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Estimation of radon gas concentration and its effective dose in the Quaternary aquifer, Nag Hammadi, Qena, Egypt

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Abstract
A radiological assessment of groundwater in the Nile Valley aquifer has been carried out to detect the radiation risk and evaluate its suitability for human uses. Twenty three groundwater samples were collected from west Nag-Hammadi to Abu tesht area from the Quaternary aquifer which considered the only main source of fresh water in the area to investigate the radon gas concentration and its effective dose. The water samples were analyzed by Rad-7 Detector to determine the radon concentration. The obtained values of Rn^{222} concentrations range from 0.38 ± 0.31 to 5.44 ± 0.96 Bq l^{-1} with an average of 1.56 Bq l^{-1}. The annual effective dose taken into the body were calculated for different age's groups such as adults, children and infants and ranged from 7.02 to 99.20 µSV Y^{-1} with average 28.54 µSV Y^{-1}, from 5.62 to 79.36 µSV Y^{-1} with average 22.83 µSV Y^{-1} and from 4.04 to 57.07 µSV Y^{-1} with average 16.42 µSV Y^{-1} respectively. The activity of Rn^{222} and annual effective dose for the groundwater in the study area were lower than the MCL of the U S Environmental Protection Agency for public water supplies.

Key Word: Radon, *Quaternary aquifer, Rad7, Western Desert, Egypt.*

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I. Introduction

Water is the most valuable and greatest natural resource in the world, and it is necessary for societal, economic, agricultural, and industrial development. Egypt is located in the arid zone of North Africa where the fresh water resources are limited to the fixed share from the Nile and groundwater systems. But in some regions such as the study area the groundwater is the only major source for all uses. At the present time, the role of water resources has become more important because the Nile water is insufficient to meet all Egyptian needs due to the increase in population and the new reclamation of desert lands, which require large quantities of water. So that groundwater in the study area is an important source not only for agriculture but even for drinking uses.

Groundwater contains a wide variety of dissolved inorganic constituents as a result of chemical interactions with geological materials, So that ground water is more radioactive than surface water and this lead to the presence on radon in groundwater because of the highest solubility of water (Sen, 2014; Sundaram et al., 2009).

Measurements of natural radioactivity in water have been performed in many parts of the world, mostly for assessing the doses and risk resulting from consuming water. It was observed that most natural radioactivity present in groundwater consists of ^{222}Rn, which varies over a wide range, depending markedly on its origin. The second source of natural radioactivity in water is ^{226}Ra (UNSCEAR, 1993).

Radon (^{222}Rn) is one of three naturally occurring isotopes of radon, which is a daughter product of radium (^{226}Ra) which in turn is derived from (^{238}U) that having natural abundance of about 99.3% of uranium within the earth's crust with varying concentration in different locations from a few Bq/l to thousands of Bq/l. It is colorless, odorless, tasteless, and is a noble gas and the heaviest of the noble gases on the periodic table, which has a half-life of (3.82 d) (Inácio et al., 2017). The other isotopes of radon are Thoron (^{220}Rn) and Actinon (^{219}Rn). Thoron is produced of the decay of (^{232}Th) with half-life of about (~56s) while, action (^{219}Rn) is formed during the decay of (^{235}U) with half-life of about (~4s) so ignored entirely.

Radon can enter into our bodies in two ways either through inhalation or ingestion. Alpha particles emitted by short-lived progeny, ^{218}Po and ^{214}Po which emitting from the decay of radon can damage the living cell in the body not only but can damage the DNA by the energy that can releases, Inhalation of these solid particles refer to the depositional on the bronchial epithelium thus exposing lung tissue to the health risk of cancer. But in term of the ingestion of water-containing radon the stomach and kidney (when mixed with blood) are expose the risk of cancer. About 90% of the total effective dose of radon received by stomach (G M Kendall and T J Smith, 2002).

The US Environmental Protection Agency estimated that out of a total of 157,400 lung cancer deaths nationally, 21,100 (13.4%) were radon related (U S EPA, 2003). And estimates that, radon in drinking water causes about 168 cancer deaths per year, 89% from lung cancer caused by breathing radon released from water, and 11% from stomach cancer caused by drinking radon containing water (Appleton, 2007). Generally, the risks from inhaled the radon released from the water are greater than ingested the water containing radon (NRPB, 2000). The risk due to radon in drinking-water derived from groundwater is typically low compared with that due to total inhaled radon but is distinct, as exposure occurs through both consumption of dissolved gas and inhalation of released radon and its daughter radionuclides (WHO, 2004).

The present study deals with the measurement of the activity concentrations of the radon (^{222}Rn) in groundwater samples in the area located between Nag-Hammadi and Abu-Tesht area. Moreover, mean annual effective dose due to radon will also calculate and compare with the maximum permissible level of the world recommended value.

II. Material And Methods

Description of study area

Location

The study area is one of the most distinct and readily available areas for all development operations in the western region of Qena governorate, which is a part of the Western desert and includes both old cultivated and new reclaimed lands. It is bounded from the north by Sohag governorate and from the south by the structural plateau of limestone. It is located between latitudes 25°45' to 26°20'N and longitudes 31°45' to 32°30'E. The area under study is considered a part of the old alluvial plains of the Nile and mainly covered by loose gravels or loamy soil, sand, silt and other detrital materials (Mahmoud, 2005; Megahed, 2013). This plain has an elevation ranging from 74 to 116 m above sea level, where this elevation increasing gradually to words the limestone plateau and decreasing gradually to words the Nile Valley.

Geology and Hydrogeology

The study area is fully covered by sedimentary rocks, belonging to the Lower- Eocene and Quaternary. Information about the geology of this area is principally found in the work of (Sandford, 1934), (Sandford, K.S. and Arkell, 1939), (Abd El-Razik, 1972), (Said, R., 1962), (Said, R., 1981) and (Said, R., 1991).

The sedimentary sequence exposed in the investigated area is composed of different rock types and ranged from Tertiary to Quaternary in its age **(fig.1)**. Tertiary units in the study area are composed of Eocene rocks and Pliocene, the lower Eocene rock is represented by Thebes Formation (the oldest unit in the study area), it is composed mainly of thinly layers of chalk and chalky limestone which are rich in chert bands and found along both sides of the River Nile and surrounded the study area from the south and the west. Pliocene deposits in the study area are represented by Issawiya formation and compose essentially out of fluviatile siltstone, sandstone and clay stone. Quaternary deposits in the area of study present in the central part of Eocene rock in the Old alluvial plain (new reclaimed lands) and Young alluvial plain (Cultivated lands) including Prenile deposits, Travertine, Fanglomerates, Wadi deposits and Nile silt deposits (Conoco, 1987)..

The study area is underlain and surrounded by some hydrological units. There are three main groundwater aquifers in and around the study area; Nile Valley aquifer represents the main unit in the Qena area. The fissured carbonate aquifer surrounds the Quaternary water-bearing sediment at both sides of the area. Finally, Nubian Sandstone Aquifer System which covers the western part of Egypt and containing of about 375.000 Km^3 of water (Mohammed et al., 2016; RIGW, 1993; SEAM, 2005).

The Quaternary aquifer represents the most important groundwater aquifer in the area, which occupies the central strip of the Nile Valley forming the old cultivated land on both sides of the Nile (floodplain). It mainly consists of graded sands and gravels overlain in the majority of the region, by semi-permeable (semi-confining) silty clay layer (Holocene age), and underlain in some locations by impermeable compact Pliocene clays. The hydraulic conductivity of this aquifer ranges from 60 to 100 m/day and from 2000 to 6000 m^2/day in the transmissivity (Abd El-Bassier, M., 1997; Abd El-Moneim, 1988).

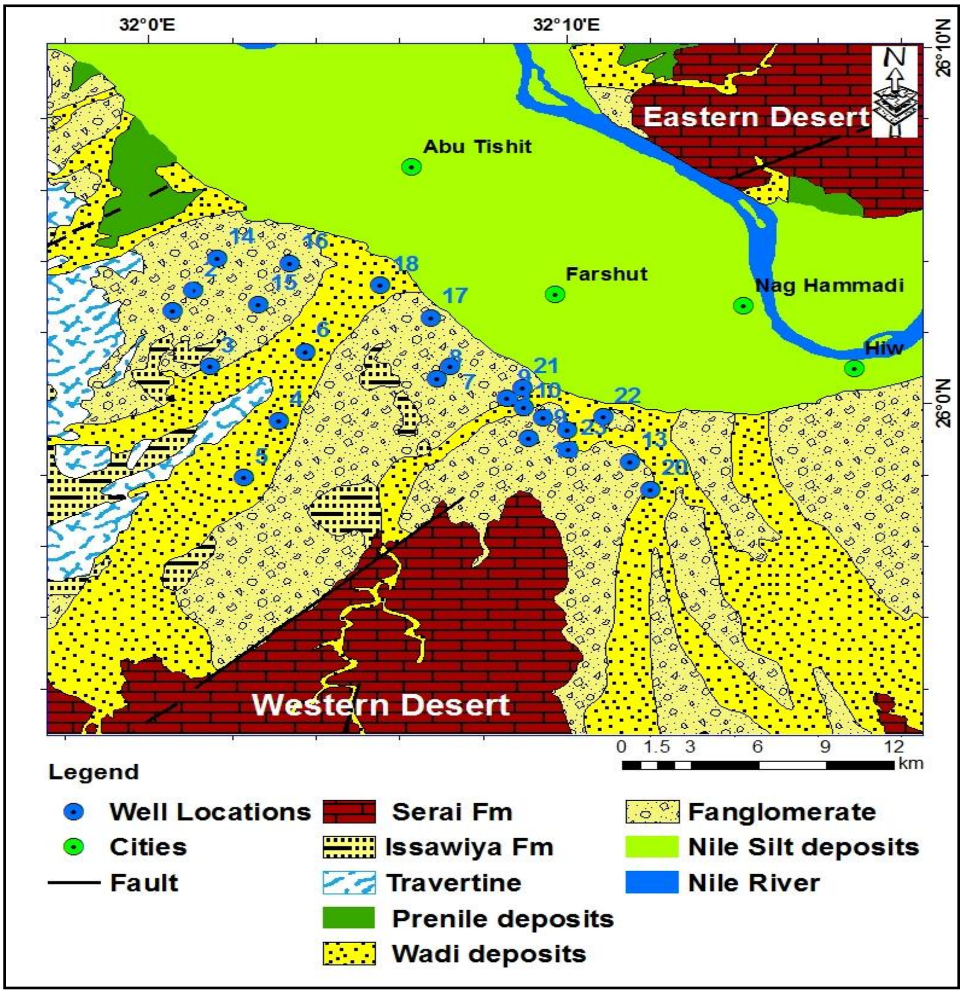

Figure 1. Geological map of study area modified after (Conoco, 1987).

Sampling

The collection of water samples for radiometric analyses requires particular care because radon is a short-lived gaseous nuclide that tends to escape from water during sampling; the bottle opened underwater during take it. A total of twenty-three groundwater sample were chooses randomly from the different wells of the study area. The physical properties of the water samples such as Hydrogen ion concentration (pH), Total Dissolved Solids (TDS) and Electrical Conductivity (EC) measured in the site during the sampling using portable pH meter (Jenway Model 430) and the geographical coordinates of the sampling sites were taken by GPS (model Garmen370) (table 1). Bottle of 250 ml were collected for Radon concentration (^{222}Rn). The taken samples were completely filled, to avoid diffusion of radon from the water into an air pocket. During the process of samples transferring from the field to the laboratory, the samples were placed inside a closed box away from direct sunlight to avoid overheating. The samples were analyzed for ^{222}Rn as soon as possible after collection, to avoid uncertainties that may be introduced by radioactive decay of radon and losses from the sample container.

Radon Measurements

The activity concentration of radon in groundwater samples of the study area was measured with RAD7 Durridge electronic detector with RAD-H2O as accessory attached **(fig.3)**. The protocol of Wat 250 ml was selected for the measurement of the radon in water samples. This protocol has a command over the RAD7 to make the measurement fully automatic.

The RAD-H2O method employs a closed loop aeration scheme whereby the air volume and water volume are constant and independent of the flow rate. The air recirculates through the water and continuously extracts the radon until a state of equilibrium develops. The RAD-H2O system reaches this state of equilibrium within about 5 minutes. During this 5 minutes of aeration of the pre-set Wat 250 ml protocol, more than 94% of the radon is extracted from the water (DURRIDGE Company Inc, 2012). The average radon concentration in the water samples is then calculated directly from these cycles.

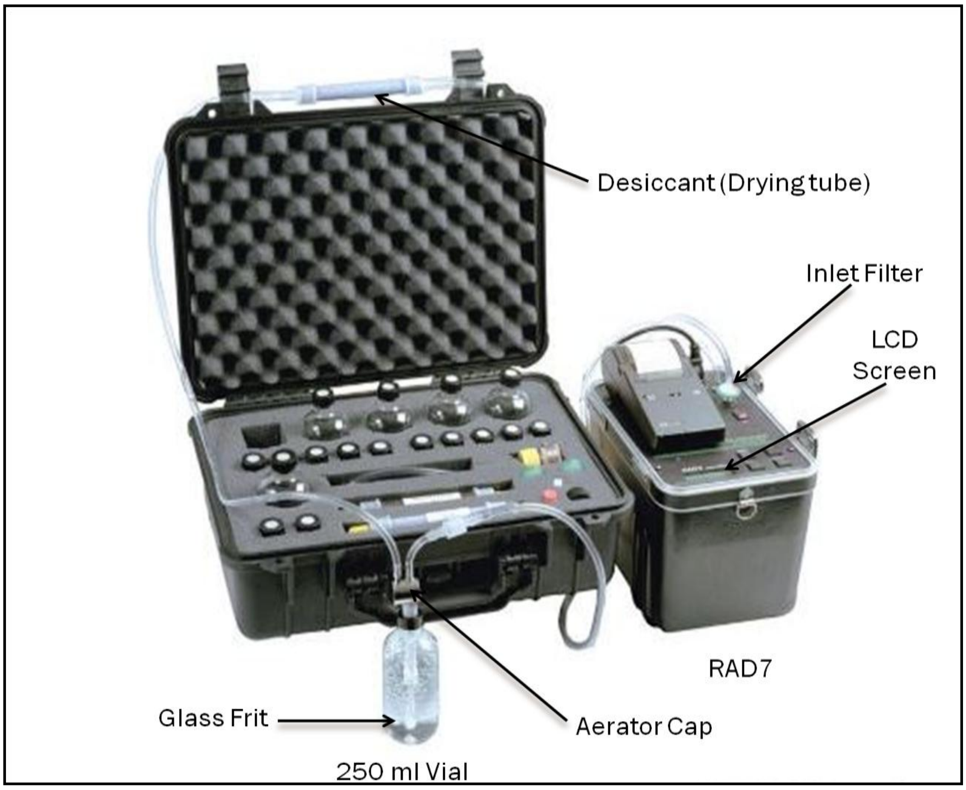

Figure 3: RAD7 Professional Electronic Radon Detector with RAD-H2O

III. Result and Discussion

Radon Concentration in groundwater

The measurements of the activity concentration of radon in the collected water samples in the study area have been carried out by using RAD7 detector and reported in table1. It can be seen that radon gas concentration in water samples ranged from 0.38 ± 0.31 to 5.44 ± 0.96 Bq L^{-1} with an average of 1.56 ± 0.54 Bq L^{-1} **(fig.3)**. The spatial distribution map of the radon in the study area **(fig.4)** show that the highest concentrations are found in the western part toward the limestone plateau and the middle part of the study area. These variations in the concentration of radon could be due to the lateral variations in the quaternary layers, the depth of the water and the differences in geochemical processes in the area.

Table1: The results of the radon concentration, pH, electrical conductivity and TDS of the groundwater samples in the study area.

Sample. No	^{222}Rn (Bq/l)	PH	TDS (ppm)	EC (µs/cm)
1	2.33 ± 0.63	7.39	2183.6	3359.4
2	5.44 ± 0.96	7.43	5755.7	8854.9
3	3.94 ± 0.85	7.56	1494.4	2299.1
4	2.45 ± 0.63	7.45	1295.8	1993.6
5	2.27 ± 0.62	7.59	1618.2	2489.5
6	1.56 ± 0.54	7.47	3090.6	4754.8
7	0.78 ± 0.39	7.73	1231.8	1895.0
8	0.96 ± 0.44	7.85	1512.2	2326.5
9	1.27 ± 0.54	7.85	711.3	1094.3
10	2.97 ± 0.86	7.8	866.4	1332.9
11	1.25 ± 0.54	7.87	2246.6	3456.2
12	2.08 ± 0.71	7.7	1744.4	2683.7
13	0.52 ± 0.34	7.75	2187.6	3365.5

14	0.96 ± 0.44	7.58	1921.1	2955.5
15	1.86 ± 0.60	7.67	1092.2	1680.4
16	0.63 ± 0.35	7.65	1789.7	2753.3
17	1.27 ± 0.56	7.58	1379.2	2121.8
18	0.72 ± 0.43	7.59	1053.3	1620.5
19	0.56 ± 0.37	8.1	1434.9	2207.5
20	0.65 ± 0.41	7.84	1033.3	1589.7
21	0.38 ± 0.31	7.72	825.3	1269.6
22	0.57 ± 0.40	7.79	935.1	1438.7
23	0.58 ± 0.39	7.75	1021	1702

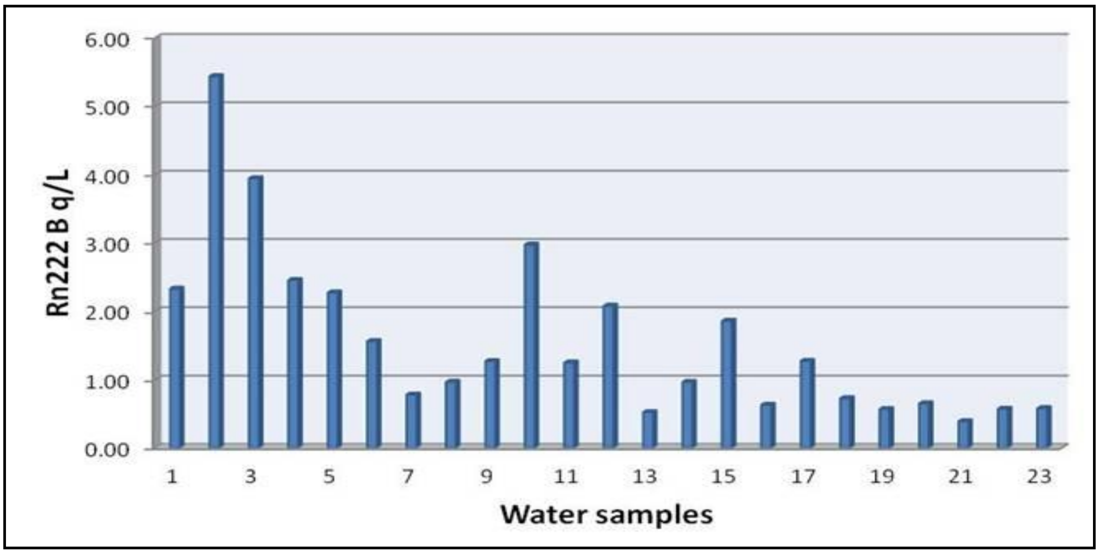

Figure 3: Radon gas concentration of water samples in the study area.

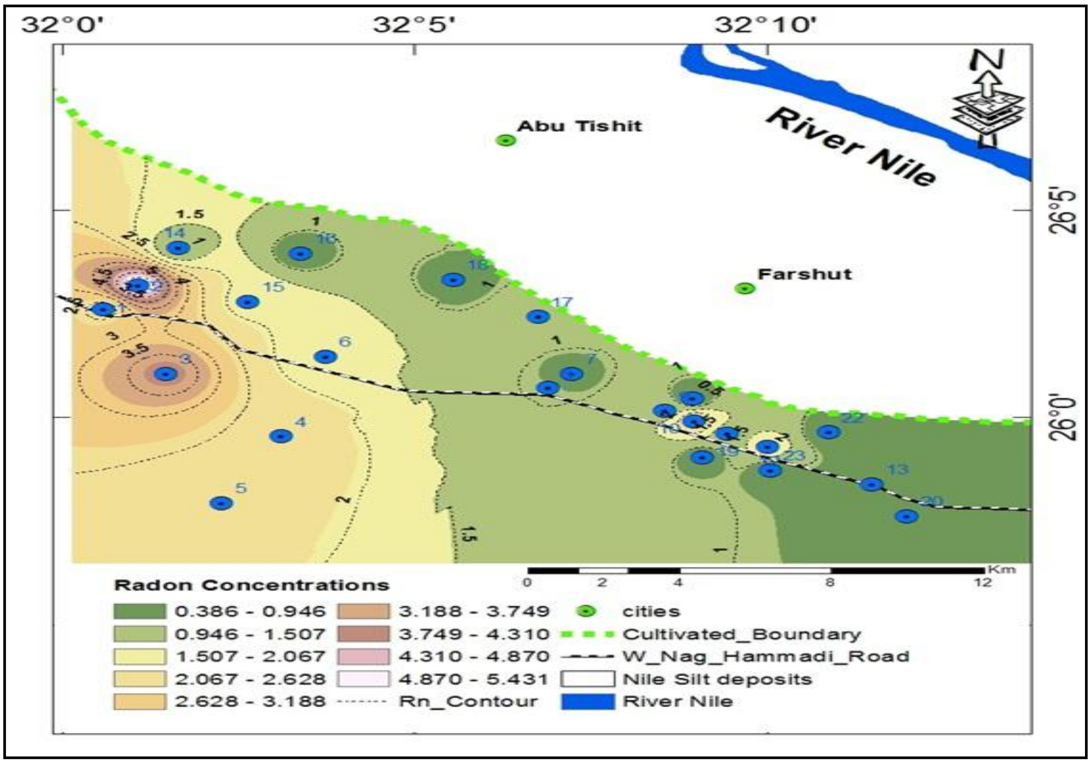

Figure 4: Spatial distribution map of the radon in the study area.

The obtained results of the radon concentration are compared with the recommendation level of the public against exposure to radon in water (100 Bq/l) which recommended by World Health Organization (WHO, 2004), and with the allowed maximum contamination level (MCL) for radon concentration in water (11 Bq/l), proposed by the U S Environmental Protection Agency (US EPA, 1999), we can be seen that the groundwater samples in the area of study are within the recommendation levels.

Table 2 refers to the comparison between the results of radon concentrations of the current study with those reported in the literature from different countries. We notice that our results are higher than concentrations of Ghana which was (0.037- 0.67 Bq/l) and concentrations of Jordon which was equal to (3.9 Bq/l as average value).While our results are very close and similar to that of Iraq which was (0.108 – 5.63 Bq/l).

Table 2: Comparison between radon concentrations in the study area with worldwide results

Country	Radon Concentration (Bq/L)	References
India	0.50 – 85.7	(Rani et al., 2013)
Algeria	2.6 - 14	(Amrani, 2002)
Saudi Arabia	1.45 - 9.15	(Althoyaib and El-Taher, 2014)
Egypt	0.04 - 10.07	(Ali, 2014)
Brazil	0.95 - 36	(Marques et al., 2004)
Sudan	1.58 – 345.10	(Idriss et al., 2011)
Italy	2.91- 21.21	(Kozłowska et al., 2016)
Jordon	3.9	(Al-Kazwini, A. T., and Hasan, M. A., 2003)
Iraq	0.108 – 5.63	(Ibrahim et al., 2017)
Ghana	0.037- 0.67	(Nguelem et al., 2013)
Egypt	0.38 - 5.44	Present Study

Annual effective doses

The estimation dose can vary significantly depending on the water consumption rates and the dose conversion factors used. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) estimated that the conversion factor of the committed effective dose from the ingestion of radon in water is 10^{-8} Sv/Bq for an adults and 2 x 10^{-8} Sv/Bq for children according to the formula:

$$\mathbf{D = C * D_{WI} * D_{CF} * 365}$$

Where, D = the annual effective dose per year for a specific age group from ingestion of ^{222}Rn in water (Sv/yr).

C = mean value of ^{222}Rn concentration in the ingested water (Bq/ l).

D_{WI} = daily water intake for specific age group.

D_{CF} = dose conversion factor for ^{222}Rn for the specific age group (Sv /Bq).

Based on the activity concentration of radon in water samples the human health risk from irradiation due to direct ingestion was assessed. Table 3 shows the calculated values of the annual effective doses of the water samples for different age's groups like adults children and infants which ranged from 7.02 to 99.20 µSV Y^{-1} with average 28.54 µSV Y^{-1}, from 5.62 to 79.36 µSV Y^{-1} with average 22.83 µSV Y^{-1} and from 4.04 to 57.07 µSV Y^{-1} with average 16.42 µSV Y^{-1} respectively.

Table3: Radon concentration with the annual effective doses due to ingestion of ^{222}Rn for different age groups.

Sample. No	^{222}Rn (Bq L^{-1})	The annual effective doses (µSV Y^{-1})		
		Adults	Children	Infants
1	2.33	42.45	33.96	24.42
2	5.44	99.20	79.36	57.07
3	3.94	71.93	57.54	41.38
4	2.45	44.77	35.82	25.76
5	2.27	41.40	33.12	23.82
6	1.56	28.40	22.72	16.34
7	0.78	14.16	11.33	8.15
8	0.96	17.56	14.05	10.10
9	1.27	23.10	18.48	13.29

10	2.97	54.24	43.39	31.21
11	1.25	22.72	18.18	13.07
12	2.08	37.88	30.31	21.80
13	0.52	9.48	7.59	5.46
14	0.96	17.55	14.04	10.09
15	1.86	33.87	27.10	19.49
16	0.63	11.45	9.16	6.59
17	1.27	23.16	18.53	13.33
18	0.72	13.16	10.53	7.57
19	0.56	10.29	8.23	5.92
20	0.65	11.80	9.44	6.79
21	0.38	7.02	5.62	4.04
22	0.57	10.35	8.28	5.95
23	0.58	10.52	8.41	6.05

IV. Conclusion

A total of 23 groundwater samples collected from the area between Nag-Hammadi and Abu-tesht area in the western part of the Nile Valley in Qena governorate were examined for ^{222} Rn. The obtained results of the activity concentration of radon in water samples are below the maximum contamination level recommended by the US Environmental Protection Agency 11.1 Bq/L.

The annual effective doses estimated for different age groups and also found lower than the safe limit proposed by the World Health Organization (WHO) 0.1 mSv Year-1. From our study, we can recommend that the groundwater in the area of the North Qena is acceptable radiologically as a drinking water and safe for life-long human consumption.

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