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Evaluation of Environmental Hazard in Underground Mines Using Adaptive Neuro- Fuzzy Model

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Abstract:

Appropriate measurement of radon and thoron in mines should be maintained to avoid their high concentrations that have, been known to be a contributing cause for lung cancer. The measurements of radio nuclei are difficult in long mines as it takes more effort and time. For this concern, adaptive Neuro-Fuzzy inference system (ANFIS) is used in the reported study to estimate the concentration of radon (Rn) and thoron (Th) daughter (D) in two phosphate mines in Egypt. Comparison of the performance of experimental readings and ANFIS estimation is done. To obtain the best input-output mapping, two different models with various input combinations are evaluated for the two mines using ANFIS. In the first model, the ANFIS training process is applied using 50% of the reading data in consequent measurment for Rn and Th (D) with respect to the distance then predicting the rest of their concentrations. In the second model 50% of random measured data for Rn and Th (D) at different distances in the mine are taken and predicting the measurements in between. Standard performance indices, such as mean absolute error (MAE) and mean absolute percentage error (MAPR) are used to compare the performance of the two models. The second model which considers random data as input to the ANFIS produced the best results. Finally, the general measured results and *their estimation will be used as bases to describe corrective actions based on underground mines radiological safety regulations.*

Key words: Fuzzy Inference System, Mines, Radon and Thoron Estimation, Radiological Safety Regulation.

1. INTRODUCTION

The radioactive gases thoron and radon and their decay products are everywhere in the open atmosphere. They show higher concentrations in the limited atmospheres of underground mines and workplaces where workers are exposed to these radio nuclides. Exposures to radon and thoron and their decay products may be extremely variable. The central radon source in workplaces with high radon concentrations is the soil, but there can also be major assistance from building materials, groundwater, the storage and processing of large amounts of materials with high concentrations of radium. Underground workplaces show high radon levels, as of the mines and caves. In a small instances, members of the public may be exposed to radon and thoron and their decay products at workplaces [1-2].

High levels of radon have been recognized as a radiation hazard causing excess lung cancer among underground miners [3]. Consequently radon has been classified as a human carcinogen [4]. Since the 1970s evidence has been increasing that radon can also represent a health hazard in non-mining environments [5, 6]. Since environmental radon on average accounts for about half of all human exposure to radiation from natural sources [7], increasing attention has been paid to exposure to radon and its associated health risks in both industrialized and developing countries.

Radioactivity measurements have been conducted in many underground phosphate mines in Egypt. They were carried out for airborne radon (^{222}Rn) and thoron (^{220}Rn) (D).

The usual measurement technique for radon and thoron daughter at different distance in mine is very difficult. Hence, the adaptive Neuro-Fuzzy inference system (ANFIS) is a class of adaptive networks which are functionally equivalent to fuzzy inference systems (FISs). ANFIS is applied to solve this problem as it takes less time and effort. This research is based on distance as well as radon and thoron (D) measurements for estimating their levels in the two investigated mines (Safaga South mine and Safaga Omelhoytat mine). Also performance comparison between practical measurements and estimated values using Neuro-Fuzzy Network is made for predicting radon (Rn) and thoron (Th) levels in each mine. First by measuring, radon and thoron levels at consequent distance and predicting the rest. Second by taking, their levels at random distance (opening, middle, end) of the mine and predict Rn and Th levels between the distance.

The paper is structured in the following way: Section 2 represents regulation for radiation safety, section 3 describes the methodology used including the model description for ANFIS, section 4 represents results and discussion and finally section 5 describes the conclusions.

2. REGULATION FOR RADIATION SAFETY

2.1 Regulatory Aspects Concerning Radiological Safety in Underground Mines and Mills

The rules are based on the law number seven for year 2010 for regulating nuclear and radiological activities in Egypt [8]. Licensing for mining and milling of radioactive ores are:

1- The regulatory authority should accept any of the following activities before giving a license:

a- Exploration and evaluation of uranium or thorium.

b- Extraction or transportation of uranium or thorium ores.

c- Construction or operation of mining and milling facilities for radioactive ores.

d- The final shutdown of the activities.

2-The regulatory authority determines the needed document including:

a- Study of radiation environmental impact.

b- Management system for radiological safety.

c- Design and construction description.

d- Plans for quality assurance.

3- The licensee should keep the records related to the design and construction for any mining and milling projects in working site.

4- The licensee should keep periodically all date related to evaluation of exposure doses to radiation as well as the internal intake of radioactivity for personnel and measured radiation levels.

5- The licensee performing mining and milling activities should inform the regulatory authority in case of:

- Any occasional leakage of radiation from the facility.
- Lost or stolen amount that may lead to radiation risk from uranium or thorium ores.
- Any trials to destroy nuclear security systems.
- Any unusual malfunction in any work system in the mine or the mill.
- The licensee should introduce periodical reports to the regulatory authority about the health and safety of the workers and any accident that may occur.

6- After the end of working life for the mining or the milling facility, the licensee should apply the necessary measures to keep the facility in stable and safe state. The radioactive effluents as well should be within the recommended levels by the regulatory authority.

7- Decommissioning should not be started for any mining or milling facility till the acceptance of the regulatory authority is given. Plan of decommissioning should be given to the regulatory authority.

8- The license which is involved in mining or milling activities should:

- Apply a system for occupational medical system.
- Construct and operate and maintain ventilation systems for work places.
- Take the necessary measures to deal safely of radioactive waste taking into consideration the security rules.

The described regulations are translated from the Arabic version of the law number (7) for year 2010 for the safe regulations of nuclear and radiological activities in Egypt.

2.2 Exposure Limits for Radiation Workers in Underground Mines and Mills

1- 0.02J (5WLM) for radon decay products
2- 0.06J (15WLM) for thoron decay products.
3- 0.7 KBq for uranium dust class Y.
4- 0.2 KBq for thorium dust class Y.
5- Effective dose of 20 msv yearly for 5 years.
6- Effective dose of 50 msv in one year [9-11].

3. METHODOLOGY

3.1 Adaptive Neuro-Fuzzy Interference System

Modify network-based fuzzy inference (ANFIS) is a combination of two soft-computing methods of ANN and fuzzy logic [12]. Fuzzy logic has the ability to change the qualitative aspects of human knowledge and insights into the process of precise quantitative analysis. However, it does not have a defined method that can be used as a guide in the process of transformation and human thought into rule base fuzzy inference system (FIS), and it also takes quite a long time to adjust the membership functions (MFs) [12]. Unlike ANN, it has a higher capability in the learning process to adapt to its environment. Therefore, the ANN can be used to automatically adjust the MFs and reduce the rate of errors in the determination of rules in fuzzy logic. This section will describe in details of the architecture of ANFIS, FISs, and network flexibility, and hybrid learning algorithm [13].

3.1.1 Fuzzy Inference System

A FIS was built on the three main components, namely basic rules, where it consists of the selection of fuzzy logic rules “If-Then;” as a function of the fuzzy set membership; and reasoning fuzzy inference techniques from basic rules to get the output. Figure 1 shows the detailed structure of the FIS. FIS will work when the input that contains the actual value is converted into fuzzy values using the fuzzification process through its membership function, where the fuzzy value has a range between 0 and 1. The basic rules and databases are referred to as the knowledge base, where both are key elements in decision-making. Normally, the database contains definitions such as information on fuzzy sets parameter with a function that has been defined for every existing linguistic variable. The development of a database typically includes defining a universe, determination of the number of linguistic values to be used for [13].

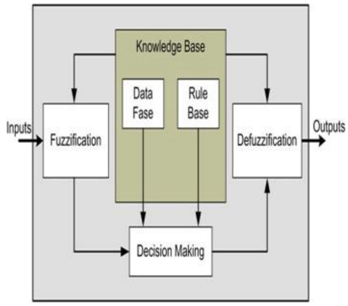


Fig. 1: Fuzzy inference system.

Each linguistic variable, as well as establishment of a membership function. Based on the rules, it contains fuzzy logic operators and a conditional statement "If-Then." The basic rules can be constructed either from a human or automatic generation, where the searching rules using input–output numerically data. There are several types of FIS, namely Takagi–Sugeno, Mamdani, and Tsukamoto. A FIS of Takagi–Sugeno model was found to be widely used in the application of ANFIS method [14].

3.1.2 Adaptive Network

Adaptive network is one example of feedforward neural network with multiple layers (see Fig. 2). In the learning process, these networks often use supervised learning algorithm. In addition, adaptive network has the architecture characteristics that consists of a number of adaptive nodes interconnected directly without any weight value between them. Each node in this network has different functions and tasks, and the output depends on the incoming signals and parameters that are available in the node. A learning rule that was used can affect the parameters in the node and it can reduce the occurrence of errors at the output of the adaptive network [12].

In learning the basic adaptive network, it is normally using gradient descent or back propagation and the chain rule. All this learning algorithms had been proposed by Werbos in 1970 [12]. Till date, gradient descent or back propagation is still used as a learning algorithm in an adaptive network. Even so, there are still found weaknesses in the backpropagation algorithm and further can reduce the capacity and accuracy of adaptive networks in making decisions. The slow convergence rate and tend to always stuck in local minima are major problems on backpropagation algorithm. Therefore, [12] have proposed an alternative learning algorithm, namely hybrid learning algorithm, which has the better ability to accelerate convergence and avoid the occurrence of trapped in local minima.

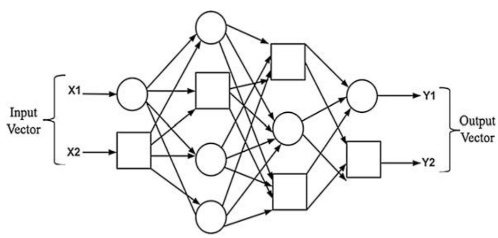


Fig. 2: Adaptive network

4. RESULTS AND DISCUSSION

In this study radon and thoron levels are estimated in two mines, Safaga omelhoytat and Safaga south mine. Two cases are studied for each mine. First, 50%of the reading data are taken in series and the rest are predicted. Second, 50% 0f the reading data is taken from three different distances at the opening, middle and end of the mine then the reading between them are predicted.

4.1 Safaga omelhoytat Mine

In this mine the radon and thoron levels were measured at different distances, twenty reading data from distance 30m to

470m was taken. Table 1 illustrate the distance [15&16] , radon and thoron daughter. Estimation of airborn radioactivity is calculated for two cases as shown in the following sections.

Table 1: Actual Measurements of Randon and Thoron.

Distance [m]	Radon [WL]	Thoron [WL]
30	0.886	0.027
50	0.912	0.029
80	0.937	0.036
105	0.958	0.037
120	0.965	0.0384
145	0.982	0.0385
180	0.983	0.0386
225	0.992	0.0392
255	0.993	0.0393
270	0.994	0.0394
285	0.995	0.0395
300	0.996	0.0396
325	0.997	0.0397
345	0.998	0.0398
365	0.999	0.0399
385	1.09	0.042
405	1.17	0.046
430	1.21	0.0472
455	1.22	0.054
470	1.28	0.057

4.1.1 Estimation of Radon and Thoron Using Series Data

In this case, the reading from 30m 270m which represent 50% of the reading data are taken in series and from 285m to 470m is predicted.

Figure 3 and 4 show radon and thoron daughter for actual, training and testing results it is observed that the actual and training results are approximately the same which indicates that the error in the testing result will be small as indicated in Table 3.

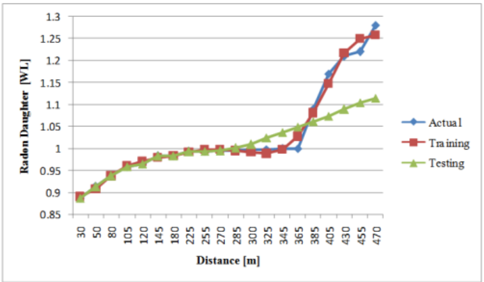


Fig.3: Radon daughter measurements for 50% testing of series data.

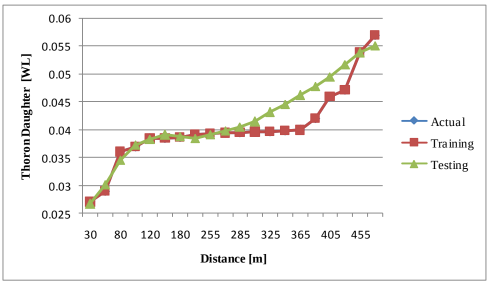


Fig. 4: Thoron daughter measurements for 50% testing of series data.

4.1.2 Estimation of Radon and Thoron Daughter for 50% Testing of Random Data

In this case, the input data for testing three reading is taken from three different distances at the opening (30m-80m), middle (255m-285m) and the end of the mine (430m-470m). The measurement of radioactive levels for radon and thoron between those reading are predicted and shown in figures 5&6. The error is calculated in Table 3.

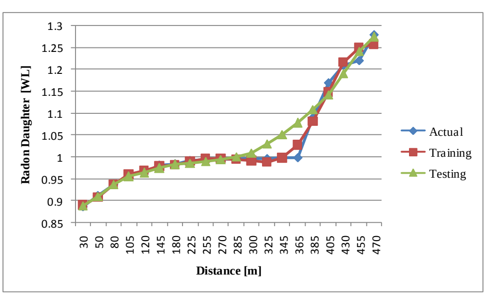


Fig. 5: Radon daughter measurements for 50% testing of random data.

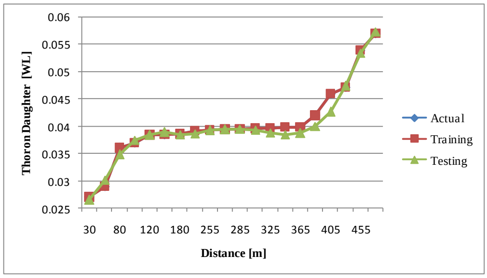


Fig. 6: Thoron daughter measurements for 50% testing of random data.

4.1.3 Comparison between Results of the Two Cases

In this section, the error and the percentage error are calculated between airborne (Rn and Th) actual measurements and the testing results as shown in Tables 2 and 3 for 50% of data taken in series order and for 50% of data taken from three different distances.

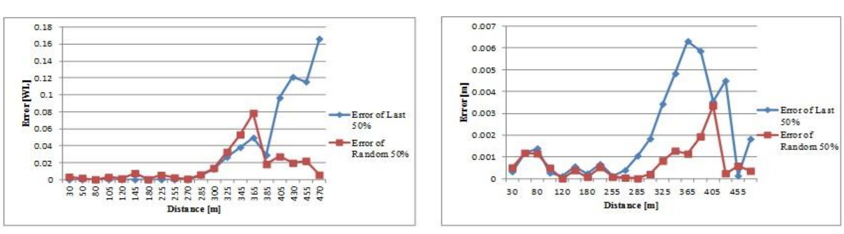
Table 2: Error and Percentage Error for Radon Calculated in the Two Cases.

Distances [m]	50% of data taken in series order		50% of data taken from three different distances	
	Error [WL]	Percentage Error (%)	Error [WL]	Percentage Error (%)
30	6.93916E-06	0.000783201	0.00322898	0.364444556
50	1.26444E-05	0.001386446	0.00186232	0.204201702
80	3.10548E-05	0.003314275	0.00018792	0.020055481
105	6.77643E-05	0.007073518	0.00282882	0.295283695
120	6.85054E-05	0.007099009	0.0012044	0.124808559
145	3.17603E-05	0.00323425	0.00748996	0.762725052
180	1.49593E-05	0.001521799	0.0003803	0.038687642
225	1.29707E-05	0.001307529	0.00548893	0.553319453
255	2.78508E-05	0.002804717	0.00231993	0.233627963
270	2.0112E-05	0.002023344	0.00083383	0.083886634
285	0.005163356	0.518930275	0.00599653	0.602666381
300	0.012486569	1.253671612	0.01352804	1.358236601
325	0.026671248	2.675150275	0.03262357	3.272173268
345	0.038068259	3.814454791	0.05319944	5.330604788
365	0.049498964	4.954851237	0.07851711	7.859570349
385	0.029064211	2.666441367	0.01818957	1.668768091
405	0.096626294	8.258657573	0.02730665	2.333901998
430	0.12107865	10.00649997	0.01966625	1.625310193
455	0.115530967	9.469751389	0.021969	1.800737999
470	0.166202355	12.98455898	0.00553986	0.432801184
Average	0.033034272	2.831675778	0.01511807	1.448290579

Table 1 shows that when 50% of data are taken in series order, The mean average error (MAE) is 0.03 WL for radon and the mean average percentage error (MAPE) is 2.83%. Also the MAE is 0.015 and the MAPE 1.44%. If 50% of data taken from three different distances. Table 3 indicates that for thoron the MAE is 0,002 and MAPE is 4.67 in case of predicting 50% of the reading data in series. The MAE is 7.16E-04 and MAPE is 1.80 for the forecasting data between 50% of the data taken at the opening, middle and at the end of Safaga Omelhoytat mine.

Table 3: Error and Percentage Error for Thoron Calculated in the Two Cases.

Distances [m]	50% of data taken in series order		50% of data taken from three different distances	
	Error [WL]	Percentage Error (%)	Error [WL]	Percentage Error (%)
30	0.0003233	1.197402565	5.07E-04	1.87808943
50	0.00116338	4.011646192	1.18E-03	4.082196985
80	0.00138701	3.852813632	1.15E-03	3.19E+00
105	0.00026411	0.713811326	4.91E-04	1.327560751
120	0.00011358	0.295773628	3.00E-06	0.00782543
145	0.00055639	1.445169169	3.85E-04	0.999674491
180	0.00023096	0.598344363	6.60E-05	1.71E-01
225	0.00066677	1.700953332	5.26E-04	1.340698973
255	0.00011342	0.288602526	7.14E-05	0.181668016
270	0.00038921	0.987831482	3.84E-05	0.097575548
285	0.00104682	2.650172847	5.97E-06	0.015119641
300	0.00183304	4.628899325	2.08E-04	0.52404657
325	0.00342915	8.637659321	8.18E-04	2.061592202
345	0.0048286	12.13215371	1.27E-03	3.202079106
365	0.00631446	15.82570411	1.14E-03	2.852184894
385	0.00586009	13.95259796	1.93E-03	4.596794683
405	0.00354661	7.710029624	3.36E-03	7.294071849
430	0.00449265	9.518322419	2.36E-04	0.49895477
455	0.00013466	0.249362472	5.80E-04	1.073512906
470	0.00182279	3.197884355	3.51E-04	0.615486273
Average	0.00192585	4.679756718	7.16E-04	1.800377736



(a) (b)

Fig. 7: Comparison between error for radon daughter predicting level (a) and thoron (b) for 50 % of the distance taken in series and 50% between reading taken in the opening, middle and at the end of mine in Safaga Omelhoytat mine.

4.2 Safaga South Mine

The actual distance and radioactivity measurements in this mine are illustrated in table 4 and 5 column 1 and 2 are taken from reference [16]. The reading data (eleven readings) are taken from distance 20 m to 380 m for radon and thoron daughter. Estimation of airborne radioactivity is calculated for two cases.

4.2.1 Estimation of Radon and Thoron Using Series Data

In this case, the input data for Fuzzy network are taken from 30m 240m and the Neuro-Fuzzy predict the radioactivity measurements from 260m to 380m are predicted in tables 4 & 5 for radon and thoron respectively.

Table 4: Radon Prediction Using 50% of Series Data.

Distances [m]	Actual Measurements [WL]	Trained Data [WL]	Tested Data [WL]
20	0.011	0.011	0.010999992
40	0.01021	0.010209997	0.010210005
140	0.0302	0.03020003	0.030199989
160	0.0303	0.03029999	0.03030002
200	0.0311	0.031099901	0.031099977
240	0.032	0.031999882	0.032000005
260	0.03243	0.032429868	0.034163052
300	0.033	0.032999852	0.039205039
320	0.048	0.048000048	0.041761461
360	0.056	0.056000086	0.046877002
380	0.059	0.059000231	0.049434896

Table 5: Thoron Prediction Using 50% of Series Data.

Distances [m]	Actual Measurements [WL]	Trained Data [WL]	Tested Data [WL]
20	0.0116	0.0116	0.011935641
40	0.01161	0.01161	0.011169526
140	0.013	0.012999963	0.013324255
160	0.015	0.015000002	0.014920637
200	0.018	0.018000054	0.01770436
240	0.0192	0.019199944	0.019355601
260	0.0196	0.019599997	0.019834743
300	0.0199	0.019899949	0.020393938
320	0.02	0.020000039	0.020557415
360	0.021	0.021000015	0.020773127
380	0.0215	0.02149989	0.020850731

4.2.2 Estimation of Radon and Thoron between Three Different Places

In this case the input data for Neuro-Fuzzy, are at the opening 20&40, the middle 200&240 and the end of the mine 360 &380 and the network predict the radioactivity measurements for radon and thoron as shown in Table 6&7 column 4.

Table 6: Radon Prediction Using 50% of Data Taken between Three Different Places.

Distances [m]	Actual Measurements [WL]	Trained Data [WL]	Tested Data [WL]
20	0.011	0.011	0.010999776
40	0.01021	0.010209997	0.010210244
140	0.0302	0.03020003	0.026031093
160	0.0303	0.03029999	0.029026953
200	0.0311	0.031099901	0.031100065
240	0.032	0.031999882	0.032000728
260	0.03243	0.032429868	0.033861472
300	0.033	0.032999852	0.042091092
320	0.048	0.048000048	0.047325861
360	0.056	0.056000086	0.055998548
380	0.059	0.059000231	0.059001247

Table 7: Thoron Prediction Using 50% of Data Taken From Three Different Places.

Distances [m]	Actual Measurements [WL]	Trained Data [WL]	Tested Data [WL]
20	0.0116	0.0116	0.011599986
40	0.01161	0.01161	0.011610029
140	0.013	0.012999963	0.01431989
160	0.015	0.015000002	0.015957313
200	0.018	0.018000054	0.01799997
240	0.0192	0.019199944	0.019199936
260	0.0196	0.019599997	0.020092403
300	0.0199	0.019899949	0.021369592
320	0.02	0.020000039	0.021251559
360	0.021	0.021000015	0.020999929
380	0.0215	0.02149989	0.021500009

4.2.3 Comparison between Results of the Two Cases

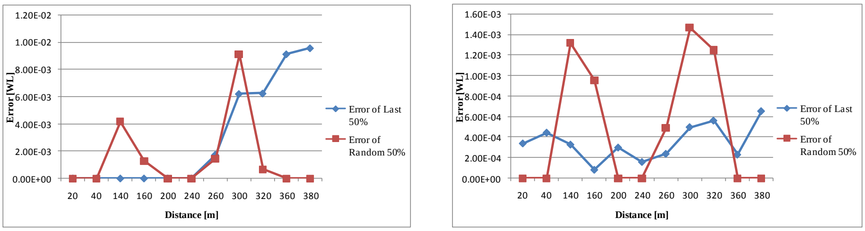
Table 8: Error and Percentage Error for Radon Calculated in The Two Cases.

Distances [m]	50% of data taken in series order		50% of data taken from three different distances	
	Error [WL]	Percentage Error (%)	Error [WL]	Percentage Error (%)
20	3.36E-04	2.89E+00	1.36E-08	0.000117121
40	4.40E-04	3.79E+00	2.89E-08	0.000248553
140	3.24E-04	2.49E+00	0.00132	10.15300122
160	7.94E-05	5.29E-01	0.000957	6.382087728
200	2.96E-04	1.64E+00	3.00E-08	0.00016644
240	1.56E-04	8.10E-01	6.37E-08	0.000331951
260	0.000235	1.197669426	0.000492	2.512258143
300	0.000494	2.482101584	0.00147	7.384884961
320	0.000557	2.78707591	0.001252	6.257793036
360	0.000227	1.080347256	7.13E-08	0.000339492
380	0.000649	3.019854445	8.55E-09	3.98E-05
Average	2.99E-03	6.33	1.51E-03	4.671333972

Table 9: Error and Percentage Error for Thoron Calculated in The Two Cases.

Distances [m]	50% of data taken in series order		50% of data taken from three different distances	
	Error [WL]	Percentage Error (%)	Error [WL]	Percentage Error (%)
20	3.36E-04	2.89E+00	1.36E-08	0.000117121
40	4.40E-04	3.79E+00	2.89E-08	0.000248553
140	3.24E-04	2.49E+00	0.00132	10.15300122
160	7.94E-05	5.29E-01	0.000957	6.382087728
200	2.96E-04	1.64E+00	3.00E-08	0.00016644
240	1.56E-04	8.10E-01	6.37E-08	0.000331951
260	0.000235	1.197669426	0.000492	2.512258143
300	0.000494	2.482101584	0.00147	7.384884961
320	0.000557	2.78707591	0.001252	6.257793036
360	0.000227	1.080347256	7.13E-08	0.000339492
380	0.000649	3.019854445	8.55E-09	3.98E-05
Average	3.45E-04	2.07	4.99E-04	2.971933494

Table 8 shows if the input data to the Fuzzy network is 50% taken in series order, the mean average error (MAE) is 2.99E-03WL for radon and the mean average percentage error (MAPE) is 6.33% for radon. Also, the MAE is1.51E-03 and the MAPE 1.44%. if 50% of data taken from three different distances. Table 9 indicates that for thoron the MAE is 3.45E-04 and MAPE is 2.07 in case of predicting 50% of the reading data in series. The MAE is 4.99E-04 and MAPE is 2.97% for forecasting data between 50% of the data taken at the opening, middle and at the end of Safaga South mine.



(a) **(b)**

Fig. 8: Comparison between error for radon daughter predicting level (a) and thoron (b) for 50 % of the distance taken in series and 50% between reading taken in the opening, middle and at the end of Safaga South mine.

5. CONCLUSION

In this work, comparison between experimental reading and Neuro-Fuzzy model is carried out to define the optimal model for predicting the radiation levels of airborne radon and thoron in two Egyptian phosphate mines. Two cases for predicting radon and thoron levels are investigated in Safaga Omelhoytat and Safaga South mine. In the first case thoron and radon reading is taken at distances in series from the opening of the mine till the middle and the rest of the data are predicted. In the second case three random reading is taken at the opening, middle, end of the mine and the radioactivity measurements are predicted in the distances between the reading value. MAE and MAPE are calculated to assess and compare performance of the two cases using Neuro-Fuzzy model. In Safaga Omelhoytat mine, the MAE and MAPE are 0.03 WL, 2.83% for radon and 0.0019 WL, 4.679% respectively, for thoron in the first case (series reading). While the MAE and MAPE for radon and thoron respectively are 0.0151WL, 1.448% and 7.16×10^{-4} WL, 1.8% in the second case (random reading). In Safaga south mine the MAE, MAPE for radon in the two cases respectively are 2.99×10^{-3},6.33% (series) and 1.51×10^{-3}, 4.677% (random), for thoron are 3.45x10-4WL,2.07% and 4.99×10^{-4}WL, 2.97%. In the two mines the results show that the Neuro-Fuzzy model are powerful tools in anticipation levels of radon and thoron and prediction using random data are better than using series reading. Also the safety regulations of the mine are presented in this research.

REFERENCES

1- Safety Reports Series No. 33,"Radiation Protection Against Radon in Workplaces other Than Mines", International Atomic Energy Agency, Vienna, 2003.

2- Safety Standards Series No. RS-G-1.3, "Assessment of Occupational Exposure due to External Sources of Radiation", International Atomic Energy Agency, Vienna, 1999.

3- International Commission on Radiological Protection, "Limits on Inhalation of Radon Daughters by Workers", Publication 32, Pergamon Press, Oxford, 1981.

4- International Agency for Research on Cancer, "Man Made Mineral Fibers and Radon, IARC Monographs", Vol.43, IARC, Lyon 1988.

5- World Health Organization, Indoor Air Quality, "A Risk-Based Approach to Health Criteria for Radon Indoors", Doc. BUR/ICP/CEH 108(S), World Health Organization Regional Office for Europe, Copenhagen, 1993.

6- International Commission on Radiological Protection, “Protection against Radon-222 at Home and at Work”, Publication 65, Pergamon Press, Oxford, 1993.

7- United Nations, "Sources and Effects of Ionizing Radiation", Report to the General Assembly with Scientific Annexes, Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), UN, New York, 2000.

8- Law number seven, Chapter four, "Regulating Nuclear and Radiological Activities in Egypt", Egypt, 2010.

9- Safety Series No. 115, "International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources", International Atomic Energy Agency, Vienna, 1996.

10- Safety Reports Series No. 33, "Radiation Protection against Radon in Workplaces other Than Mines", International Atomic Energy Agency Vienna, 2003.

11- International Basic Safety Standards, "Radiation Protection and Safety of Radiation Sources", General Safety Requirements, International Atomic Energy Agency, Vienna, 2014.

12- Jang, J-SR. "ANFIS: Adaptive-Network-Based Fuzzy Inference System", IEEE Transactions on Systems, 1993.

13- Brown, Martin and Christopher John Harris," Neurofuzzy Adaptive Modelling and Control", Prentice Hall, 1994.

14- Cheng, Chun-Tian, Jian-Yi Lin, Ying-Guang Sun, and Kwokwing Chau, "Long-Term Prediction of Discharges in Manwan Hydropower Using Adaptive-Network- Based Fuzzy Inference Systems Models", Advances in Natural Computation, 2005.

15- Ashraf E. Khater, M.A. Hussein, and Mohamed I. Hussein, "Occupational Exposure of Phosphate Mine Workers: Airborne Radioactivity Measurements and Dose Assessment", Journal of Environmental Radioactivity, Vol. 75, (2004).

16- J. Bigu, Mohamed I. Hussein and A.Z. Hussein, "Radioactivity Measurements in Egyptian Phosphate Mines and Their Significance in the Occupational Exposure of Mine Workers", Journal of Environmental Radioactivity, Vol. 47, 2000.