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Radium and Radon Exhalation Studies in Some Soil Samples from Singa and Rabak Towns, Sudan using CR-39

Abd-Elmoniem A. Elzain[1,2] , Y. Sh. Mohammed [2,3], Kh. Sh. Mohammed[4,5], Sumaia S. M[1,2]

[1]Department of Physics, University of Kassala, Kassala, P.O.Box: 266, Sudan.

[2]Department of Physics, College of Science & Art, Qassim University, Oklat Al- Skoor, P.O.Box: 111, Saudi Arabia.

[3]Physics Department, College of Science, Dalanj University, Dalanj, Sudan

[4]Mathematics Department, College of Education, Dalanj University, Dalanj, Sudan

[5]School of Mathematical Sciences, Dalian University of Technology, Dalian 116024, PR China

Abstract: ***Measurements of radium concentration and radon exhalation rates (surface and mass exhalation rates) were made for a number of 120 soil samples from Singa and Rabak towns in Sudan. In this study we used the can technique, containing CR-39, to estimate the radium concentration and radon exhalation rates from the soils of the studied areas. The average radium concentrations from soil samples were found to be(82 $\pm$8) Bq.kg^{-1} to (34 $\pm$3) Bq.kg^{-1} for Singa and Rabak towns respectively. The radon concentration, surface and mass exhalation rates were found to be (19.9 $\pm$2.0) kBq.m^{-3}, (17.6 $\pm$1.8) Bq.m^{-2}.h^{-1}, (354 $\pm$36) mBq.kg^{-1}.h^{-1} for Singa town, and (8.2 $\pm$0.8) kBq.m^{-3}, (7.2 $\pm$0.7) mBq.m^{-2}.h^{-1}, (145 $\pm$15) mBq.kg^{-1}.h^{-1} for Rabak town. From this study we found that, there was a linear relationship between the indoor radon concentration and the radium concentration in the soil. All the values of radium content in soil samples of study areas were found to be lower than the permissible value of 370 Bqkg^{-1} recommended by Organization for Economic Cooperation and Development.***

Keywords: Radium, surface exhalation rate, mass exhalation rate, CR-39 detectors, Can technique, Soil.

1. Introduction

Radon is a radioactive noble gas that does not chemically react with other elements. However, it can change the physical properties of the surrounding medium. Its half- life allows it to migrate long enough to travel long distances and accumulate indoors. The radon concentration in the ground depends on the radium content of the soil and the emanation power of soils and rocks [1-3]. Radium is a solid radioactive element under ordinary conditions of temperature and pressure. Radium is a decay product of uranium in the naturally occurring uranium series. When radium decays in soil, the resulting atoms of radon isotopes first escape from the mineral to air-filled pores. The rate at which radon escapes from soil into the surrounding air is known as radon exhalation rate of the soil. This may be measured by either per unit area or per unit mass of the soil. The measurement of radon exhalation rate in soil and building materials is helpful to study radon health hazard [4,5]. Among many factors affecting radon exhalation, one of the most important is radium content of the bedrock or soil [6]. Being aware of the hazardous effects of radon exhalation on human health, it was necessary to conduct measurements of radium content in the soil. Higher values of ^{226}Ra in soil contribute significantly in the enhancement of environmental radon.

However, radon exposure shows an extreme variation from location to location and depends primarily on the exhalation rate of radon from the soil. Since radium present in the soil is the main source of indoor radon, the estimation of radium content along with the radon exhalation rate in the soil was carried out. In the present study investigations have been carried out to measure the radium content and radon exhalation rates in soil samples collected from some areas of Singa and Rabak towns in the Sudan by using can technique containing SSNTDs of type CR-39. This survey is conducted to continue our various works of measuring indoor radon concentrations [7- 10], soil gas radon concentration [11], radon concentration and exhalation rates in building materials [4] and water [12, 13]. The importance of this work, is that, it represent the first study on measuring radon exhalation rates and radium content in Singa(Capital of Sennar State), and Rabak town(Capital of the White Nile State), in the Sudan.

1.2 The Study area

Singa is the capital of Sennar State in Sudan, it is located at 13° 9′ 0″ N, 33° 56′ 0″ E it is situated at an elevation of 439 meters (1,440 feet) above sea level, on the west bank of the Blue Nile at a distance of 360 kilometers (220 miles) to the south-east of the capital Khartoum, and 60 kilometers from Sennar city.

While Rabak is a city in southeastern Sudan and the capital of the White Nile State at 13° 11′ 6″ N, 32° 44′ 38.4″ E. It is one of the major cities of Sudan. In addition to that city is located on the eastern bank of the White Nile, approximately 260 kilometers (160 mi) south of Khartoum and 340 kilometres (210 mi) west of the Ethiopian border. Rabak lies some 362 meters above sea level.

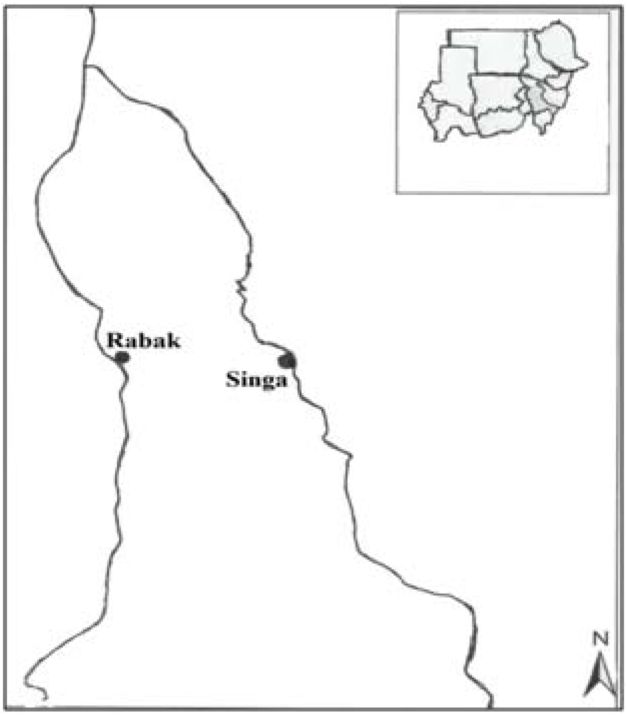

Figure 1: The map of Singa and Rabak towns, Sudan

2. Measurement Technique

The can technique [14–16] was employed for the measurement of radium concentration, radon concentration and radon exhalation rates in soil samples from 10 different locations of Singa and Rabak towns in Sudan (Figure 1). An amount of 4 kg from each sample was collected under the depth 30 cm within 1.5m of the foundations of the dwelling in selected locations, the samples were dried in a temperature controlled furnace (oven) at a temperature 100 ± 0.1°C for 24 h to ensure that moisture is completely removed, then the samples were crushed to a fine powder and sieved through a small mesh size to remove the larger grains size and render them more homogenous. About 250 g of each sample was placed in a plastic can of dimensions of 10 cm in height and 7.0 cm in diameter [4]. A passive method (can-technique) using SSNTDs for measurements of radon exhalation rate was used [1, 4, 18, 19].

A piece of CR-39 detector of size 2 × 2 cm was fixed on the top of inner surface of the can, in such a way, that it is sensitive surface always facing the sample. The can is sealed air tight with adhesive tape and kept for exposure of about three months. During exposure period, the detector is exposed freely to the emergent radon from the sample in the can so that it could record alpha particles resulting from the decay of radon in the remaining volume of the can. After that, the dosimeters were separated from the sample cup, collected and chemically etched in a 30% solution of KOH, at $(70.0 \pm 0.10)^{o}$C for a period of 9 hours. The resulting α tracks were counted under an optical microscope of magnification 400X.

The track density was determined and converted into activity concentration C_{Rn} (Bq.m^{-3}) by using Eq (1) [4, 17, 20]:

$$C_{Rn} = \frac{\rho}{K\,t} \qquad \text{........(1)}$$

where ρ is the track density (tracks per cm^2), t is the exposure time and K is the calibration constant which was determined previously to be:

K= 3.746×10^{-3} tracks.cm^{-2}h^{-1}/Bq.m^{-3} [4].

In order to measure radon concentration and its exhalation rate, using the sealed can technique, the radon exhalation rate in terms of area E_x (mBqm^{-2}h^{-1}) is calculated by using Eq (2), as: [4, 20]:

$$E_x = \frac{\lambda VC}{A[t + \lambda^{-1}(exp(-\lambda t) - 1)]} \qquad \text{........(2)}$$

Moreover, the radon exhalation rate in terms of mass E_M (Bqkg^{-1}h^{-1}) is determined by Eq (3): [4,20]:

$$E_M = \frac{\lambda VC}{M[t + \lambda^{-1}(exp(-\lambda t) - 1)]} \qquad \text{........(3)}$$

The radium concentration in soil was calculated using the relation: [1, 17, 20]:

$$C_{Radium} = \frac{\rho hA}{KT_eM} \qquad \text{........(4)}$$

Where: C_{Radium} is the effective radium content of soil sample (Bq·kg^{-1}), C is the mean radon concentration measured by CR-39 (Bq.m^{-3}h), t is the exposure time (hours), V is the hollow holder volume (m^3), λ is the radon decay constant (h^{-1}), A is the surface area from which radon is exhaled (m^2) and M is the mass of the sample (kg), h is the distance between the detector and the top of the soil sample.

Te is the effective exposure time, which is related to the actual exposure time T by the relation [21].

$$T_e = T - 1/\lambda(1 - e^{-\lambda T}) \qquad \text{........(5)}$$

3. Results and Discussion

In the present work, the values of radon, radium concentrations and radon exhalation rates are determined in a number of 120 soil samples collected from different locations of Singa and Rabak towns in Sudan. Table 1. represents the radon, radium concentration values and the radon exhalation rates for soil samples in Singa town. Figures 2-4. Presents the radon concentration, radium concentration vs surface and mass exhalation rates of radon for Singa town areas.

The maximum and minimum radon concentration values were found to be 22.8 and 16.0 kBqm^{-3} respectively. The radon, radium concentrations, surface and mass radon exhalation rates were found to be (19.9 ± 2.0)kBqm^{-3}, (82 ± 8) Bqkg^{-1} and (17.6 ± 1.8) Bqm^{-2}h^{-1}, (354 ± 36) Bqkg^{-1}h^{-1}, in Singa towns, respectively. The distribution of the measured values through the town inner areas are found to be in the same range, constituting the higher measured values for all concentrations and exhalation rates in this study.

The higher recorded values for Singa town may be due to that, Singa town is located along the west bank of the Blue Nile, its soil is classified as being belonged to river terrace soils. During its flowing period, the Blue Nile carries large amounts of suspended material (sedimentary deposits) which re-sediments as silt clay, sandy clay, and sand and gravel [22, 23]. The water takes away soil and sand from high altitude through the tributaries falling through the foothills of present mountains from highlands in Ethiopia.

Figure 2. present the radon concentration through Singa town areas. Southern singa recorded the maximum value this maybe due to that this area is nearer to the banks of the river this may maximize the concentration value [11]. The minimum value of concentration was measured in the eastern region of the town, this region is noticed to be far from the river and with some grasses and trees, the soil is partly moist and sandy, this may minimize the concentration values [4, 11].

Figures 3 and 4. Presents the Radium concentration vs surface and mass exhalation rates, the relation in both figures are linear relationship between the concentration values of radium and the exhalation rates (surface and mass).

Table 2. shows the radon, radium concentration values and the radon exhalation rates for soil samples in Rabak town, while figures 5-7. presents the radon concentration, radium concentration vs surface and mass exhalation rates of radon for Rabak town areas.

The maximum and minimum soil gas radon concentrations were recorded to be 10.7 and 5.1 kBqm^{-3} respectively. The radon, radium concentrations, surface and mass radon exhalation rates were (8.2 ± 0.8) kBqm^{-3}, (34 ± 3) Bqkg^{-1} and (7.2 ± 0.7) Bqm^{-2}h^{-1}, (145 ± 15) Bqkg^{-1}h^{-1}, in Rabak town. The distribution of the measured values through the town inner areas is found to be recording the minimum values throughout this study if we compare with Singa town for all concentrations and exhalation rates in this survey.

The lower recorded values for Rabak town may be due to that, Rabak town is located on the eastern bank of the White Nile. The white Nile is originate from Victoria lake in Uganda, the river is long, the velocity of the water in the stream is slow as compared with Blue Nile. Due to this reason, the most appeared property of the soil is sandy, moist in large regions of the town, this may giving the minimum value of measurements as we compare with Singa town.

Figures 5. present the radon concentration through Rabak town areas. Northern, middle and southern areas of Rabak recorded the same lightly higher value than of the eastern and western regions of the town. All these values maybe due to that the soil is seen to be sandy and sometimes moist; this may minimize the concentration values.

Figures 6 and 7. Presents the Radium concentration vs. surface and mass exhalation rates for Singa town areas. The relationship in both figures are also found to be linear.

A comparison of our results with other results in Sudan and other Countries are shown in Table 3.

Table 1: Values of radon, radium concentrations, radon exhalation rates from soil samples of Singa town, Sudan.

Area	*No of samples*	*Min kBqm^{-3}*	*Max kBqm^{-3}*	*(C±S.D) kBqm^{-3}*	*(E_x±S.D) Bqm^{-2}h^{-1}*	*(E_M±S.D) mBqkg^{-2}h^{-1}*	*(C±S.D) Bqkg^{-1}*
Northern Singa	**12**	**18.35**	**20.5**	**19.5 ± 1.8**	**17.3 ± 1.6**	**347 ± 31**	**80 ± 7**
Southern Singa	**12**	**18.77**	**22.8**	**20.8 ± 2.4**	**18.4 ± 2.1**	**370 ± 43**	**86 ± 10**
Middle Singa	**12**	**18.77**	**21.6**	**20.1 ± 2.0**	**17.8 ± 1.7**	**357 ± 35**	**83 ± 8**
Western Singa	**12**	**18.39**	**21.6**	**20.4 ± 1.8**	**18.0 ± 1.6**	**362 ± 32**	**84 ± 7**
Eastern Singa	**12**	**16.01**	**21.4**	**18.8 ± 2.1**	**16.6 ± 1.9**	**335 ± 38**	**77 ± 9**
Average	**60**	**16.0**	**22.8**	**19.9 ± 2.0**	**17.6 ± 1.8**	**354 ± 36**	**82 ± 8**

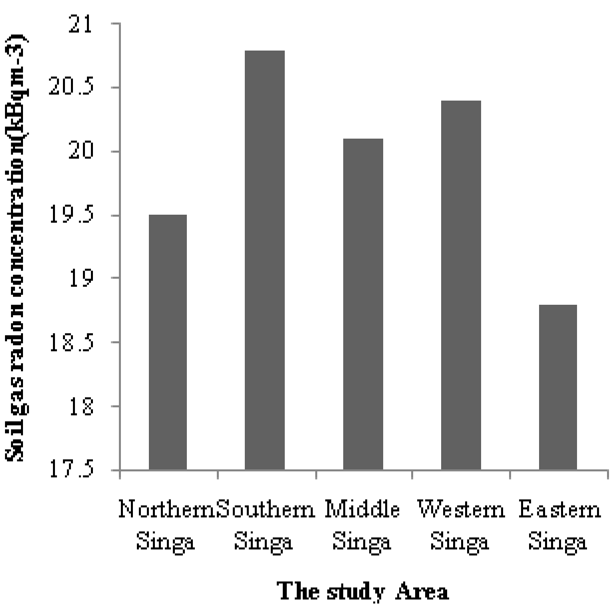

Figure 2: Radon concentration with respect to the study area in Singa town

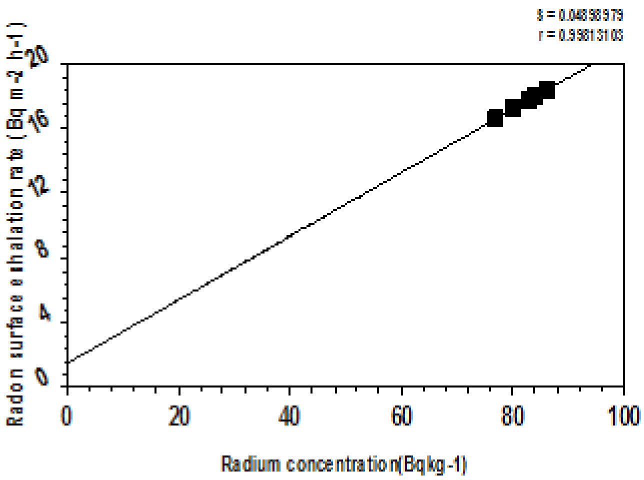

Figure 3: Surface exhalation rate vs. radium concentration for soil samples of Singa town.

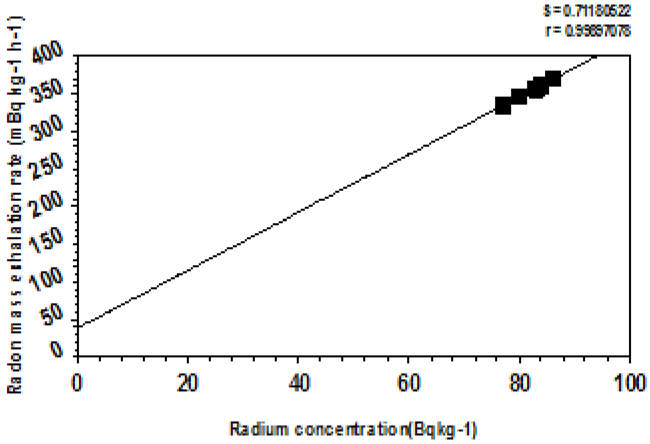

Figure 4: Mass exhalation rate vs. radium concentration for soil samples of Singa town

Table 2: Values of radon, radium concentrations, radon exhalation rates from soil samples of Rabak town, Sudan.

Area	*No of samples*	*Min kBqm^{-3}*	*Max kBqm^{-3}*	*(C$\pm$S.D) kBqm^{-3}*	*($E_x \pm$S.D) Bq/m^{-2}h^{-1}*	*($E_M \pm$S.D) Bqkg^{-2}h^{-1}*	*(C$\pm$S.D) Bqkg^{-1}*
Northern Rabak	12	7.4	10.7	8.6 ± 0.8	7.6 ± 0.7	153 ± 15	36 ± 3
Southern Rabak	12	6.5	10.2	8.9 ± 1.0	7.9 ± 0.9	159 ± 17	37 ± 4
Middle Rabak	12	7.3	10.2	8.6 ± 0.8	7.6 ± 0.7	153 ± 15	36 ± 3
Western Rabak	12	5.8	9.3	7.3 ± 0.8	6.4 ± 0.7	129 ± 13	30 ± 3
Eastern Rabak	12	5.1	8.4	7.3 ± 0.8	6.5 ± 0.7	130 ± 15	30 ± 3
Average	60	5.1	10.7	8.2 ± 0.8	7.2 ± 0.7	145 ± 15	34 ± 3

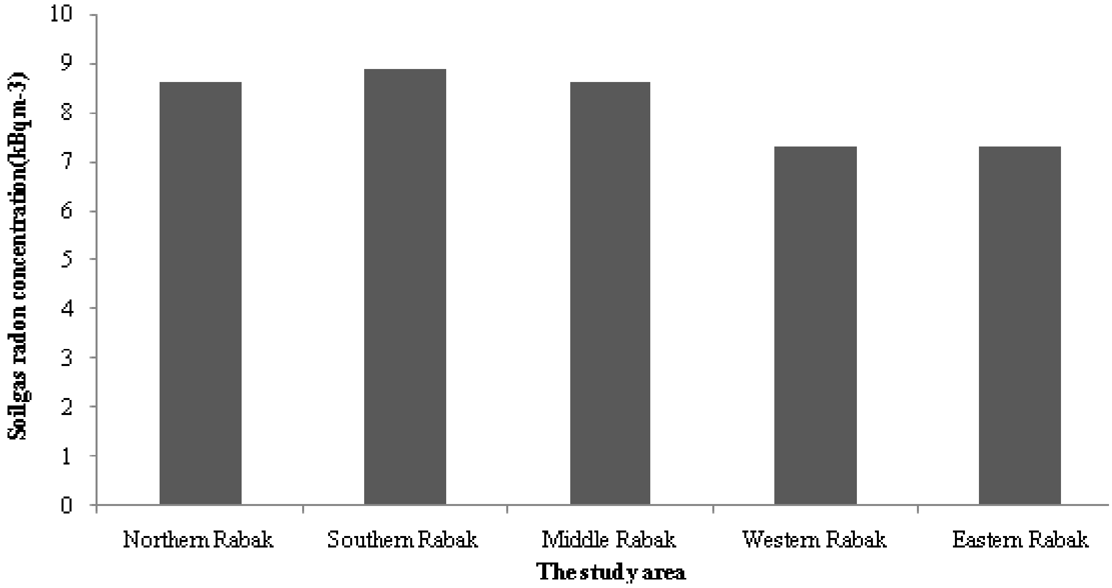

Figure 5: Radon concentration with respect to the study area in Rabak town.

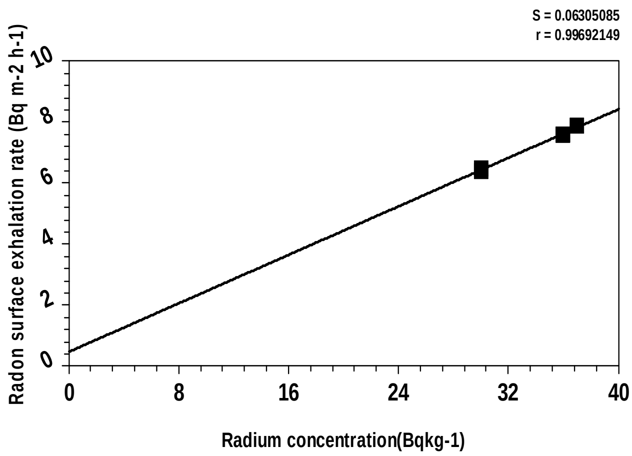

Figure 6. Surface exhalation rate vs. radium concentration for soil samples of Rabak town.

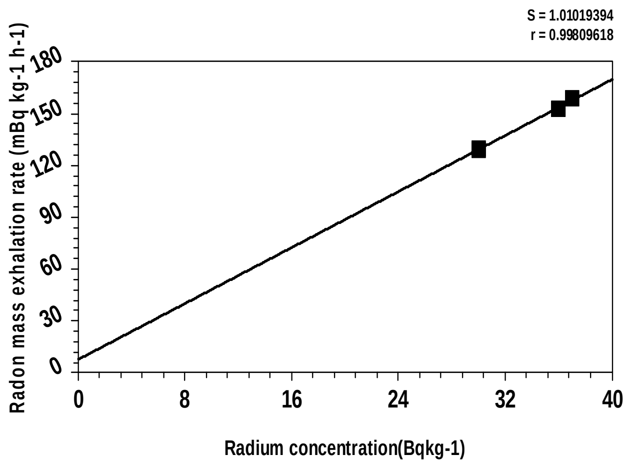

Figure 7. Mass exhalation rate vs. radium concentration for soil samples of Rabak town

Table 3: Values of concentration and exhalation rates of radon and radium concentration in different countries as compared with our study

Country	(C± S.D) kBqm^{-3}	(E_x± S.D) Bqm^{-2}h^{-1}	(E_M± S.D) mBqkg^{-2}h^{-1}	(C± S.D) Bqkg^{-1}	Reference
India	-	0.76	23	19.6	[24]
Saudi Arabia	6.71	8.4	251	33	[1]
Ethiopia	-	-	-	40.29	[25]
Egypt	4.35	-	-	-	[26]
Kassala, Sudan	2.63	-	-	-	[11]
Rabak Sudan	8.20	7.2	145	34	This study
Singa, Sudan	19.9	17.6	354	82	This study

4. Conclusions

The can technique containing CR-39 plastic track detectors have been used for the measurement of radon exhalation rate and radium concentration in soil samples collected from Singa and Rabak towns in Sudan. Radium concentration in soil samples varies from (82 ± 8) Bq.kg^{-1} to (34 ± 3) Bq.kg^{-1} for Singa and Rabak towns respectively. The radon exhalation rates in these samples has been found to vary from (19.9 ± 2.0) kBq.m^{-3}, (17.6 ± 1.8) Bq.m^{-2}.h^{-1}, (354 ± 36) mBq.kg^{-1}.h^{-1} for Singa town, and (8.2 ± 0.8) kBq.m^{-3}, (7.2 ± 0.7) mBq.m^{-2}.h^{-1}, (145 ± 15) mBq.kg^{-1}.h^{-1} for Rabak town.. The values of radium and radon exhalation rate in soil samples of the study areas are found to be linearly dependent with exhalation rates. The measured values were compared with others all over the world.

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Author Profile

Abd Elmoniem Ahmed Elzain is Associate Professor in Applied Radiation Physics and Researcher) received the B.Sc. in Physics from Kassala University – Kassala - Sudan (1996) and High Diploma of Physics from Gezira University – Madani – Sudan (1997) and M.Sc. in Physics from Yarmouk University – Erbid – Jordan (2000) and PhD in Applied Radiation Physics from Kassala University – Kassala – Sudan (2006). He worked at Kassala University since 1996 up to 2010 then from 2010 up to now at Qassim University – Kingdom of Saudi Arabia

Yousif Shoaib Mohammed (Assistant Professor of Computational Physics) received the B.S. in Physics from Khartoum University – Oudurman – Sudan (1994) and High Diploma in Solar Physics from Sudan University of Science and Technology – Khartoum – Sudan (1997) and M.S. in Computational Physics (Solid – Magnetism) from Jordan University – Amman – Jordan and PhD in Computational Physics (Solid – Magnetism – Semi Conductors) from Jilin University – Changchun – China (2010). and worked as Researcher at Africa City of Technology – Khartoum – Sudan since 2012. He worked at Dalanj University since 1994 up to 2013 then from 2013 up to now at Qassim University – Kingdom of Saudi Arabia

Khidir Shaib Mohamed (PhD student in Computational Mathematics) received the B.S. in Mathematics from Dalanj University – Dalanj – Sudan (2006) and M.S. in Applied Mathematics from Jilin University – Changchun – China (2011). He work as a lecturer of mathematics at College of Science – Dalanj University since (2011). Now he is a PhD student in Computational Mathematics at School of Mathematical Sciences, Dalian University of Technology, Dalian – China

Sumia Salih Mahmoud is Assistant Professor in Physics, received the B.Sc. in Physics from Kassala University – Kassala - Sudan (1997) and High Diploma of Physics from Sudan University of Science and Technology – Khartoum – Sudan (1999) and M.Sc. in Physics from Sudan University of Science and Technology – Khartoum – Sudan (2005) and PhD in Physics from Sudan Academy of Science – Khartoum – Sudan (2011). She worked at Kassala University since 1997 up to 2013 then from 2014 up to now at Qassim University – Kingdom of Saudi Arabia.