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An Artificial Neural Network Model for Earthquake Prediction and Relations between Environmental Parameters and Earthquakes

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***Abstract*—**Earthquakes are natural phenomena that occur with influence of a lot of parameters such as seismic activity, changing in the ground waters' motion, changing in the water's temperature, etc. On the other hand, the radon gas concentrations in soil vary as nonlinear generally with earthquakes. Continuous measurement of the soil radon gas is very important for determination of characteristic of the seismic activity. The radon gas changes as continuous with strain occurring within the Earth's surface during an earthquake and effects from the physical and the chemical processes such as soil structure, soil permeability, soil temperature, the barometric pressure, etc. Therefore, at the modeling researches are notsufficient to knowthe concentration ofradon gas. In this research, we determined relationships between radon emissions based on the environmental parameters and earthquakes occurring along the East Anatolian Fault Zone (EAFZ), Turkiye and predicted magnitudes of some earthquakes with the artificial neural network (ANN) model.

***Keywords*—**Earthquake, Modeling, Prediction,Radon.

I. Introduction

THE earthquake formations are among the most complex geological phenomena occurring on the earth surface, and they are formed under the influence of a number of parameters [1]. Variation of radon in the soil gas and groundwater is the most important geochemical tracer among of suggested a lot of earthquake indicators.

Radon (^{222}Rn), take place inert gas category in the periodic table. It is colorless, odorless, and flavorless and it is occurred by decay of ^{226}Ra in the natural radioactive decay chains in the Earth's crust. ^{222}Rnhas 3.82-day half-life and is produced in the rock layer. Geological structure of a geographical region influences the radon emissions. In addition, physical conditions such as rainfall and barometric pressure in the environment affect the behavior of the radon [2], [3]. It is an inert gas, so itdoes not react under normal conditions. Emission of radon is also affected by meteorological and seasonal variations. On the other, precipitation and the moisture of the soil have positive effect on the radon emissions and barometric pressure partially affects as negative the radon emissions [4], [5], [6].

Amount of radon emission changesalong the fault line, geothermal resources, uranium deposit, during the volcanic activity and before or during the formation of earthquake [7], [8], [9].

When regional stress increases, expansion of rock masses could cause an increase surface area of rocks due to cracking, so these processes increase the transport of radon from its original enclosures into the groundwater [10].

Okabe in 1956 did first investigation between radon and earthquake. He indicates radon as an earthquake tracer and demonstrates positive correlation between daily variations of radon with seismic activity. Radon is fairly soluble in water and is an inert gas, which does not make compound. Fluctuations of radonconcentration in the ground water improve substantially tectonic motions [11].

According to King (1978); concentration of the soil radon gas on the Earth surface increase after earthquakes due to pressure of the Earth's layers. This variation causesthe radon anomaly [7].

Because radon variation and earthquake formation that come true with a lot of parameters, they are a very complex problem as mathematical andnumerical approaches fall short of this problem. For this reason, in this research, we have used artificial neural network (ANN) that is quite useful for the solution of complex problems with parameters that areaffectedthe radon concentrations and formation of earthquake. ANN can easily solve non-linear relations between radon, earthquake and the environmental parameters.

II. Methods

A. Artificial Neural Network Modeling

ANN is a parallel method technique that derives new information, explore with learning. These capabilities donot achieve another conventional programming, so ANNs have been extensively used complex real-world problems.

ANN model generally consists of an input layer, one or several hidden layers and an output layer [12]. Every layer connected each other with weights. Behavior of ANN depends on both weights and input-output functions [13]. Fig. 1 shows highly simplified ANN. The ANNs succeed for incomplete-data sets, information, and very complex problems [14].

ANNs can learn with using examples that carry out by people and can determineresponses.Similarly,they can successfully perform learning, identify, classification, generalization, and optimization.ANNs learn with examples. These networks comprise each other connected neurons. Each connection has a weight value. ANN's information is in hiding in these weights. Each neuron comes together with one

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another as parallel three layers. Thus, a network comprises. These layers are input layer, hidden layer and output layer. Information is transferred by input layer and is processed by hidden layer. Then,the information is sent to the output layer [15]. Information transfers to the network by using weights values. If weights take the correct values, then true outputs generate for network inputs. This process means network's training [13].

Lavenberg-Marguart (LM) method is the most commonly used for training in the ANNs. This method is a modification of the classic Newton algorithm [1]. LM reduces learning time and increase ratio of investigation. Therefore, it is used largely [12].

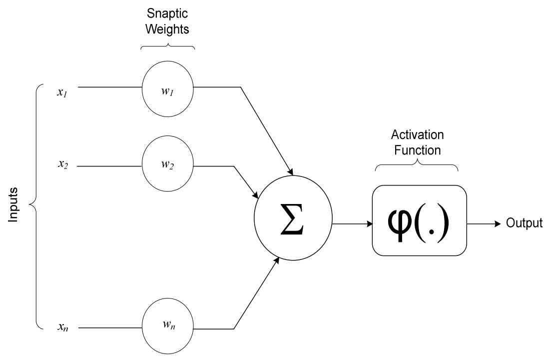

Fig. 1 Model of an artificial neural network

B. Cluster Analysis

Cluster analysis is a group of multivariate techniques. The main purpose of this technique categorizes objects according to object's own characteristic features. Cluster analysis benefit from some measure which is calculated by similarity of variables or diversity of variables, and it divide variable's particular prototype. Generally, cluster analysis division as the hierarchical and non-hierarchical method.Hierarchical cluster analysis uses distance value of data set unit. During this process, it uses dendrogram that is known as the tree-like diagrams.

The hierarchical cluster analysis starts with each case in a separate cluster and then combines the clusters at each step until only one cluster is left. If there are N cases, then this involves N-1 clustering steps or conjunctions [15]. Hierarchical cluster is useful to determine the number of clusters in the data [16].

Cluster process of units in a data set is effectuated with each other similarity or each other distance. Using distance measuring determine by according to variables' discrete or nominal, ordinal, interval, rational. The most using distance measurement is Euclidean method.

Distance between two units with Euclidean computed as

$$d(i,j) = \sqrt{(x_{i1} - x_{j1})^2 + (x_{i2} - x_{j2})^2 + \cdots + (x_{ip} - x_{jp})^2} \quad (1)$$

If variables that using cluster analysis weighting according to the degree of importance, then Euclidean distance measure will be following equation.

$$d(i,j) = \sqrt{w_1(x_{i1} - x_{j1})^2 + w_1(x_{i2} - x_{j2})^2 + \cdots + w_p(x_{ip} - x_{jp})^2} \quad (2)$$

Cluster analysis identifies structures in data sets without providing information on cause-effect relationships. Cluster analysis widely has implemented for meteorological in the recently [17].

III. Results and Discussion

This study consists of two sections. First section is ANN, and second section is cluster analysis. In the first section, earthquake magnitude is estimated by ANN. In the second section, cluster analysis is applied for radon and environmental factors.

Earthquakes are one of the most complex problems with formation. Earthquakes indicate non-linear changing. In the modeling, this kind of problem, classical mathematical models fall behind and these models do not model occurring variation during earthquake formation. For this purpose, in this study ANN that is a good tool is used and evaluated the performance. East Anatolian Fault System (EAFS)is selected for study area. Method applied for 69 earthquakes, which occurring between 18/02/2005 and 9/10/2010. Magnitudes of these earthquakes are more than 3. In order to predict to earthquake magnitude, during the earthquake occurrence, the soil radon gas amount (kBq/m^3), latitude and longitude, steam pressure (mbar), wet bulb temperature (^{0}C), dry bulb temperature (^{0}C) and temperature (^{0}C) of the soil at 10, 20 and 50 cm depths accepted as input data for ANN (Fig. 2). The meteorological data given by Turkish State Meteorological Service and earthquake data recorded by Republic of Turkish Prime Ministry Disaster and Emergency Management President. When the instrumental magnitude of the earthquakes and the results from ANN model are compared then the relative error between these two magnitudes appeared to vary between %0 and %6.25 (Table I).

Amount of radon strongly is affected by environmental factors in addition to seismic activity. Changing of the radonconcentration is classified according to seismic activity and environmental changing.

TABLE I
Basic Statistics for Magnitude of Earthquakes

Earthquakes	Measured values	Predicted values
Number	69	69
Minimum magnitude	3.8	3.8
Maximum magnitude	5.8	5.7
Mean	4.28	4.27
Median	4.1	4.11
Standard deviation	0.497	0.51

In this research, we used a non-hierarchical clustering algorithm based on Euclidean distance for cluster analysis.Atmospheric affects are analyzed with change of radon according to location by this method. Cluster analysis was conducted using SPSS.Dendrogram obtained is given in Fig. 3.

TABLE II
THE TEST DATA FOR ANN

Date	Latitude (N)	Longitude (E)	Radon (kBqm^{-3})	Steam Pressure (mbar)	TS 10 cm ^{0}C	TS 20 cm ^{0}C	TS 50 cm ^{0}C	Wet Bulb T. (^{0}C)	Dry Bulb T. (^{0}C)	Magnitude of earthquake (Mw)	ANN Model	Relative Error %
28.12.2005	38.7982	40.0977	6	4	1.4	2.2	4.2	-2.6	-0.8	4.4	4.3	2.27
09.02.2007	38.3415	39.1698	6	3.8	5	6	6.1	1.6	2	5	5	0
23.02.2007	38.3856	39.3136	41	4.1	5	7	8.2	-2.4	-0.6	3.9	3.8	2.56
28.02.2007	38.2787	39.2638	40	7.7	10.2	11.4	11.6	5	6.7	5.2	5.2	0
08.03.2007	39.0433	40.4592	10	7.8	6.6	6.2	8.8	4.6	5.8	4.8	4.5	6.25
11.03.2007	38.3320	39.2912	11	7.6	7.2	0.6	8.7	4.2	5.2	4	3.9	2.5
14.04.2007	38.3528	39.2848	8	8.4	9.4	9	9	7.2	10.2	4.5	4.5	0
19.12.2009	38.1022	38.2125	10	7.6	7.2	7.6	8.7	4.2	5.2	3.8	3.8	0
08.03.2010	38.7468	40.0060	5	3.8	3.6	4.8	7.2	-2	0.5	4.8	4.8	0
09.03.2010	38.7310	39.9895	17	5	4.4	6	7.8	-1.4	-0.6	4.3	4.5	4.65

Q mode cluster analysis of the whole data for variables produced dendrogram of station association reflecting the main constituents of fault. It is possible to divide the dendrogram in Fig. 3 into three main groups or clusters. Locations in the Cluster 1 (1-3, 5-9, 14, 16-19, 20-35, 31, 32-36, 38, 41-49, 50-58, 60-62) are located between sub-humid Mediterranean climate with semiarid climate.

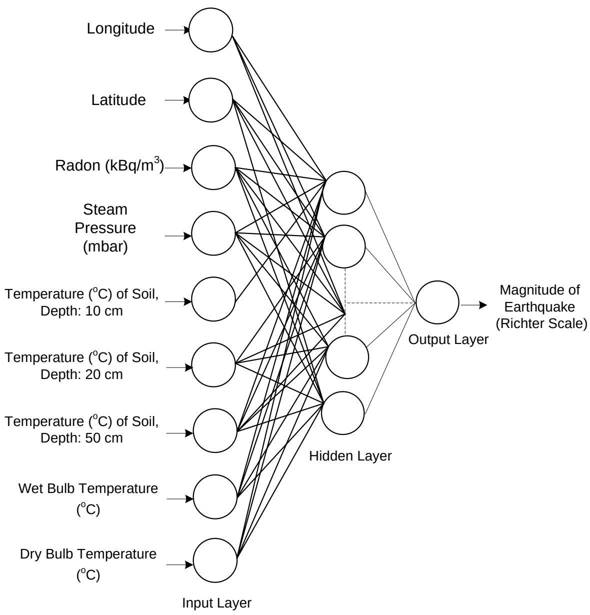

Fig. 2 Neural Network architecture that was used in modeling magnitude of earthquake

In addition, these stations take place between East Anatolian Fault System and North Anatolian Fault System. These stations generally have low level radon concentration. Being little of changing in the radon levels for these stations in cluster 1 resulting from radon concentration affected environmental factors rather than seismic activity.

Locations in the Cluster 2 (4, 37, 39, 40, 63-68) are located near dam or near lake. In these stations, radon concentration more changing verifies and is higher than Cluster 1. Having more diversity of radon and have higher concentration in this region, resulting from the amount of moisture in these stations further than other stations, and correspondingly increasing the transport of radon.

Locations in the Cluster 3 (10-13, 15) are the most near East Anatolian Fault System. Doing investigation of the radon amount, in these stations radon concentration is the most according to the other clusters. According to this, radon concentrations changing in these stations arise from seismic activity, and concentration affected fewer than environmental factors.

IV. CONCLUSION

The advantage of ANN according to the numerical methods is that the optimization can be done very fast, no mathematical form of the relation between input and the output data is necessary. These advantages are especially non-linear systems. The disadvantage of neural network is that they require a lot of data to give good confidence in the results [14]. The cluster analysis reduces the number of variables, so complex problems can explain easily.

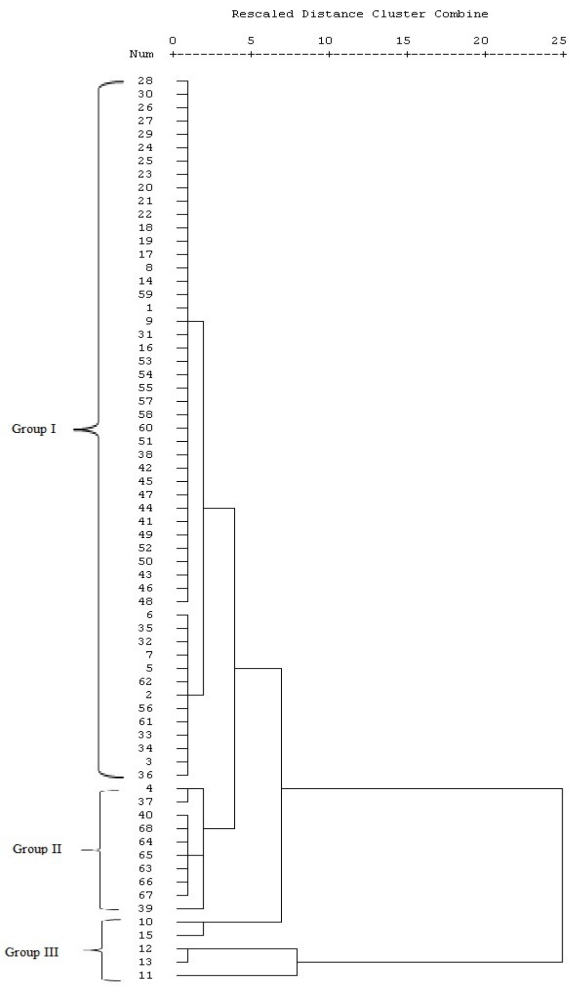

Fig. 3 Dendrogram showing station association at EAFS

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