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FORECASTING THE UPWELLING PHENOMENON USING AN ARTIFICIAL NEURAL NETWORK

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Abstract. In this paper, we investigate the upwelling phenomenon using data of 97 monitoring stations in Ouargla and El Oued valleys located in the Low Septentrional Sahara south of Algeria. This research paper constitutes a contribution to the morphological, hydrological, hydrogeological study of the water table in order to understand the processes of upwelling groundwater. By using ArcGIS as a mapping tool, we worked on real UTM coordinates in X and Y for real data overlay drawn maps in clear and usable way of this phenomenon. On the other hand, we propose a new method based on neural network to model the level fluctuation of the groundwater as well as to predict the evolution of the water table level. The obtained model allows us to warm this harmful phenomenon and plan sustainable solutions to protect the environment. The finding shows that the obtained model provides more significant accuracy rate and it drives more robustness in very challenging situation such as the heterogeneity of the data and sudden climate change comparing to the related research.

Keywords: upwelling phenomenon, monitoring stations, modeling, ArcGIS software, neural network

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1. INTRODUCTION

The upwelling of the water table level is in large part related to the consumption irrigation water for palm plantations that are main agrarian culture, mostly distributed in the south of Algeria, especially in Ouargla and El Oued. Recently, many research works achieved to overcome the aforementioned phenomenon constraints by performing the environmental, urban, demographic plans as well as they have tried to give some definitions to this phenomenon according to the vulnerability classes of the study areas. However, they could not yet arrive to the model to which the different parameters referred. Whereas this phenomenon balanced between its inputs and out puts, the entries consist mainly of water for irrigation (from deep waters) where the outputs are mainly due to evapotranspiration of vegetation, carried out to the Chott (saline lakes), and Sebkhas (salt pans).

Firstly, the inputs exceed outflows so the table rises and fills the pores of the overlying ground (between 10 and 40% by volume), where the capillary action is facilitated and the evaporation increases, which govern the stabilization of the water level. Secondly, in winter when the evaporation is low, the groundwater can be flushed in low spots and form free water surfaces in saline lakes (Chott). On the other hand, with the increases of the temperature, the water evaporates, and there occurs gypsum, salt.

This paper is organized as follow: firstly, we introduce the upwelling phenomenon and its harmful consequences, then a previous work will be presented, and we will present the neural network for modeling. Finally, a discussion about the obtained results is given and the conclusions are provided.

By analyzing the groundwater level, we see that there is an increase in water level over the years, due to several factors, mainly oasis irrigation. However, in recent years, we notice a big change in agrarian and political visions, and a tendency to use other types of agricultural crops such as potatoes, vegetables, olive trees. All these types of agriculture require more water from deeper aquifers, due to the scarcity of rainfall in this arid region. It triggers a phenomenon of saturation of the water table, which also causes the harmful effect of rising groundwater. In order to minimize environmental damage as well as maintain the pace of development in the region, first of all, public attention should be paid to proper resource management, avoiding bad practices, and introducing a monitoring system in the affected area in order to save palm trees as a cultural heritage.

2. PROBLEM STATEMENT

2.1. Origin of upwelling in the shallow aquifer in the south of Algeria

2.1.1. The superficial layer of El Oued and Ouargla

The system of shallow aquifers exists everywhere in the Sahara especially in rain- and flood-fed depressions and valleys. These shallow and deep aquifers (CT and CI) constitute the most important water reserve of Algerian Sahara since they provide numerous water wells course to supply water for the livestock and livestock farmers, but they can also give rise to oases or small-irrigated gardens with palm trees. Souf-Ghouts is the case of agricultural know-how in El Oued characterised by places dug between dunes as a specific method of implantation of palm groves relating to this region, allowing the roots of the palm trees to reach the capillary rise of the surface area where the phreatic zone is less than 15 m. In 2000, we received the data for over 1,000 wells; their depth varies from 30 to 80 m. The extract flow rate is of the order of 6,820 l/s, the permeability of the sands approaching 4 to 10 m/s (Zouini 2000).

2.1.2. Piezometric flow and upwelling zones

The hydrodynamic behavior of the surface water is shown by three piezometric measurements (February 1993, April 1995 and August 1997) over 200 wells, the basis for the analysis were the map and model. The establishment of different piezometric maps, led us to the following conclusions: the main direction of flow is generally from the south to the north and is in line with the morphology of dunes from deep drilling. On the one hand, it is connected with the lack of drainage system (due to negligence) and on the other, with urban waste – no sanitation network, as confirmed by further high concentrations of nitrates and bacteriological analysis) (Chehma 2011).

In short, the rising water level is certainly due to infiltration in permeable sands with a flow of about 3,800 l/s. This significant amount comes from deep aquifers of the Continental Intercalary and terminal complex, and infiltrates the shallow water table in the form of irrigation water and urban waste. The standards of drinking water supply and irrigation of the Sahara region exceed 400 l/day/capita. This quantity of water waste is mostly favored by the lack of irrigation water meter, industry, or anarchic individual holding (Chehma 2011).

2.1.3. The irrigation water drainage problem

Poor drainage or its lack in irrigated areas in the region led to a gradual swelling of the water table that produces a long-lasting state of excessive saturation affecting the root activity. This water-logging is the result of losses of irrigation water due to leaks and seepage from fields irrigated, land depressions, steep slopes without natural drainage system; in addition, drainage takes place inside the syncline bowl. All of this constitutes a significant part of this problem.

2.1.4. Variation of water table level and its consequences

Within the last ten years, the use of water for irrigation in Souf was very poorly conducted due to the absence of a drainage system and outfall has created serious problems of agricultural development. Discharges of domestic water in the absence of adequate sanitation has contributed to the creation or swelling of the surface water table causing pollution of its waters (Remini and Kechad 2011). As a whole, the problem of the increase of the water table level in Souf has created numerous problems in the field of agriculture (growing the date palm), the *ghout*, housing and public health. Now, there are over 28,600 date palms damaged (over a third of El Oued palm trees) and nearly 2,300 *ghouts* are drowned. Standing water appeared in some low areas of the city including Nezla wedges and Sidi-Mestour, causing subsidence of road networks. The harm to public health has been manifested by the appearance of malaria and in 2004, several cases of typhoid were reported in El Oued (Remini and Kechad 2011). These cases are certainly due to poor water quality still taken from the wells. Typhoid fever is a bacterial infection caused by ingestion of contaminated food or water. These disturbing findings require urgent action (Chehma 2011).

2.1.5. Rise and fall of the water table level (annual changes)

The wells which had been approved in this study, were examined in terms of changes in the depths of the water and its location and changes in underground water level. We can clearly see the repeatability and periodic cyclicality in changes in levels. Fig. 1 shows the response of groundwater levels to vertical water feeding (precipitation), where a rise was noted of the levels corresponding to the changes in precipitation, due to the proximity of water surface levels, as well as to high permeability of the ventilation range. Hence, we conclude the great role that can be played by the recharge water in the transfer of pollutants to the groundwater, which requires the removal of any sources of potential contamination, preventive measures to protect groundwater in this area of pollution.

In addition, the stability and balance in the conditions of aquifers, thanks to the good use of the aquifer, allow for the reconstruction of groundwater reserves as a result of the availability of food sources. Taking into account the water level fluctuations in the summer period caused by irrigation waters, it can be concluded that the water level in this area will not deteriorate significantly. However, one must be careful when considering long-term protection. On the other hand, we noted that the aquatic layer is annually fed with multi-component water (natural, artificial) of different values (depending on regions), and, therefore, groundwater is largely renewable. Finally, the groundwater system in this region shall be dependent on the climate (the water division line) and shall be directly related to rainwater precipitation. In the study area, where relative stability in the groundwater level was observed, concentration of intensive agricultural activities within the study area contributes to the conservation of water nutrition during the period drought through the infiltration of part of irrigation water and access to groundwater, where the surface of the water is located at relatively low depths.

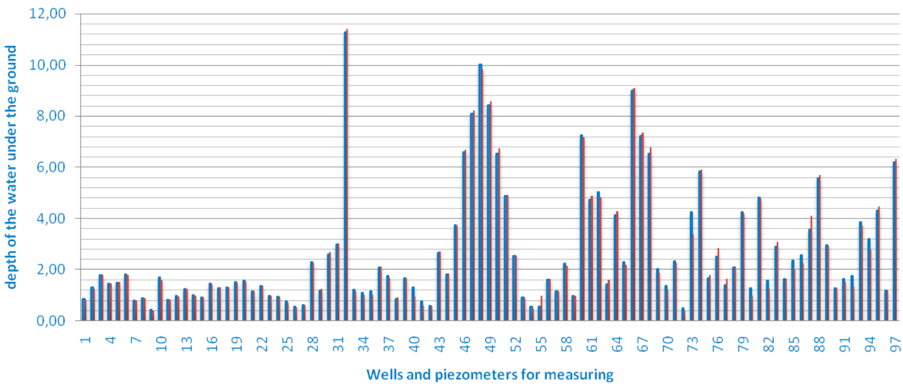

Fig. 1. Histogram of the fluctuation of the water table in 97 monitoring wells for groundwater level measurement in El Oued and Ouargla valleys (south of Algeria)

In order to further explain the seasonal changes that occur in the study area, we have adopted another method, namely drawing two maps that divide the groundwater depths into rises and falls periods and the evolution of these depths during these two periods. Changing the areas covered allows us to divide the study area into gradient ranges for the groundwater depths (Benguergoura and Remini 2016). In the Ouargla region, practically similar to the El Oued region (geological and hydrogeological continuity), the aquifer lithology was demonstrated by piezometer boreholes carried out by ENAGEO (1990), with a depth ranging from 6 to 10 m. To the south of Ouargla, the water table is made up of fine to medium clayey sand, rarely coarse, and more towards the north (N'goussa and Sebkhet Sefiounes) the sands are rich in gypsum, which becomes dominant in Sebkhet Sefiounes. Besides, we note the lithological continuity that exists between the underlying Miopliocene sands and the Quaternary sands, which suggests that the two formations constitute practically the same aquifer. The studies of ground water level by Lelièvre (1969) and Nesson (1978) show in general, as elsewhere in the entire eastern basin of the Lower Sahara, that the direction of the flow of water from the water table follows that of the aquifer of the Terminal Complex, i.e. that from the south to north (Ouargla-Chott Melrhir axis). However, in Ouargla there are two distinct zones separated by a watershed at the level of Bor El-Haïcha which results in:

– the main flow towards the north (Sebkhet Sefioune),

– secondary flows towards the Sebkhas around Ouargla.

The piezometers were the subject of this report. They are concentrated in and around the city of Ouargla, and extend in one or two lines towards the North to Sebkhet Sefioune along the axis of the Oued Mya Valley. Their distribution provides a good view of the slope of the aquifer along the axis of the valley. The Sahara is the largest desert, where desert conditions reach their greatest harshness (Chehma 2011, Nesson 1978). The northern Sahara, with 1 million km^2, is dominated by an extreme Mediterranean climate, where rain always occurs in winter (Chehma 2011, Nesson 1978). In the Sahara, rainfall is not only infrequent, but still very irregular. The monitoring of flow conditions is specific to the absence of regular water flow in the oases, the disorganization of the fluvial system and the dispersion of water in the form of "ponds" (*gueltas* or *redirs*) (Capot-Rey 1952, Estienne and Godard 1970). In the northern Sahara, there is the sedimentary basin which is a vast groundwater basin with an area of 780,000 km^2, with a maximum thickness of 4,000 to 5,000 m (CASTANY 1982). The potential of the Algerian Sahara in terms of water resources is estimated at 5 bn m^3 (ANRH 2000).

The structures in the Sahara sedimentary basins are characterized by large, deep rain-fed reservoirs, which date back to the rainy periods of the Quaternary. The water table of Continental Terminal (100–400 m depth), and the groundwater of Continental Intercalary called "Albian" (1,000–1,500 m depth) contain large reserves (from 30,000 to 40,000 bn m^3) but because the very low turnover rate, the exploitable potential is very limited (5 bn m^3/year) (Chehma 2011). These Saharan water potentials are an asset for all economic and social activities at the regional level. In addition, there was observed the economic development of other areas thanks to these waters (Chehma 2011). Kriebel *et al*. (1998) investigated the costal upwelling prediction with a mixture of neural networks, whereas Chaudhari (2008) presented a novel method for the detection and segmentation of upwelling regions in AVHRR SST data.

3. CRITICS OF PREVIOUS WORKS AND HYPOTHESES

The present study concerns the phenomenon of groundwater uplift in the study area. It is clear that previous studies need to be re-analyzed with other criteria in mind, and assumptions can be overlooked for one reason or another. Unfortunately, most authors interested in general descriptions of the upwelling phenomenon, do not pay attention to mathematical models. The subject of this research work (where use the morphological, physical, hydro parameters) is to achieve a high accuracy model capable of predicting the table water level.

4. MATERIALS AND METHODS

4.1. Mapping by using the ArcGIS software

In this section we present the variation of phreatic zone level measurement of the last ten years. The maps given below (Fig. 2 and 3) were elaborated in May 2015 by using the ArcGIS software.

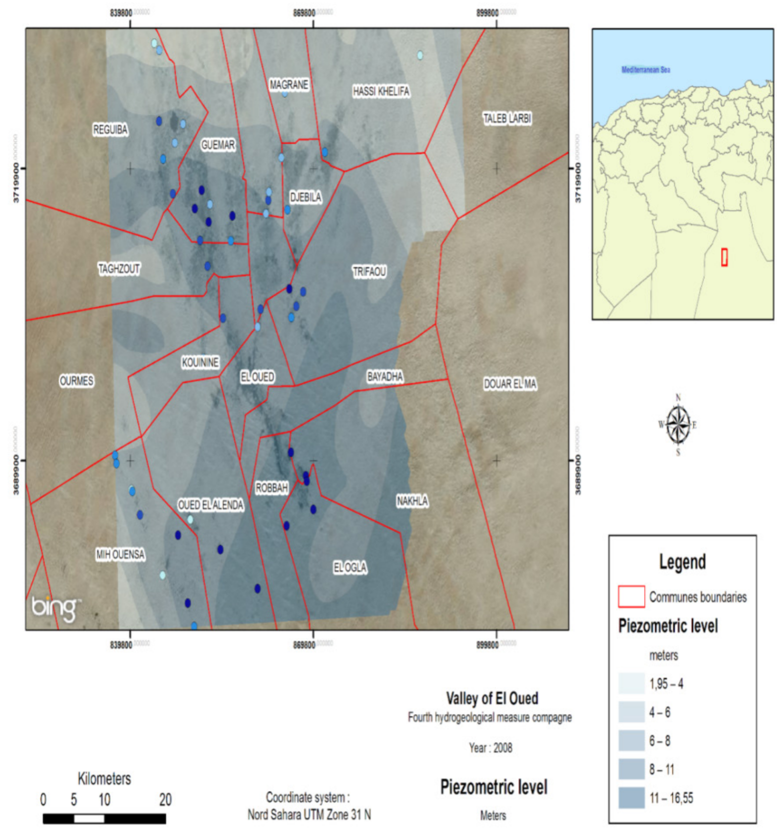

Fig. 2. Map of valley of El Oued (south-east Algeria) showing the spatial distribution of the groundwater level rises and falls located at 97 monitoring stations (hydro-geological measure conduced in 2008)

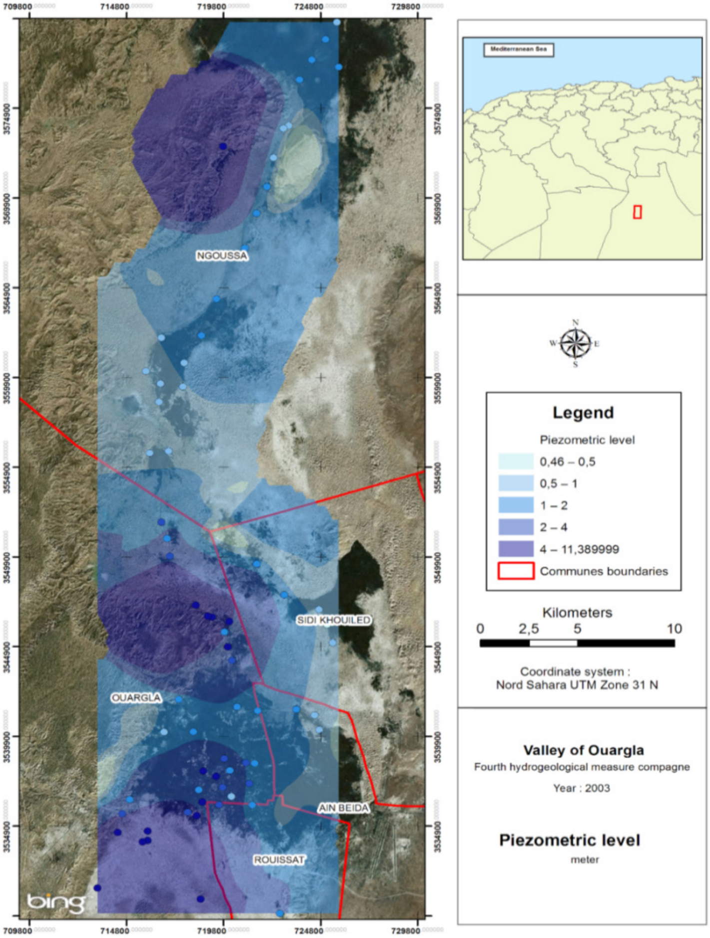

Fig. 3. Map of valley of Ouargla (south-east Algeria) showing the spatial distribution of the groundwater level rises and falls located at 97 monitoring stations (hydro-geological measure conducted in 2008)

4.2. Modelling and prediction using a neural network

This section describes the prediction paradigm of supervised learning, which is commonly used to model the upwelling phenomenon. The Artificial Neural Network (ANN) is a parallel distributed information processing system that has certain characteristics resembling biological neural networks of the human brain (Haykin 2005, Nayak *et al*. 2006, Mohanty *et al*. 2010). ANN models have been widely applied in various fields of science and technology involving time series forecasting, pattern recognition and process control (Nayak *et al.* 2006, Djelal and Saadia 2013). The neural network is defined by the structure of adjoin between nodes, method of measuring its weight and an action function (Mohanty *et al*. 2010). There are different kinds of neural networks, e.g. Hopfield, Perceptron, etc. Neural networks can be categorized according to their training algorithms. Different kinds of training algorithms are feedforward backpropagation, radial basis function, gradient descent with momentum and adaptive learning rate back propagation, Levenberg–Marquardt (LM), Bayesian Regularization (BR), etc. (ASCE 2000a, b). The neural network which is usually used for hydrological field is a multilayer progressive neural network with the back propagation learning algorithm. In the present work, we have used the neural network in order to predict the level of the phreatic zone. Fig. 4 illustrates the structure of the supervised learning of the neural network, where the training algorithm must adjust the parameters of the neural network to minimize the error. In Fig. 4, x represents the vector of the input data which consist of: the soil salinity, volumetric flow rate, and NO_3; y represents the vector of the output, and $\hat{y}$ is the predicted value of y, i.e. it represents the level of the phreatic zone. This network is composed of one input layer of three neurons, one hidden layer of twenty neurons and one output layer of one neuron. The neural network is capable of implementing a set of functions:

$$f(x, w),\ \ w \in A$$

where: A is a set of parameters (weights and biases) in the neural network (Djelal and Saadia 2013).

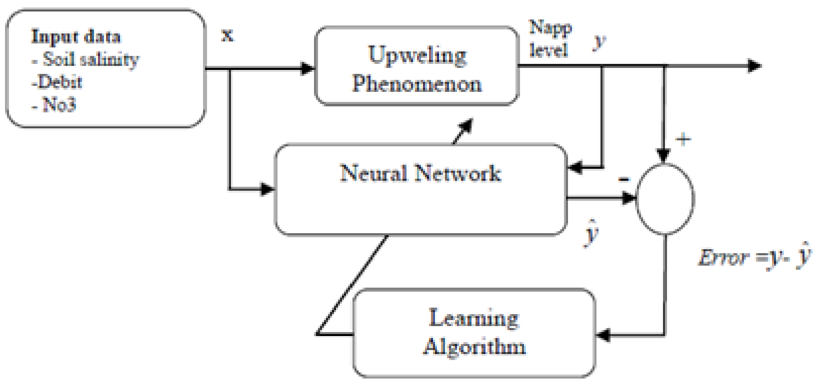

Fig. 4. Neural network supervised learning

4.2.1. Modeling based on neural network

In this section, we present the neural network architecture and the way it is used in order to model the upwelling phenomenon. It is worth mentioning that we have to follow these steps:

– to propose an accurate architecture for the neural network, i.e. the number of the neurons that constitute the input layer, the hidden layer and the output layer,

– to provide the activation function (to process the data),

– to provide the training algorithm (in order to minimize the prediction error).

The general architecture of neural network uses three-layer neural networks with the same activation function; nonlinear sigmoid function (Djelal and Saadia 2013).

$$f(x) = \frac{1}{2} X_g \frac{1 - \exp(-4x / X_g)}{1 + \exp(-4x / X_g)} \tag{1}$$

where: *Xg* is the parameter determining the sigmoid function shape.

4.2.2. Learning process of the neural network

This process of learning provides us with the parameters of the neural network, i.e. weights and the biases. Before starting this process, we must fix the criterion or the cost function that describes the relationship between the target and measured values. In our dataset, which is composed of a set of input/output, we have relied on a supervisor to learn the neural network: The Levenberg–Marquardt algorithm uses this approximation (eq. 2) to construct the Hessian matrix as follows (Djelal and Saadia 2013):

$$w_{k+1} = w_k - \left[J^T J + \mu I\right]^{-1} J^T e_f \tag{2}$$

where: w_k is a vector of current weights and biases, and where the scalar μ is equal to zero (similar to Newton's method). When μ is large, this becomes gradient descent with a small step size. Then Newton's method is faster and more accurate. Thus, μ is decreased after each successful step (low performance function) and it is augmented only when a tentative step increases the performance function.

5. RESULTS AND DISCUSSION

5.1. Fluctuation of the water table

The obtained results of different well-depth measurement are drawn in the histogram below. It shows the variation of the groundwater level. The study of seasonal changes in groundwater levels is useful in determining the general features of a system during a specific time period, the annual changes indicate how stable the system is. Therefore, we have collected data and information on changes in the depth of groundwater levels in some of the wells in the study area at the Directorate of Water Resources in El Oued and Ouargla valleys (south of Algeria). Measurements were taken from the beginning of 2008 to the end of 2010, for 97 wells located within the area. During the years of observation, the changes in the depths of the water and its location as well as in water capacity were examined (Fig. 1).

Fig. 1 shows the deep changes of groundwater in the wells with the amount of rainfall and water irrigation from 2008 to 2012 in the period from January to August. The observed groundwater was thick. It rests on a thick waterproof level. It occupies the bottom of the Ouargla and El Oued valleys, where maximum fluctuation Value is 85 cm, minimum fluctuation value – 2 cm and average fluctuation value – 2 cm.

5.2. Mapping by ArcGIS evaluation

In Fig. 2 and 3, we can note the groundwater level measured for this harmful phenomenon that presents a great a risk of environmental vulnerability referring to the groundwater of these two valleys, therefore, many researchers are studying it and defining the causes and trying to think of adequate solutions. In general, the study and analysis of the value of groundwater change during the year provided important information on the value and nature of sources of nutrition and drainage, and this relates to the variables that occur in the cases in which groundwater is present – either natural (water, evaporation, etc.) or artificial (irrigated land, leakage from irrigation channels, pumping from wells for local purposes). The depth of the water given using an electric probe with a depth of investigation of 100 m is compared; we carried out the measurements of the depth of the underground water, or the static level (SL) of the water table of the study zone between the different wells and their evolution with time. Our observations of different wells (see Fig. 2 and 3) show that in the case of most piezometers, the water is less than 2 m below the surface of the ground. The depth extends over a wide range from 0.48 m up to 10.51 m. The south-west region has a relatively deep water table: between 6 and 10 m. It is more than 8 m in the piezometer at Hassi Berahla, while towards the North (at Bor El-Haïcha), we recorded a depth of 10.51 m at the level of the piezometer P059. The water table is, therefore, deep in this water point because the structure is located in the sandy-gravel formations of the Mio-Pliocene (water table).

5.3. Modeling evaluation

The results of the neural network learning are illustrated in Fig. 5, whereas the best validation value is 1.91 at the epoch number 10. Fig. 6 illustrates the regression plots of the neural network outputs with respect to targets for training, validation, and test sets. In the case of the perfect fit, the data should fall along a 45-degree line, where the network outputs are equal to the targets. To evaluate the performance of model provided by the neural network technique, we have proposed to calculate the measures of the mean magnitude of relative error (MMRE) and the standard deviation magnitude of relative error (StdMRE). These two criteria are widely used in evaluating the model's quality (Conte *et al*. 1986, Elish 2012).

$$MMRE = \frac{1}{n}\sum_{i=1}^{n} MRE_i \tag{3}$$

where: MRE_i represents the normalized measure of the difference between the actual output values of the model (y_i) and predicted value $(\hat{y}_i)$ given by:

$$MRE_i = \frac{|y_i - \hat{y}_i|}{y_i} \tag{4}$$

where the use of StdMRE is very important because it is less sensitive to extreme values compared with MMRE.

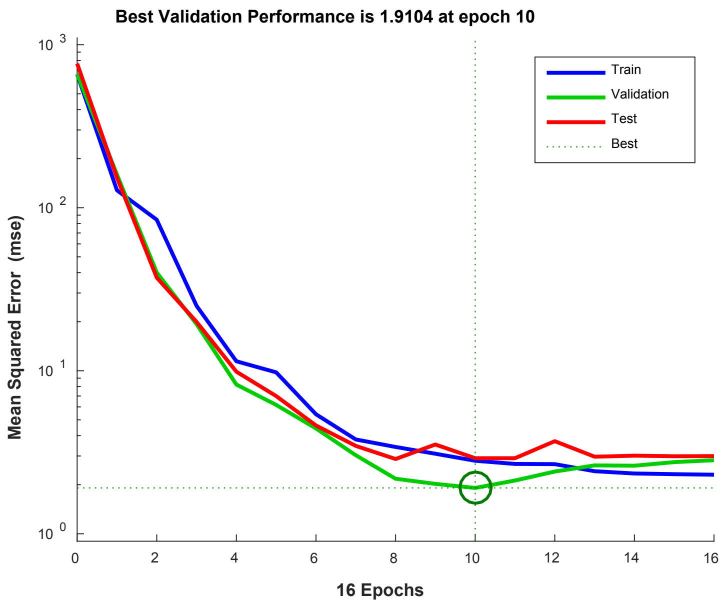

Fig. 5. Learning results

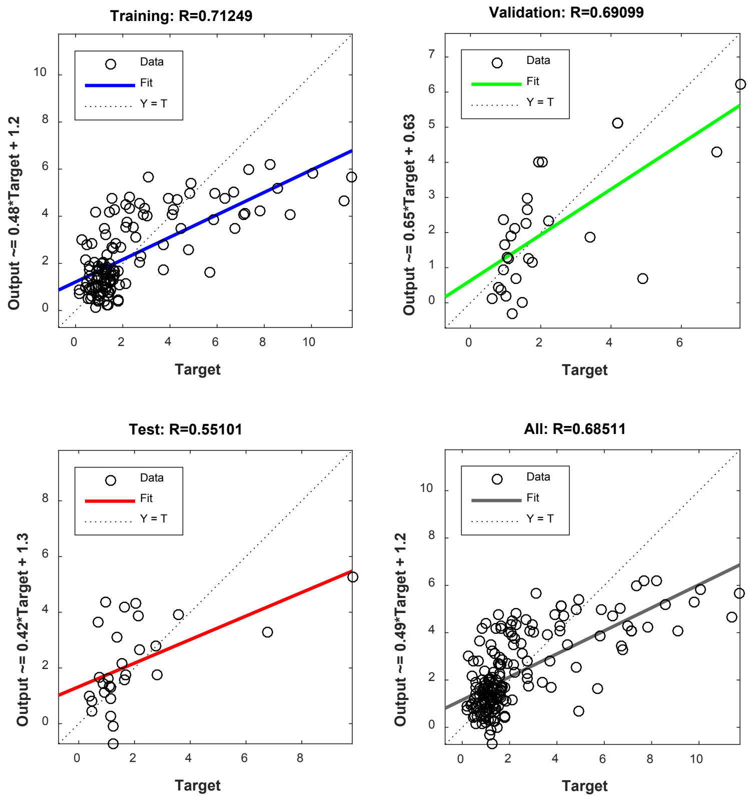

Fig. 6. Regression plots

6. CONCLUSIONS

In our research, our attention was paid to many parameters (morphological, hydrological, hydrogeological) of the groundwater rising phenomenon. The data collected in the study area (Ouargla, El Oued, southern Algeria) should form the basis for finding lasting solutions. One of them is the introduction of appropriate irrigation systems and a drainage system to drain the soil. Studying the issue of the accuracy of hydrographic predictions depends on the validity of the initial information to be drawn in the scheme of filtration calculation. Creation of maps for the distribution of hydrogeological parameters of basins and zones can be achieved after a detailed study of the salient properties of these areas (through test leakage work). Researching on the salient properties of the water-bearing class, clarification of the laws and circumstances of the formation of these properties, and mapping of watercourses based on values calculated in some of the studied sites (Pumping experiments) is a very complex process, especially in areas with complex hydrogeological conditions such as the case of the study area. The need to develop methods for determining hydrogeological parameters has resulted in a change in the method of creating watercourses, and other maps have been developed in recent years, especially after the extensive use of mathematical models to solve various hydrogelological issues. In the hydrogeological model, in order to check the structure of the water-bearing layer, the reproduction of a water-level map is carried out. The proposed technique of modeling based on neural network was validated; by analyzing of obtained results we can assess that the result model presents very good accuracy. For further research we suggest the use of the neuron fuzzy logic in order to accelerate the learning procedure. This approach will be the goal in our future research.

7. ACKNOWLEDGEMENT

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