the waters of the Seybous river and the chemical rush of the iron and of the manganese in oxidizing middle (0.7 $mg.l^{-1}$ of O2).

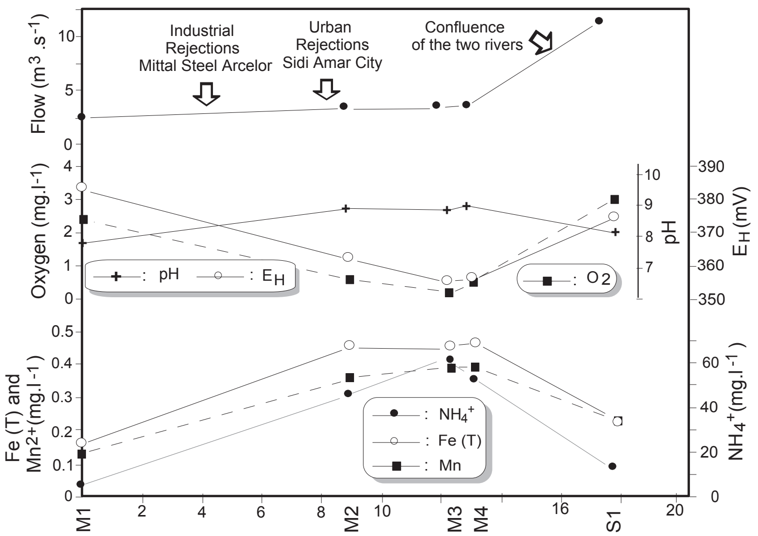


Fig. 2 The evolution of iron and manganese and (Flow – $NH_4^+$pH-Eh- $O_2$) through the plain of Annaba

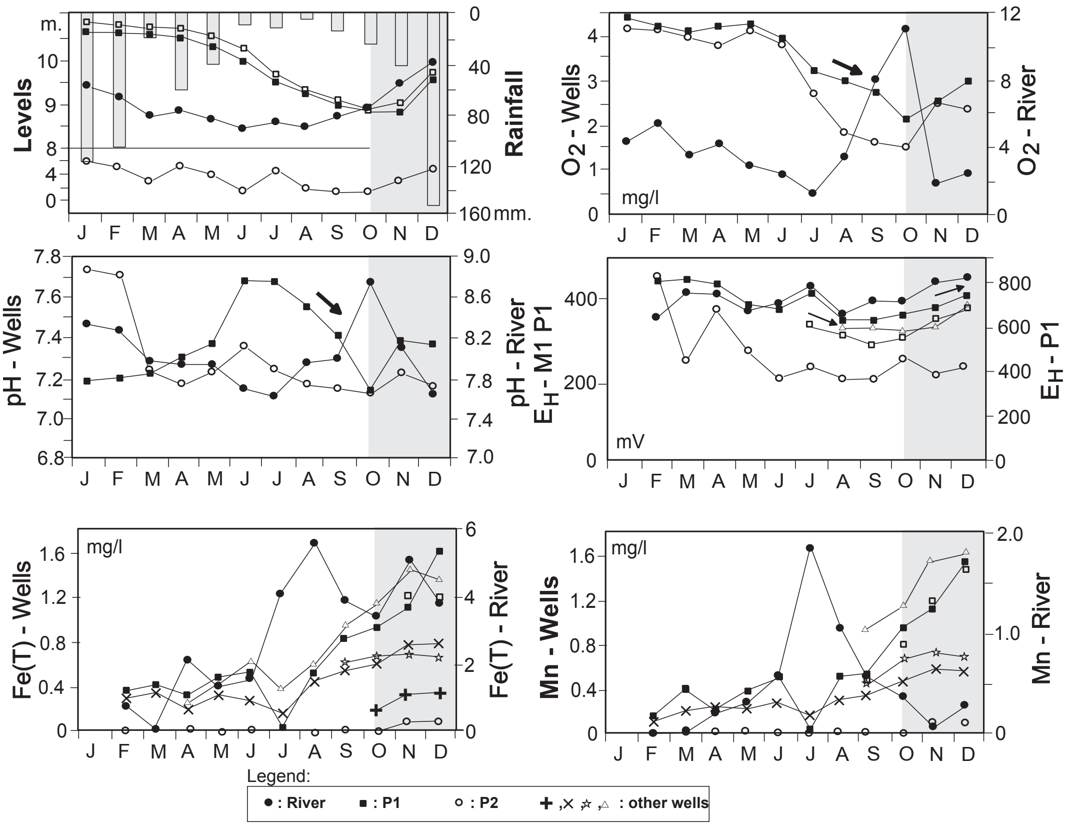


Fig. 3 The evolution of concentration of element in wells and river of Meboudja (M1= river, P1, P2 = Wells)

The figure 3 show that a high iron and manganese contents, are observed for the wells located down gradient and near Mittal Steel-Arcelor. Also, high TDS is observed in these wells.

## 5. Groundwater flow and mass transport modelling

Groundwater contamination is limited with the mass transport processes. These processes determine maximum extent of plume spread and geometric character of the concentration distribution. Advection is by far the most dominant mass transport process in contaminant migration. Hydrodynamic dispersion is usually a second order process. The magnitude and direction of advectif transport is controlled by the configuration of water table or piezometric surface, presence of sources or sinks, permeability distribution within the flow filed and flow domain.

The hydraulic head is obtained from the solution of a three dimensional groundwater flow equation (Bear, 1972)

$$\frac{\partial}{\partial \chi i}\left[K_{ii}\frac{\partial h}{\partial \chi j}\right]+q_s=S_s\frac{\partial h}{\partial t} \quad (1)$$

where Ss is the specific storage of the porous material.

The transport equation is linked to the flow equation through groundwater velocity term given by

$$v_i=\frac{K_{ii}}{\theta}\frac{\partial h}{\partial \chi i} \quad (2)$$

Where

Kii a principal component of the hydraulic conductivity tensor;

h hydraulic head;

θ the porosity of the porous medium.

MODFLOW software (McDonald and Harbaugh, 1988) is used for the hydraulic simulation. All these parameters are important in controlling the groundwater velocity, which drives advectif transport. Adding dispersion to advective transport can cause important changes in the shape of a plume. Another important process is sorption and irrespective of the model describing sorption, the process was of paramount importance in controlling contaminant transport. The partial differential equation describing three-dimensional transport of contaminants in groundwater (Javandel et al., 1984) can be written as

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial \chi i}\left[D_{ij}\frac{\partial C}{\partial \chi j}\right]-\frac{\partial}{\partial \chi i}\left(v_i C\right)+\frac{q_s}{\theta}C_s+\sum_{K=1}^{N}R_k \quad (3)$$

where

C the concentration of contaminants dissolved in groundwater;

t time;

χi the distance along the respective Cartesian co-ordinate axis;

vi the hydrodynamic dispersion coefficient;

vi the seepage or linear pore water velocity;

qs the volumetric flux of water per unit volume of aquifer representing sources (positive) and sinks (negative);

Cs the concentration of the sources or sinks;

θ the porosity of the porous medium;

Rk chemical reaction term.

Assuming that only equilibrium controlled linear or non-linear sorption and first order irreversible rate reactions are involved in the chemical reactions, the chemical reaction term can be expressed as (Grove and Stollenwerk, 1984)

$$\sum_{k=1}^{N}R_k=-\frac{\rho_b}{\theta}\frac{\partial \overline{C}}{\partial t}-\lambda\left[C+\frac{\rho}{\theta}\overline{C}\right] \quad (4)$$

where

$\overline{C}$ the concentration of contaminants sorbed on the porous medium;

λ the rate constant of the first-order rate reactions;

ρb the bulk density of the porous medium.

Rewriting Equation (4) as

$$\frac{\rho_b}{\theta}\frac{\partial \overline{C}}{\partial t} = \frac{\rho b}{\theta}\frac{\partial C}{\partial t}\frac{\partial \overline{C}}{\partial C} \quad (5)$$

We can rewrite Equation (3) by substituting Equations (4) and (5) as

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial \chi\, i}\left[D_{ij}\frac{\partial C}{\partial \chi\, j}\right] - \frac{\partial}{\partial \chi\, i}(viC) + \frac{q_s}{\theta}C_s - \frac{\rho\, b}{\theta}\frac{\partial C}{\partial t}\frac{\partial \overline{C}}{\partial C} - \lambda\left(C + \frac{\rho\, b}{\theta}\overline{C}\right) \quad (6)$$

Rearranging the terms we get the governing equation of mass transport model

$$R\frac{\partial C}{\partial t} = \frac{\partial}{\partial \chi\, i}\left[D_{ij}\frac{\partial C}{\partial \chi\, j}\right] - \frac{\partial}{\partial \chi j}(v_i C) + \frac{q_s}{\theta}C_s - \lambda\left(C + \frac{\rho\, b}{\theta}\overline{C}\right) \quad (7)$$

where R is the retardation factor, defined as

$$R = 1 + \frac{\rho b}{\theta}\frac{\partial \overline{C}}{\partial C} \quad (8)$$

*5.1. Groundwater flow model*

The numerical approaches for solving mass transport equations are approximate forms of the advection-dispersion Equation (7) as a system of algebraic equations or alternatively simulating transport through the spread of a large number of moving reference particles (particle tracking). The second step is to provide boundary condition and assign values of concentration or loading rates defining various boundaries for all nodes located along boundary of the domain. Initial conditions and transport parameters were specified for all nodes. The seepage from the Meboudja was simulated by giving additional recharge input to the model. Constant concentration was assigned in different parts of the Meboudja based on ambient surface was as well as groundwater concentrations measured during field investigations.

The simulated model domain consists of 40 rows and 40 columns and 1 layer covering an area of 8000 x 8000 m. The superficial aquifer mostly consists of a 10-15 m thick alluvium along the Meboudja. The simulated vertical section has a maximum thickness of 15 m. The groundwater recharge at the rate of 100 mm $yr^{-1}$ has been simulated in the top layer. Continuous seepage from the Meboudja stream was simulated as additional recharge in the model. The first stage of modeling is flow simulation for computation of hydraulic head distribution. The distribution of hydraulic head and hence the velocity field is unaffected by migration of plume because density and viscosity of contaminated groundwater is nearly the same as uncontaminated water in the area. The flow equation was therefore, first solved independently of the mass transport equation. Further, water level observations in the area indicate that hydraulic gradients do not change significantly with time. Thus groundwater flow was assumed to be in a steady state and the groundwater heads were computed by visual MODFLOW (Guiger and Frantz, 1996) using Slice Successive Over Relaxation (SSOR) package (McDonald and Harbaugh, 1988). The flow model was calibrated by adjusting several parameters within a narrow range of values until a best fit was obtained between observed data and simulated results. The accuracy of the computed water levels, see Fig. 5 was judged by computing mean error, mean absolute error and root mean squared error computed for 15 observation wells. The calculated mean error, mean absolute error and root mean squared error under steady state condition is –0.14, 3.2 and 3.6 m, respectively.

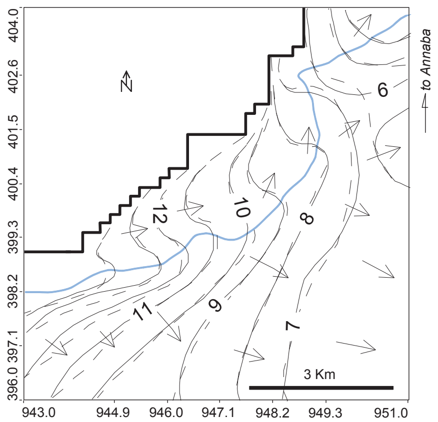


Fig. 4. Distribution of hydraulic heads for February 2007. Dashed lines, simulated; continuous lines, measured. Contour interval, 0.5 m.

### *5.2. Mass transport Model*

Mass transport in three dimensions (MT3D) is a computer model for simulation of advection, dispersion and chemical reactions of contaminants in three-dimensional groundwater flow systems (Zheng, 1990). The model is used in conjunction with a block-centred finite difference flow model MODFLOW. Dispersion was accounted for the particle in motion by adding to the deterministic motion a random component, which is a function of dispersivities. The mean concentration for each grid block was calculated as the sum of the mass carried by all the particles located in a given block divided by the total volume of water in the block. The values of dispersivity in longitudinal and two transverse directions (Y and Z) were assumed to be 10, 1 and 0.1 m, respectively, and the values were taken from the literature (Kimbrough et al., 1999; Domenico and Schwartz, 1990; Tevissen, 1993). The tendency for $\alpha L$ to be about 10 times larger than $\alpha TH$ and for $\alpha TZ$ to be much smaller than either of them is in line with the concentrations observed in the area. The initial TDS concentration assigned in the rest of the area is about 2180 mg $l^{-1}$. The relatively smooth decline of TDS concentration away from the Meboudja suggests a relatively constant rate of loading. Thus a constant TDS concentration at different nodes on the Meboudja was assigned varying from 4500 mg $l^{-1}$ at source (Mittal steel) near the Sidi Amar and 3500 mg $l^{-1}$ away from the Mittal steel at about 7 km downstream of the Meboudja. The computed iso-concentration contours indicate that the plume is expanding and follows the hydraulic gradient implying that advection is the dominant mechanism of spreading.

The extent of contaminant migration from the Meboudja stream could be seen by computed iso-concentration of TDS contours of transport model for the period of 1997-2007. The contaminant migration was found expending up to 600 m from the Meboudja during the last 05 years, see Fig.5 . Inaccuracies in the simulated flow field could have existed, which produced somewhat more divergent flow pattern from what actually exists. Because we have given uniform pumping rates for the wells and diffuse source concentration at all nodes of the Meboudja, this problem could be related to the complex interaction between groundwater and surface water.

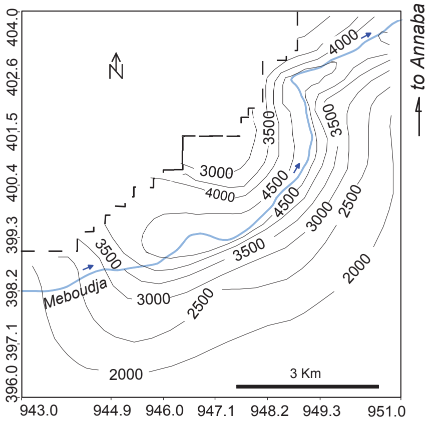


Fig. 5. Computed TDS concentration (mg $L^{-1}$) of groundwater in the lower Seybouse plain.

## Conclusion

Here a case study of groundwater/surface water pollution due to uncontrolled industrial effluent discharges and its environmental impact on groundwater regime is presented. Groundwater pollution extends laterally 500-600 m from the Meboudja, in which initial pollutants load, in the alluvial areas covering villages Sidi-Amar and El-Hadjar. The extension of pollution is due to heavy pumping for irrigation, resulting in induced seepage from Meboudja due to stream aquifer interaction, which in turn carries surface water effluent to the groundwater regime. The contaminated groundwater is being exploited for agriculture and industrial purposes in the absence of major surface water sources in the area. The modeling study has helped to gain a better insight of the hydrogeologic set up and assessment of contaminant migration.

The untreated effluents emerging from the industries must be monitored for maintaining the standards prescribed for TDS concentration by the environment inspection for various industries in the region. The present study provided a base line data for assessment of contamination in the El-Hadjar area. For reduction of the stream aquifer interaction, the pumping around the Meboudja wadi should be reduced. Periodical monitoring of the water quality has to continued to check the rise in TDS concentrations of groundwater.

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