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Potential groundwater contamination by toxic metals around an abandoned iron mine, Bekkaria (Algeria)

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Abstract. This study evaluates potential groundwater contamination with toxic metals in and around an abandoned iron mine in Algeria. The studied mine is situated in East Algeria near the frontier with Tunisia. The exploitation of the iron mine terminated in 1967, however, our present interest is the impact of the mine's waste heaps on the groundwater and surface water in the area. Two aquifers are present, the first is situated at three metres under the ground and is connected with the wadi Oued el Kebir; the second is situated at 20 metres deep. The traces of water in the mine waste dump indicate that during the period of peak stream flow, as a result of snowmelt runoff, a losing stream exists that facilitates the displacement of pollutants. The performed analysis permitted us to study the presence of Metal Trace Elements (MTE) in the first aquifer and the wadis. The electrical conductivity near the mine is very high, this is explained by the high concentrations of sulphates, chlorides, calcium and sodium. The spatial variation of the chemical concentrations observed is probably related to the transport of dissolved chemicals from the iron mine waste. The graphs of the results show high concentrations of MTE reducing with the distance to the mine. The neural network modelling performed, confirms this conclusion.

Keywords: Iron – Algeria – Contamination – Water

Contamination des eaux souterraines par les métaux toxiques d'une mine de fer abandonnée : Cas de la région de Bekkaria (Tébessa).

Résumé. *La mine de fer est située dans l'extrême Est algérien. Son exploitation s'est arrêtée en 1967. Nous nous intéressons à l'impact de cette mine abandonnée sur les eaux souterraines et les eaux de surface. Ce qui revient à l'évaluation de la contamination potentielle des eaux par les métaux toxiques dans la zone de dépôt des terrils. La zone d'étude recèle deux aquifères, le premier très proche du sol et est en relation avec le wadi Oued el Kebir, le second est situé à 20 mètres de profondeur. Ainsi les précipitations entraînent le déplacement des terrils et des polluants, contribuant ainsi à la pollution des eaux et des sols. Les analyses réalisées montrent l'évolution des ETM (Elément Trace Métallique), dans les deux aquifères. Nous remarquons que la conductivité électrique est très élevée près de la zone de dépôts des terrils, elle est induite par les fortes concentrations en sulfates, en chlorures, en calcium et en sodium. Les concentrations observées sont générées par dilution. Les teneurs en éléments traces diminuent en s'éloignant de la zone de dépôt des terrils. La modélisation par la méthode des neurones artificiels confirme les résultats obtenus par l'hydrochimie.*

***Mots clés**: Fer – Algérie – Contamination – Eau*

I – Introduction

Tébessa is a city on the frontier with Tunisia. It is located in the extreme North-East of Algeria (fig. 1), at the edge of the desert, approximately 230 km south of Annaba on the Mediterranean coast. The area is limited to the south by the sector of Biskra, to the west by that of Constantine and in the east by the Tunisian border. The climate is semi-arid.

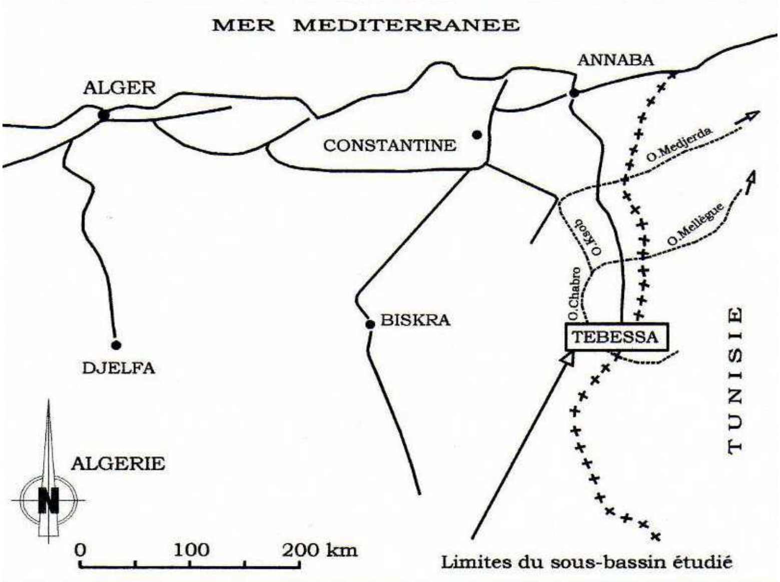

Figure 1: Situation of the study area.

In the studied zone the outcrop formations are of the sedimentary type. They are characterized by the presence of triassic formations, on which we will focus our interest. In the Tébessa area the most important triassic outcrops are those of Djebissa, Ouenza, Boukhadra, Mesloula, Boujaber, northern Hameimat and southern Hameimat. These outcroppings are saliferous and have developed a structure of several mineralogical zones. These formations contain different concentrations of metals such as lead (Pb), Zinc (Zn), Barium (Ba) and Strontium (Sr). Djebissa mountain contains traces of poly-metalic ores and iron. A layer of this iron comes from the iron mine of Khanguet which does not form part of our study area. The Pb-Cu index are in close contact with Cenomanian-Turonien on the South-East side, carbonated rocks (limestone) contains a mineralization with crystals either spread, in veins, or in nests. The products of epigenese can also be encountered: cerusite, limonite and hypogene minerals of copper represented by grey copper ore and digenite hypergenes represented by malachite and azurite.

II – Research outline

As climatic factors contribute to the propagation of the pollutants, the study of climatic factors proves to be essential. In order to study the climatic influence we considered two extreme years. The first is the year 1972-1973, which is considered to be very wet with a precipitation of about 625 mm. In this year the wet season was spread out over ten months. Conversely the year 1996/1997, with only 207 mm precipitation is a very dry year; the wet season is spread out over two months (December and January) and the rain started again mid-March until mid-May.

The shallow aquifer (less than 10 m deep) and the wadi are directly exposed to pollution, in contrast to the deep aquifer which is supplied by infiltration, in other words after a stay of water, allowing reactions between water and soil. They are therefore studied in this work.

The piezometric map of July 2006 shows that, in general, the piezometric surface (fig.2) has the same morphology as the topography. The flow comes in from the south-east as well as the north-west. The appearance of a steep depressed zone located in the north of Ain Chabro can be noted.

This situation is caused by the exploitation of drilled and natural wells in this area; more than thirty exploited wells are listed in the study area.

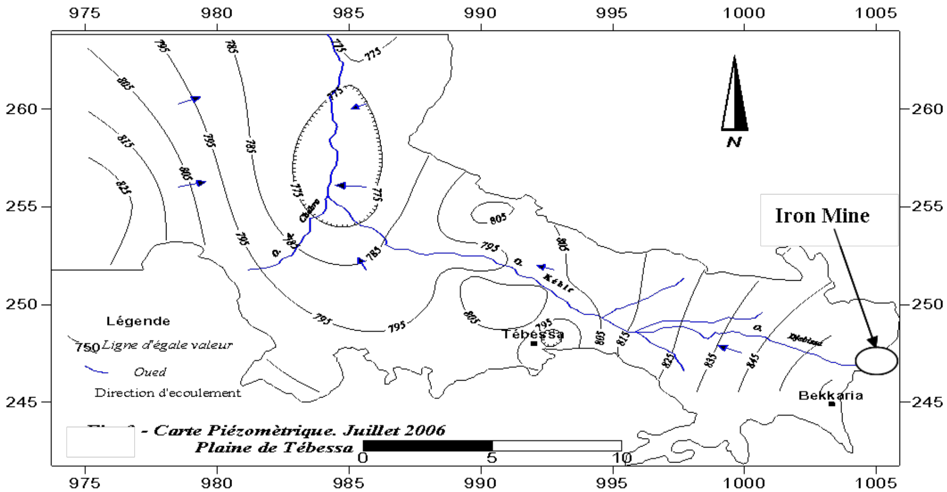

Figure 2: Piezometric map of the shallow aquifer (July 2006).

After the mining in the area was stopped (fig.3), no initiative for environmental protection was taken. This has reflected negatively on the environment. Indeed, for many years the spoil heaps remained deposited on the soil surface upstream of the wadis and the aquifer, directly exposing them to possible pollution. To demonstrate the effects of these spoil heaps on the water quality of this area, we will study the quality of water of both the wadis and the wells. The research will mainly focus on the analyzed metals and on the saliferous outcroppings upstream of the study zone.

Figure 3: Mount Djebissa and the abandoned mine.

The chemical components of the surface waters were the first part of this study. The analyses related to 8 points (fig.4), being distributed on the two wadis; wadi Djebissa and Oued el Kebir, according to the direction of the flow determined by piezometric map.

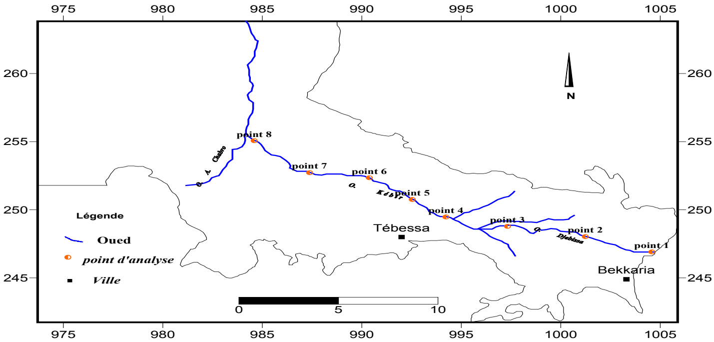

Figure 4: Distribution of sampling points of surface water.

The analyzed elements are: major cations and anions (Ca, Mg, Na+K, Cl, SO_4, HCO_3), trace elements, and the Sr^{2+} /Ca^{2+} ratio.

III – Results of measurements and analysis

Concentration of major elements and MTE in surface waters

The graphs show the concentration (mg/liter) of major elements present in the surface water over time (month, year). Figures 5 & 6 show that important concentrations of sulfates (1000 mg/l) and chlorides (800 mg/l) are present. These two elements move simultaneously. This is aggravated by the climate; indeed during the wet period the dissolution of gypsiferous formations introduces sulfate in the water. During the dry season the evapotranspiration increases the concentrations of chemicals by decreasing the dilution. Furthermore, chlorides are added. Sodium evolves in the same way as chlorides and sulfates. The other elements are more or less stable (table 1).

In the centre of the plain we notice an increase in Ca (400 mg/l) and HCO3 (700 mg/l). The concentrations of other substances such as Mg (250 mg/l), sulfates (400 mg/l) and chlorides (400 mg/l) decrease, but remain important during the dry period. The bicarbonates show an increase for the last points; this is explained by the contribution by the carbonate border.

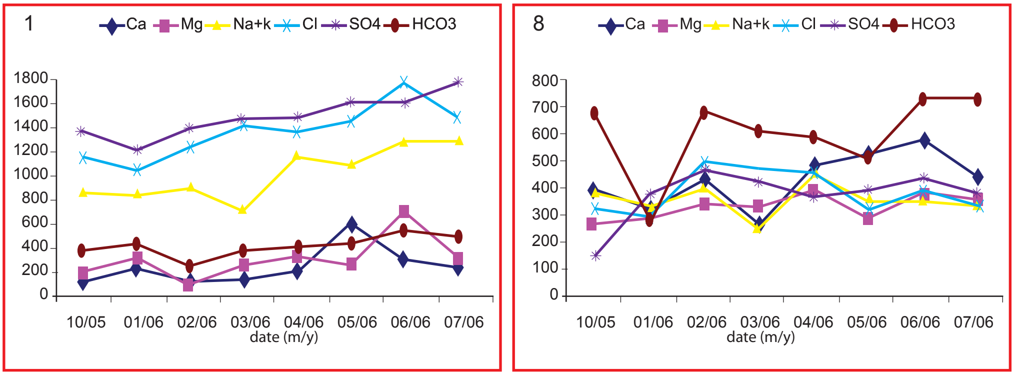

Fig. 5: (point 1) &. 6 (point 8): Spatial and temporal variation of concentration (mg/l) of major elements in surface water

Table 1: Concentrations of the major elements in point 1 and 8 in surface water in wet and dry periods.

	Periods	Ca	Mg	Na+K	Cl	HCO3	SO4
P1	October2005	129	160	833	1128	367	1343
	January 2006	200	271	725	967	360	1137
	February 2006	153	134	725	1160	260	1352
	March 2006	251	376	609	1320	466	1360
	April 2006	258	304	1040	1128	412	1272
	May 2006	537	295	940	1182	421	1280
	June 2006	226	573	967	1451	466	1280
	July 2006	223	296	1040	1272	537	1549

	Periods	Ca	Mg	Na+K	Cl	HCO3	SO4
P8	October2005	386	260	380	350	720	111
	January 2006	340	271	330	302	369	341
	February 2006	390	295	382	430	669	411
	March 2006	251	300	235	420	560	369
	April 2006	430	382	420	383	571	320
	May 2006	478	295	334	320	550	355
	June 2006	494	314	326	317	664	418
	July 2006	430	314	291	296	730	400

The variation of the metal trace elements in the surface water is irregular. Iron and manganese evolve together especially during the wet period. The contribution of these two elements is probably due to the dissolution of iron from the abandoned mine. Copper especially presents a light increase for the dry period; zinc has certain stability for the whole graphs. The observation of the graphs demonstrates a decrease in the concentrations of the trace elements away from the mine (fig.7 & 8), (Table 2). This tendency highlights a probable trapping of the MTE by the soil.

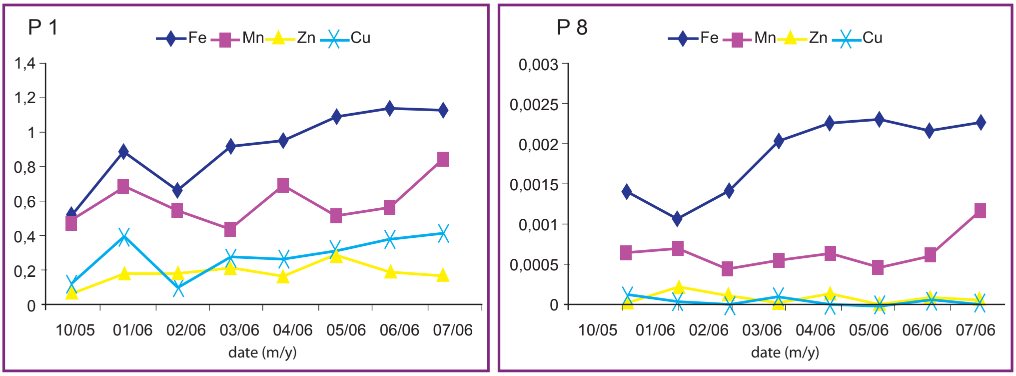

Fig. 7 & 8: spatial and temporal variations of MTE elements in surface water at points 1 and 8 (Fe, Mn, Zn , Cu)

Table 2: Distribution of the trace elements in surface water in wet and dry periods.

	Periods	Fe	Mn	Zn	Cu
P1	October2005	0,55	0,52	0,018	0,051
	January 2006	0,98	0,764	0,12	0,388
	February 2006	0,72	0,579	0,149	0,086
	March 2006	0,99	0,44	0,107	0,215
	April 2006	0,97	0,6	0,167	0,227
	May 2006	1,08	0,49	0,209	0,245
	June 2006	1,12	0,484	0,12	0,275
	July 2006	1,12	0,716	0,09	0,24
P8	October2005	0,0017	0,0008	0,0001	0,0002
	January 2006	0,0012	0,0008	0,0003	0,0001
	February 2006	0,0015	0,0006	0,0002	0,0001
	March 2006	0,0024	0,0007	0,0001	0,0001
	April 2006	0,0025	0,0008	0,0002	0,0001
	May 2006	0,0024	0,0007	0,0002	0,0001
	June 2006	0,0023	0,0008	0,0001	0,0001
	July 2006	0,0024	0,0014	0,0001	0,0001

Concentration of major elements and MTE in Djebissa wells:

The second part consisted of analyzing the water of wells. The points taken are distributed in the plain near the mount Djbissa (fig. 9)

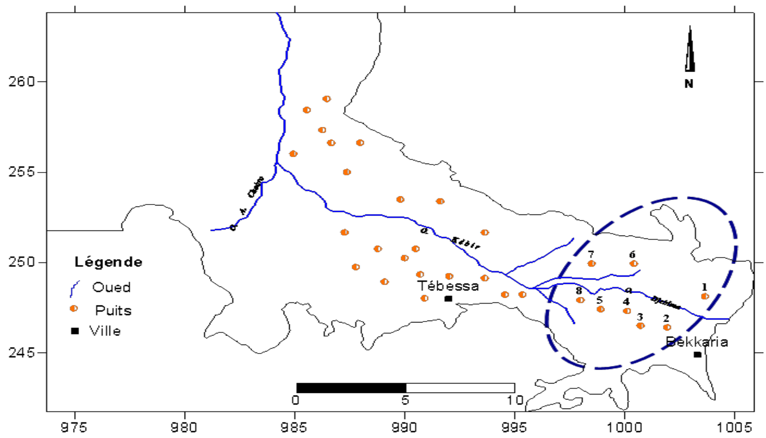

Figure 9: distribution of the sampled water wells.

The examination of the graphs carried out (fig.10), shows that water is characterized by high concentrations particularly of chlorides, sulphates and sodium. At well N°1, the concentrations for the three elements oscillate between 700 (Na+K) and 1600 mg/l for chlorides. In well 8, we noted a very steep fall of these concentrations, the maximum reached is about 700 mg/l and the minimum borders 400 mg/l.

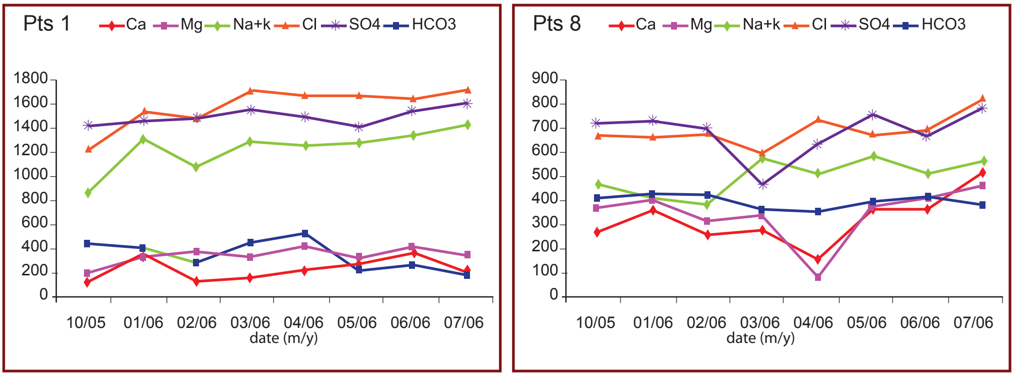

Figure 10: Spatial variation of major elements, in groundwater.

The concentrations of MTE in the groundwater samples collected from wells of the first aquifer, (fig.11), remain low. However, the iron concentrations are about 0.2 mg/l indicating water pollution. For the well 8 located far from the mine, the concentrations decrease to reach 0.05 mg/l.

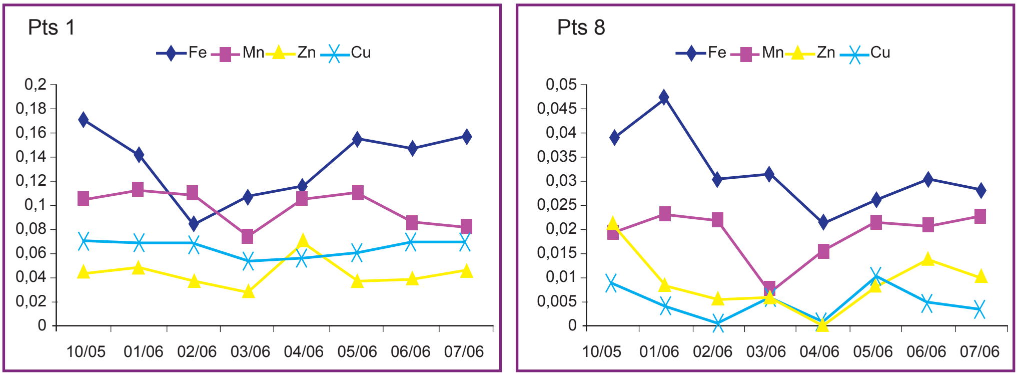

Figure 11: Spatial and temporal variation of presence of MTE in groundwater at points 1 and 8.

The interpretation of the results highlights a double variation of the concentrations:

- The first, the horizontal direction, indicating a decrease of the concentrations away from the mine. This distribution is generated by the flows that transport chemical elements.
- The second, the vertical variation, showing that water of the aquifer is not contaminated, which highlights a trapping of metals by the sediments.

Confirmation by Sr^{2+}/Ca^{2+} ratio :

The study of the Sr2+/Ca2+ ratio gives an indication of the influence of sorted gypso-saliferous on the water salinity. Strontium is related to the evaporites. The strong contents of Sr2+ in water are explained only by the dissolution of celestite (Sr SO4); a mineral associated with gypsum, it thus serves as a good marker of the presence of the evaporites.

In surface water (fig.12) the Sr^{2+}/Ca^{2+} ratio reached important values highlighting the influence of sorted gypsiferous substances on the quality of water. Indeed the dissolution of minerals contained in the formations enriched water in elements traces.

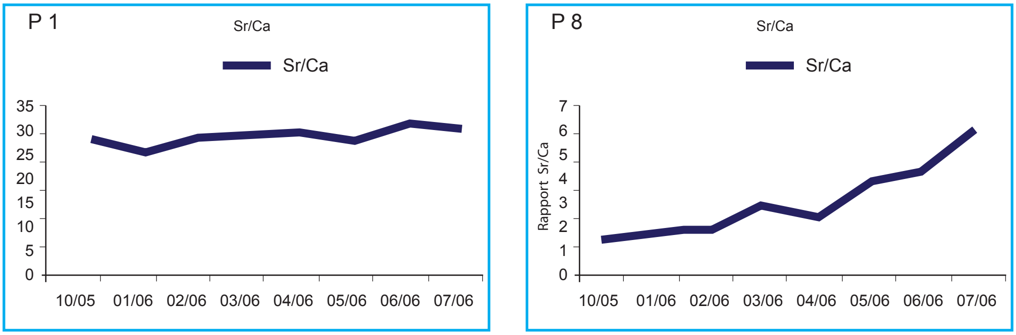

Figure 12: Sr2+/Ca2+ ratio over time in surface water at points 1 and 8.

IV – Neural networks analysis

Modeling constitutes another tool for the description of the impact of the iron mine on the quality of water. To complete our work we chose a model based on networks of artificial neurons.

Presentation of this method

A network of artificial neurons (RNA or ANN) is a nonlinear empirical model. It is composed of inter-connected elements of treatment (neurons) working jointly to solve a specific problem. Hecht Nielsen (1990) gives the following definition: a network of neurons is a system of calculation made up of strongly inter-connected simple elements of treatment, which process the data by their change of dynamic state in response to an external entry.

Connections between the neurons

The networks of neurons (fig.13) are organized in layers; these layers are composed of a certain number of inter-connected neurons which contain a function of activation.

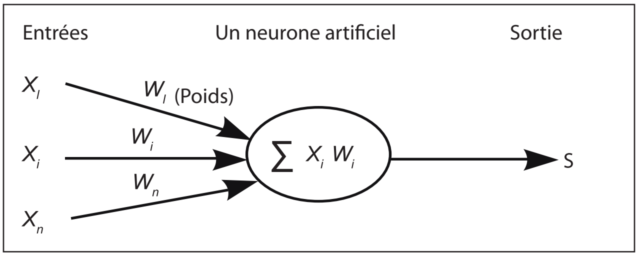

Figure 13: neural network

Creation of the model

In this work, a multi-layer network of Perceptron was selected as model of the system where the network treats a vector of input being composed of the variables including Ca, Mg, Na, K, Cl, SO4, HCO3, NO3, pH, M, and Sr/Ca. These vectors of input produced a vector of output (left) which is electric conductivity (EC). The network of MLP can be represented by the following compact form: {EC} = ANN [Ca, Mg, Na, K, Cl, SO4, HCO3, NO3, pH, mineralisation, Sr/Ca].

Choice of the execution criteria:

The data for the quality parameters of subsoil waters analyzed for the year 2006 were employed to create the model of the RNA by using STATISTICA software, neural network version 4.0. The parameters of water quality include: concentration of calcium (Ca^{2+}) ions, magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), sulfate ($S0_4^{2-}$), bicarbonate (HCO_3^{-}), nitrate (NO_3), hydrogen (pH), mineralization (M), and the strontium ratio on calcium (Sr^{2+}/Ca^{2+}). These parameters which represent the quality of water are regarded as input variables while the output variable (left) is electric conductivity (EC). The statistical parameters used in this work are: the Root Mean Square Error (RMSE) and the coefficient of R2 determination

Results and discussion:

The types of networks considered are: MLP (3 and 4 layers), RBF, GRNN and linear. During the analysis, 697 networks were examined. The best optimal model of the found RNA is the MLP (3 layers) with 6 hidden nodes (figure 3). The minimal error of 0.3125517 is compared with the other types of networks RNA (table 3).

Type of Network	Error (RMS)
GRNN	3.31
RBF	3.08
Linear	2.14
MLP (4 layer)	1.16
MLP (3 layer)	0.31

Table 3: Error RMS in various neural networks.

The model has an excellent performance in the checking with a report/ratio of regression of 0.016 and a correlation coefficient higher than 99% for the training. The sensitivity analysis of the water quality variables of RNA in phases of the training and of checking indicates that mineralization (M) and the strontium on calcium ratio (Sr^{2+}/Ca^{2+}) are the most important factors influencing electric conductivity in groundwater.

V – Conclusion

The work carried out concerns the effects of the spoil heaps deposited upstream of two wadis and a system of aquifers. The measurements carried out demonstrate that water of both the wadis and the sub-surface aquifer are charged with MTE. The concentrations observed in water of the wadis are, however, very high compared to the water of the wells. This would be due to the trapping of the MTE which takes place in the soil layer separating the two levels of water. The study of the ratio Sr^{2+}/Ca^{2+} shows the influence of the gypsiferous formations on the water quality. The results obtained by the mathematical model confirm this relation well.

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