Cumhuriyet Science Journal
CSJ

e-ISSN: 2587-246X
ISSN: 2587-2680

Cumhuriyet Sci. J., Vol.39-1(2018) 87-94

Forecasting of Ra-226, Th-232 and U-238 Concentrations using Artificial Neural Networks (ANNs)

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Received: 30.11.2017; Accepted: 31.01.2018 *http://dx.doi.org/10.17776/csj.359924*

Abstract: Identification and modeling of radioactive concentrations in a region is very important for the region in terms of radiological hazards. Artificial Neural Network (ANN) can successfully model large systems. The validity of the model was tested by entering the data of the proposed ANN model that had never been entered into the system. In this research, average activity concentrations of ^{226}Ra, ^{232}Th and ^{238}U in the water samples collected from the lake are 1.439 Bql^{-1}, 4.508 Bql^{-1} and 14.682 Bql^{-1}, respectively. The characteristics of the study area are also determined with the spatial maps and ANNs are used to prediction and modeling of the radionuclides. The mean square errors for the obtained results are less than 1.5%. The correlation coefficient close to +1 indicates the validity of the model for this study.

***Keywords*:** Natural Radioactivity; Transport, Distribution, Radium, Thorium, Uranium, Modelling, Prediction, Artificial Neural Network

Yapay Sinir Ağları (YSA) Yöntemi Kullanarak Ra-226, Th-232 ve U-238 Konsantrasyonlarının Kestirimleri

Özet: Bir bölgedeki radyoaktif çekirdek konsantrasyonlarının belirlenmesi ve modellenmesi radyolojik tehlikeler açısından bölge için oldukça önemlidir. ANN büyük verilere sahip sistemleri başarılı şekilde modelleyebilir. Önerilen ANN modelinin sisteme daha önce hiç girilmemiş verileri girilerek modelin geçerliliği test edildi. Bu çalışmada, çalışma alanından toplanan su örneklerindeki ortalama aktivite konsantrasyonları ^{226}Ra, ^{232}Th ve ^{238}U çekirdekleri için sırasıyla 1.439 Bql^{-1}, 4.508 Bql^{-1} ve 14.682 Bql^{-1} dir. Çalışma alanın karakteristikleri de belirlendi ve ^{226}Ra, ^{232}Th ve ^{238}U radyoaktif çekirdek konsantrasyonlarının tahmini ve modellemesi için Yapay Sinir Ağları (YSA) kullanıldı. Elde edilen sonuçlara ait ortalama kare hatalar 1,5 tan azdır. Korelasyon katsayısının da +1 e yakın çıkması modelin geçerliliğinin bu çalışma için uygunluğunu göstermektedir.

***Anahtar Kelimeler*:** Doğal Radyoaktivite, Taşınım, Dağılım, Radyum, Toryum, Uranyum, Modelleme, Tahmin, Yapay Sinir Ağı

1. INTRODUCTION

Natural radiation is usually classified as either terrestrial or cosmic radiations. The most significant naturally occurring radioisotopes are radionuclides from the ^{238}U and ^{232}Th series with their degradation products. These radionuclides occur in small amounts in the Earth's crust with varying concentrations. Thus, natural environmental radiation varies from region to region around the World and even there are

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differences between regions are very close together [1,2].

The geological structures there are various amounts of radioactive material. The presence of radionuclides in the earth's crust is a source of natural radioactivity. Almost all uranium is found in nature as the isotope ^{238}U. Uranium is not free in nature and also uranium minerals are generated as combine to with various elements. In almost all types of rocks and waters found radioactivity in trace amounts. Thorium there is very low density in river and ocean waters and is moved adhered to particles by deposited on the sea floor and rivers. ^{226}Ra is occurred of the resulting ^{238}U decay and is one of the most important finds of natural radioactive substances in water. Generally, it is absorbed by the substance being transported on the river, radium throw in particles high salinity region. It cannot move very far from where it occurs in salt-free groundwater, because absorption is likely [3,4,5].

The aim of this study was to obtain ANNs modelling and predictions of some radionuclides for the Hazar Lake region of Elazig province. This study is based on the measurements of the natural radionuclide activity concentrations in water. The water samples collected from the region were analysed for the concentration of ^{226}Ra, ^{232}Th and ^{238}U by gamma sensitive ST7 Scintillation Counter in the laboratory. An ANN model as addition to chemical analysis of water samples was proposed using the activity concentrations of radionuclides and the results of chemical of water. In the literature, applications of ANN have been reported in various areas in nuclear physics [6-13]

2. MATERIAL and METHODS

Research Area

Hazar Lake is the deepest freshwater lake (about 250 m) of Turkey and is also among the deepest lakes in the world. The lake has a tectonic structure and is on the Eastern Anatolian Fault Line, which is one of the most seismically active fault lines in the world. The research area is located at the north of the basin Çelemlik Mountain (1747 m) and Mastar Mountain (1724 m), south of the Hazar Baba Mountain (2347 m) [14].

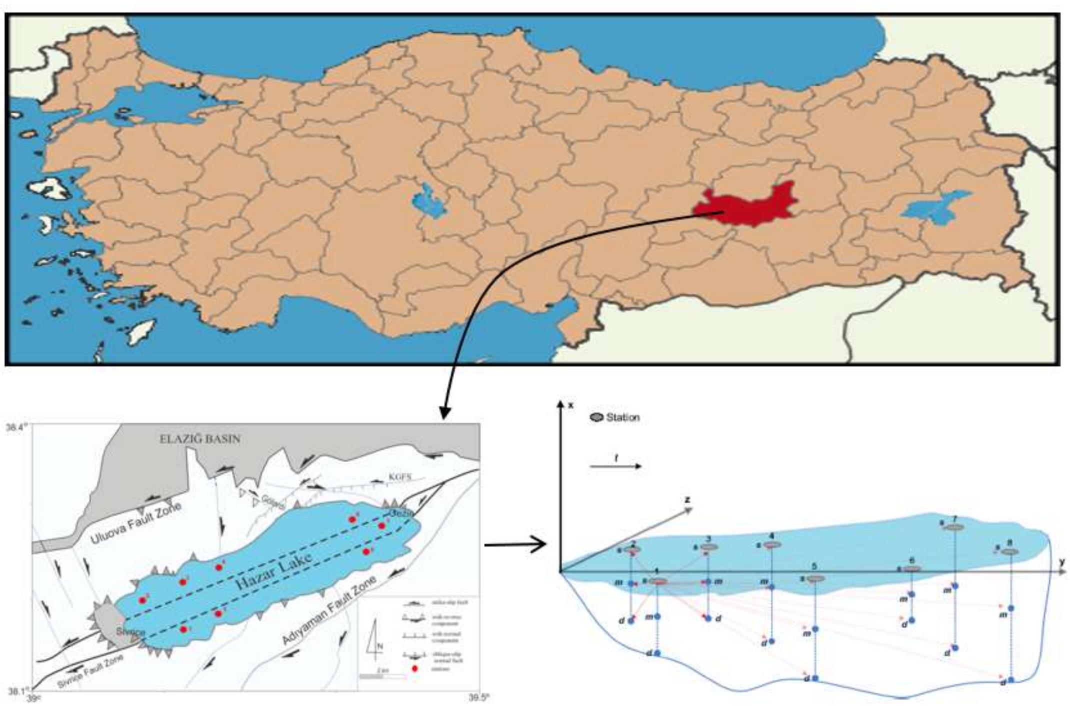

Figure 1. Research area and sampling stations.

Water samples were taken from surface, middle and bottom depths and from different sections located around of the lake to determine the activity concentration of Hazar Lake. Sampling stations are shown in Figure 1. 24 water samples are collected from the research area.

Sterilized 1 liter bottles are used for radioactivity analysis. Three samples from the same sample are prepared for the measurement analyses. Samples are placed in beakers and water samples were evaporated by evaporation without boiling at 60 ° C. The remains in the beakers are transferred to the planets with the help of pure water. The planets are dried under UV lamps and placed directly in the counter for counting.

The activities of ^{226}Ra, ^{232}Th and ^{238}U were achieved by gamma sensitive ST7 Scintillation Counter. Obtained measurement results were calculated gamma activities of the samples using Eq.1

$$A = \frac{C}{\varepsilon . P_{\gamma} . V_s} \quad \mathrm{Bq/l} \tag{1}$$

where C is the count per unit time, ε is efficiency detector of characteristic gamma ray, $P\gamma$ is characteristics of gamma rays released probability, V_s is volume of sample and A is gamma activity.

Artificial neural network modelling

Artificial Neural Networks (ANNs) methodologies are the whole of methods developed by taking the neurons in the human brain as an example. The neurons are the basic elements artificial neural networks, too. They come together via the connection and they form the ANNs. An artificial neuron that is the smallest of the information processing elements of ANN. Its basic structure given in Fig. 2. An artificial neuron consists of several basic parts, namely: Components of output, transfer function, combining function, weights and inputs.

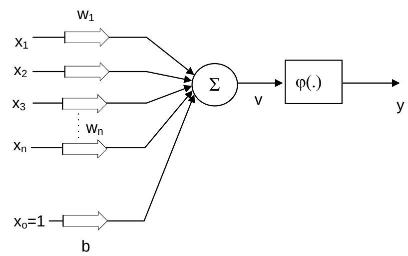

Figure 2. Artificial Neuron Model

Through the systems called the cells in ANN, the signals flow through each other. In an ANN, each connection has a weight and it is the multiplier of the signal passing through the link. For each cell determine its output to the net inflow implements generally a nonlinear activation function [15].

$$v = wx + b \tag{2}$$

$$y = \varphi(v) \tag{3}$$

where w is matrix cell weights, x is input vector to cells, v is a net inflow of cells, b is cell bias input, y is cell output and φ (.) is shows activation function of the cell. Collecting function, nerve cell performs a linear combination of the inputs and the numerical sum of these two vectors gives the net input [16].

ANN model used in this research, depending on the inputs and output are shown in Fig. 3.

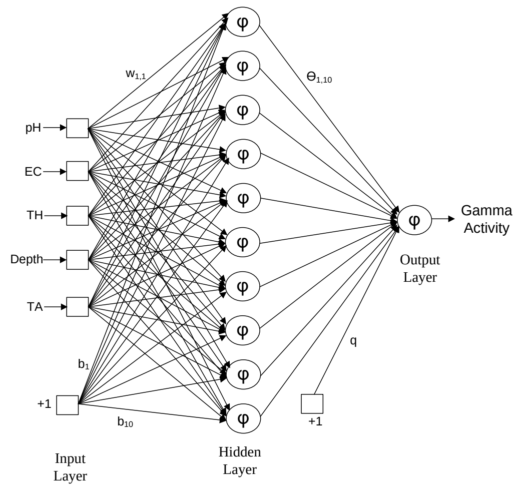

Figure 3. Feed forward back propagation ANN architecture that was used in modelling.

Herein EC is electrical conductivity; TH is total hardness; Depth is depth range of the lake and TA is total alkalinity, which ANN represents entry.

Table 1. ANN architecture and training parameters

Architecture	
Number of layers	3
Number of neuron on the layers	Input: 5, hidden: 10, output: 1
Activation function	Tan-sigmoid, Purelin
Training parameters Learning rule	Backpropagation
Adaptive learning rate	0.01
Momentum constant	0.5
Mean squared error	0.0004
Epochs	20.000

The back-propagation algorithm (BPA) is used in this study. BPA is known to give very meaningful and consistent results, especially in prediction or estimation studies [16]. There is no specific standard for the number of hidden layers. This number is somewhat directly proportional to the experience of the analyst. The number of neurons in this layer usually varies from 5 to 20. In this study, hidden layer is formed from 10 neurons. The ANN model is run under 20,000 iterations and results are obtained.

The number of iterations in the ANNs model affects the learning coefficient and the learning rate. It is preferable to select the learning coefficient [0, 1]. If the learning coefficient is chosen around 0, then the number of iterations also increases. In other words, convergence slows down. If the learning coefficient increases, then the number of iterations decreases. Perhaps this may save time in terms of program operation, but this time the model goes to memorize [16, 17].

Another important parameter in the ANN is the momentum coefficient. Its value can range from 0 to 1. Small selection of the momentum coefficient leads to better results [17].

3. RESULTS and DISCUSSION

The Hazar Lake has an interesting geological structure. The lake is a tectonic lake. The presence of the Earth on one of the most active faults in the East Anatolian Fault Zone causes the lake's natural radioactivity to be well above the standards. The contribution of the fault lines to the natural radioactivity of the environment is indisputable. Other natural disasters, such as earthquakes or floods, cause large displacements in and around the earth's crust. This leads to an increase in the natural radioactivity of the environment in question. Lake Hazar is one of the most beautiful examples of this. The average concentrations found in this study are 1.439 Bq/l for ^{226}Ra, 4.508 Bq/l for ^{232}Th and 14.682 Bq/l for ^{238}U, respectively.

In Figure 4, the activity concentrations of ^{226}Ra, ^{238}U and ^{232}Th in the lake is given respectively. The maps in figure 4 were drawn with the Triple Diagram Method [18].While ^{226}Ra concentration has the highest value in the southwest part of the lake, ^{238}U concentration has the northwest part of the lake. The concentration of ^{232}Th seems that have a high concentration distribution in the southwest part of the Lake and in the north-south direction in mid-latitudes. High concentrations of activity in different parts of the lake can result from the fact that the geology and environmental factors of the lake are more influenced by the distribution of these radionuclides and consequently, radionuclides accumulate in the soil and rocks near these parts.

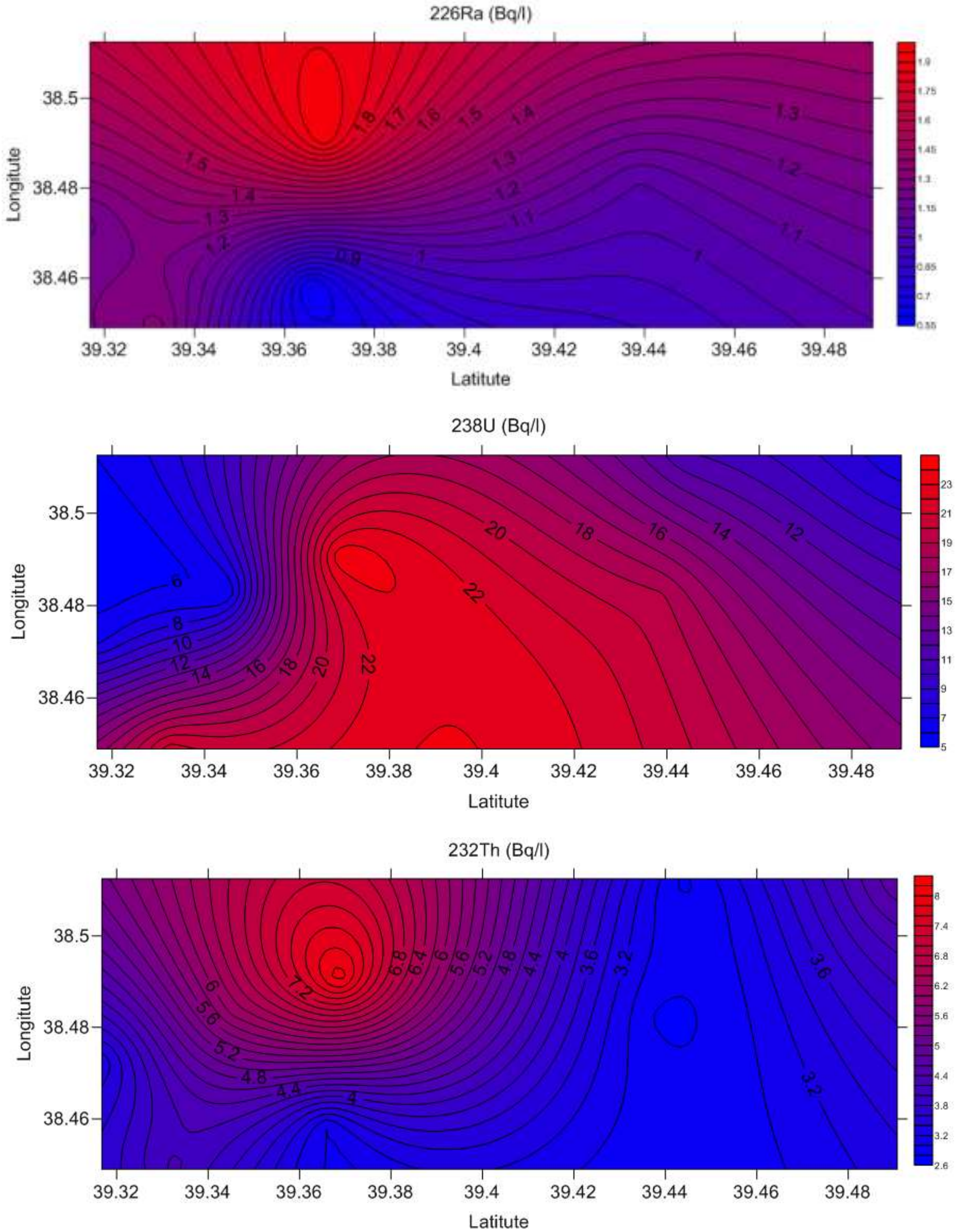

Figure 4. Activity concentration distributions for ^{226}Ra, ^{238}U and ^{232}Th, respectively.

In this study, in the training of ANN, five parameters pH, electrical conductivity (EC), total hardness (TH), total alkalinity and the water lake's depth are used for natural radionuclides (^{226}Ra, ^{232}Th and ^{238}U) as input parameters. Target output parameters are activity values of radionuclides. 19 out of 24 samples obtained from stations were used to train (ANN), and 5 of them were used to test the artificial neural network trained. Test samples that are not introduced to ANN before this are estimated by ANN.

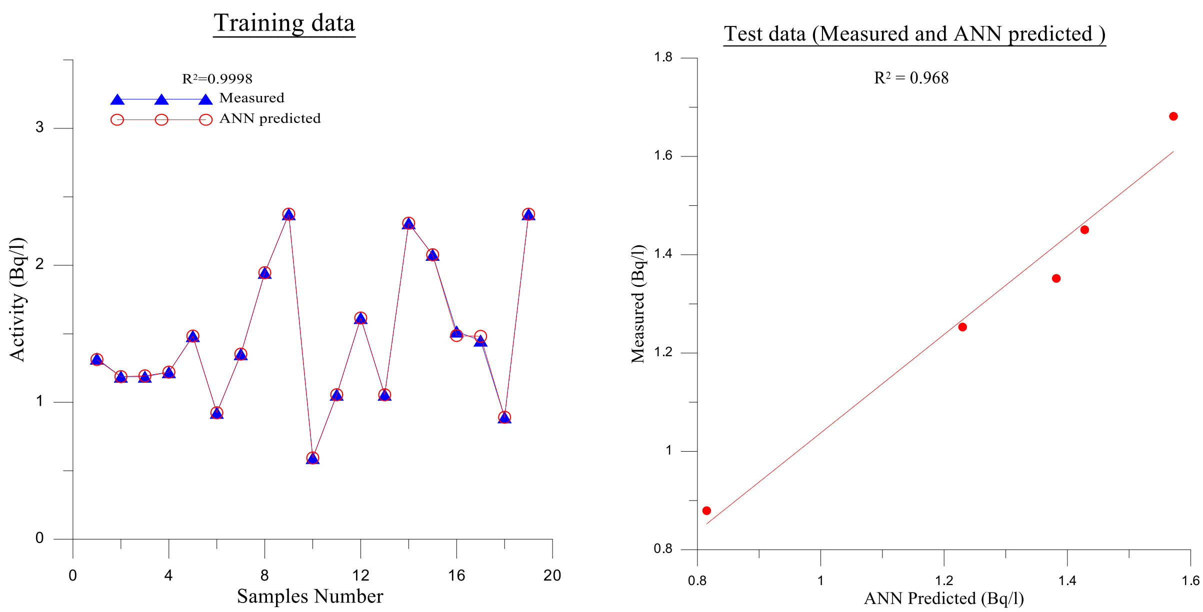

Figure 5. ^{226}Ra activity values predicted by ANN and measured for training data and test data.

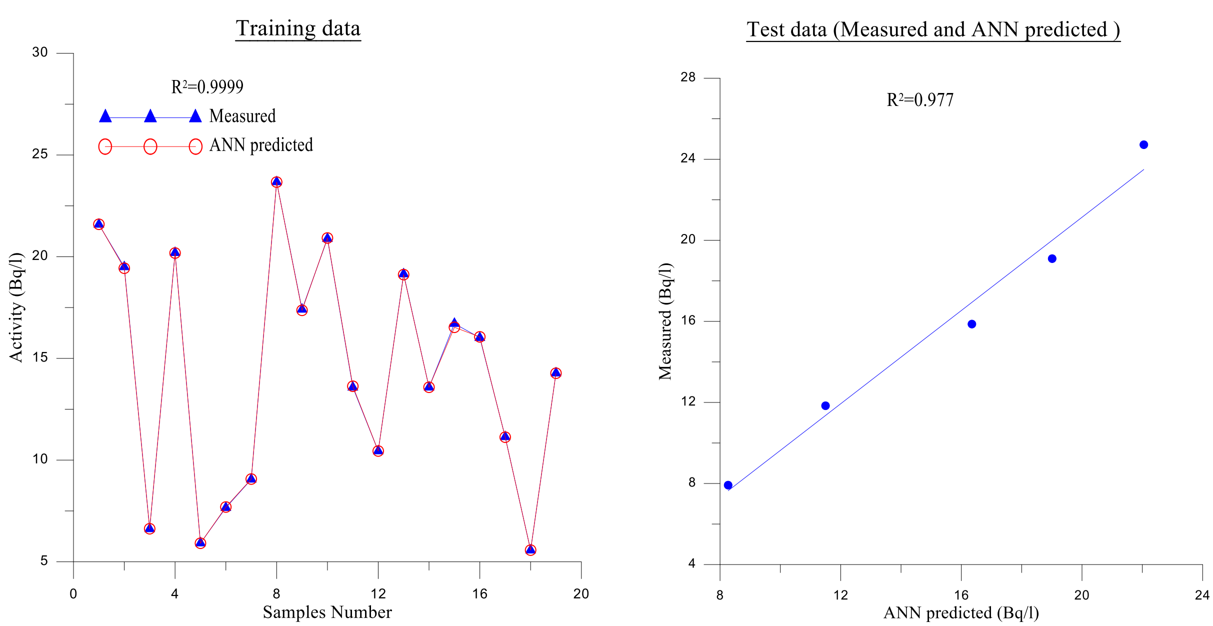

Figure 6. ^{238}U activity values predicted by ANN and measured for training data and test data.

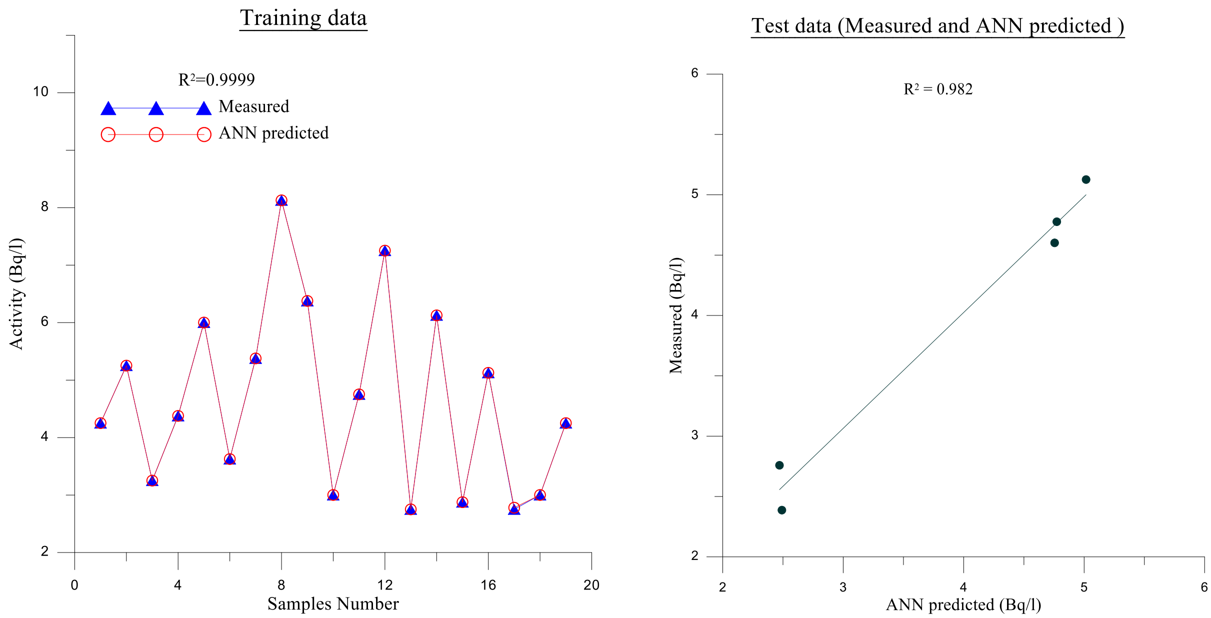

Figure 7. ^{232}Th activity values predicted by ANN and measured for training data and test data.

ANN training and testing procedures are carried out using activities of ^{226}Ra, ^{238}U and ^{232}Th and some chemical properties of the lake water. The test created for ^{226}Ra, ^{232}Th and ^{238}U radionuclide after was performed separately training. During the training, number of cycles (epochs) showing how many instruct to program of system is very important because this number must be both as much as takes place of learning and as low as will be less of extreme learning. If over the number of cycles, it actualizes more learning and installation a faulty model arises. In this case mean square error (Table 5) and correlation values are required.

Table 5. Rates error of test results calculated with ANN

Error	^{226}Ra	^{238}U	^{232}Th
MSE*	0.0036	1.5191	0.0258

* $MSE = \frac{1}{N}\sum_{k=1}^{N}\left(d(k) - y(k)\right)^2$

MSE where d(k) is measured value; y (k) is shows the predicted values. At the end of network training, performance values of the tests and performance values of training can be seen in Table 5. In addition to performance values, calculate correlation in the output of the system is an important criterion. Correlation coefficient between the results of estimated and the measured values for ^{226}Ra, ^{238}U and ^{232}Th are 0.968, 0.977 and 0.982, respectively (Fig. 5, 6, 7). In the best ANN structure, MSE values should be close 0 and R^2 should be close to 1.

4. CONCLUSIONS

The ANN model has been applied to the Hazar Lake (Elazig) for ^{226}Ra, ^{238}U, and ^{232}Th radionuclides. In our study, concentrations behaviour of radionuclides in Hazar Lake was successfully predicted. This study provides solution ways to problems overly complex and the understanding of physical processes such as particular estimated and system modelling. ANN, an artificial intelligence methodology, can be reliably used for similar estimation studies.

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