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Radiological Risk Estimation of Drinking and Irrigation Water from Siwa Oasis, Western Desert, Egypt

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Abstract: The objectives of this work was to determine the radiological health risk due to natural radionuclides (e.g., ^{226}Ra, ^{228}Ra and ^{40}K) in drinking and irrigation water resources in Siwa Oasis. The water resources in Siwa Oasis are diverse and include the Nubian sandstone aquifer system (NSSAS), Tertiary carbonate aquifer system (TCAS) as well as springs and lakes. The mean values of annual effective dose obtained for infants, children and adults were 0.86, 0.57 and 0.37 mSvy-1, respectively. The mean life-long cancer risk and the mean hereditary effects due to ingestion of radionuclides by adults show that 14 out of 10,000 may suffer some form of cancer fatality and 52 out of 1000,000 may suffer some hereditary effects. The obtained results indicates a very poor negative or neglected correlation between ground water and soil, which means a very low impact from water to soil in Siwa Oasis. The radiological health risk data obtained were within their safe values.

Keywords: Radiological Risk, Western Desert, Siwa Oasis.

1 Introduction

Siwa oasis (29.12° N, 25.43° E) is located in the Western Desert of Egypt, approximately 330 km from Matrouh City situated in the northern Mediterranean coastal zone, 560 km from Cairo and 70 km from Libyan-Egyptian borders (Figure. 1) [1].

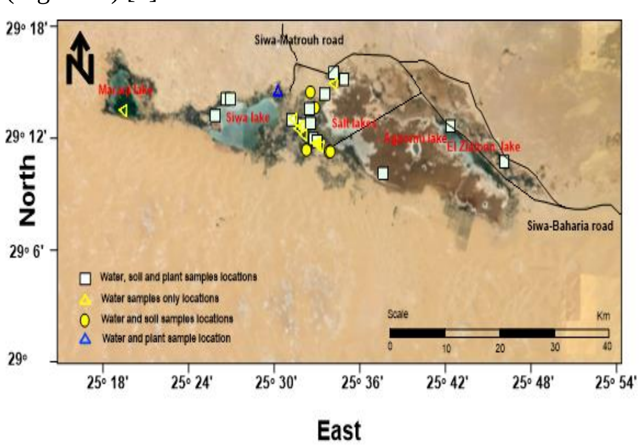

Fig.1: Samples locations [1, 2].

Groundwater is the most preferred and sometimes the only source of water in many places in Egypt. In Siwa oasis the groundwater is the key of life, where there is no permanent or even ephemeral fresh water streams. The groundwater is under artesian conditions. It is available from the natural springs and free flowing wells tapping both the deep aquifer (the Nubian sandstone aquifer system, NSSAS) and the shallow aquifer (Tertiary carbonate aquifer system, TCAS) [3].

The groundwater is used for drinking, agricultural and domestic purposes. Lakes are the natural discharge areas for the drained water from the cultivated lands, natural springs, and artesian wells. Water resources within Siwa oasis include the groundwater and surface water of lakes (Figure. 1).

In the last few decades, the need to groundwater increased to cover the demands of agricultural, tourist and economic development in the oasis. Hundreds of water wells were constructed to meet the expansion of the cultivated area, urbanization activities and food industries [4]. The improper distribution of these wells and over exploitation of groundwater led to a decrease in both the pressure head and water quality [5].

Natural radionuclide present in water beyond the safe levels can be considered to have potential risks to human. Increased concern for the radiological status of drinking water has led to an increased demand for data on water quality. The recommended reference dose level (RDL) of committed effective dose is 100 μSv from one-year consumption of drinking water [6]. Gamma rays can enter

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the skin and interact with tissues or organs. Uranium and radium found in water do not emit strong gamma radiation, so showering with that water will not pose any significant risk. However, if this radionuclide is inhaled or ingested through eating and drinking, the emissions rays can come into direct contact with sensitive tissues or organs in the body [7]. Findings of many studies have shown that long-term exposure to uranium in drinking water may cause toxic effects to the kidney and can lead to cancer [7].

The aims of this work were to determine the associated annual effective dose for different age groups, cancer and non-cancer risks due to natural radionuclides intake via water consumption.

2 Materials and methods

2.1 Annual Effective Dose

Estimation of annual effective dose from ingestion of radionuclide in water samples was estimated on the basis of the mean activity concentration of the radionuclides. This was done for different age categories. Assumptions on the rate of ingestion of water were made. In this work, the rate of water intake was based on UNSCEAR [8] recommendation. Sex age groups were considered for calculation, infants (0-1 years), children (1, 5, 10 and 15 years), and adults (≤ 17 years). The annual effective dose (AED) due to ingestion of water was computed using the following formula [8].

$$AED(mSvy^{-1}) = \sum_{i=1}^{3} DCF_{ing}(i) \times A_i \times L \qquad (1)$$

Where; $DCF_{ing}(i)$ is the dose coefficient of a particular radionuclide in $Sv.Bq^{-1}$ for a particular age category. A_i is the specific activity concentration of radionuclide in the water sample measured in $Bq.l^{-1}$ and L is the radionuclide intake in liters per year for each age group categories.

2.2 Cancer and Hereditary Risk

In addition to the estimated annual effective dose, the cancer and hereditary risk due to low dose without any threshold doses known as stochastic effect were estimated using the ICRP cancer risk methodology [9]. Radiation risks to members of the public resulting from exposure to low dose much emphasis were placed on the reduction of these radiological risks to natural radiation.The ionizing radiation is normally known as chronic risk of somatic or hereditary damage of human tissues, thus nominal lifetime risk coefficient of fatal cancer recommended in the ICRP recommendations of the members of the public was taken as 5.5 × 10-2. For hereditary effects, the detriment-adjusted nominal risk coefficient for the whole population as stated in ICRP [10] for stochastic effects after exposure to low dose rates was estimated at 0.2 × 10-2. The risk to population was then estimated using risk coefficient presented in ICRP report [10] and assumed 70 years' lifetime of continuous exposure of the population to low level radiation. According to ICRP methodology, the cancer risk and hereditary effect were calculated using the following equations:

Cancer Risk =Total annual Effective Dose (Sv) × Cancer risk factor (2)

Hereditary Effect = Total annual Effective Dose (Sv) × Hereditary effect factor (3)

By applying equation 2 and 3 the radiation risk due to ingestion of ^{226}Ra, ^{224}Ra and ^{40}K in drinking water and using dose coefficient for ingestion of radionuclides for members of the public to 70 years of age [9]. The results are shown in Table 1. The results of the cancer and non-cancer risk components were evaluated from the estimated total annual effective dose of the various age groups.

3 Results and Discussion

3.1 Risk Estimation

The specific activity concentration of ^{226}Ra, ^{224}Ra and ^{40}K in measured samples were ranged from <DL to 5.6 ± 0.7 $Bq.l^{-1}$, from <DL to 6.7± 1.5 Bql^{-1} and from <DL to 25.6 ± 5.9 Bql^{-1} respectively [1].

The annual effective dose for different age groups calculated for 30 water samples collected from different locations from the central and western parts of Siwa Oasis are presented in table 1 considering the ingestion of ^{226}Ra, ^{232}Th and ^{40}K in drinking water. While the estimated cancer Risks and the Hereditary Effects of adult member of the public are presented in table [2].

As showed in table 1 the water samples can be divided into two equal groups. The first group with fifteen sample shows an activity concentration <D.L. for all radioactive isotopes under investigation. For this group, the drinking water is acceptable from radiation protection point of view. The second group shows different values of natural radioactive isotopes concentrations. The annual effective dose due to ingestion of the second water group samples are estimated for three different age groups: Infants, children and adults; with children group is divided to four sub-groups. For infants (< 1 years old) the calculated effective doses were changed from 0.03 to 3.3 $mSvy^{-1}$ with an average 0.86 $mSvy^{-1}$. While for children (1-2 year old) from 0.05 to 2.64 $mSvy^{-1}$ with an average 0.95 $mSvy^{-1}$, for children (2-5 years old) from 0.02 to 1.63 $mSvy^{-1}$ with an average 0.56 $mSvy^{-1}$, for children (7-12 years old) from As showed in table 2, the result of the estimated fatal cancer risk to adult per year in each of the drinking water sampled ranged from 0.79E-6 (sample 23) to 0.70E-4(sample 15) with the associated lifetime fatality cancer risk of 0.55E-4 to 49.02E-4.

Table 1: The annual effective dose in (mSv.y^{-1}) for different age categories.

Water Body	Sample Code	infant<1	1-2 year	2-5 years	7-12 years	15-17 year	>17 years
TCAS	1	3.30	1.62	0.86	0.64	0.49	0.32
	5	0.00	0.00	0.00	0.00	0.00	0.00
	6	0.00	0.00	0.00	0.00	0.00	0.00
	7	0.00	0.00	0.00	0.00	0.00	0.00
	8	0.99	0.48	0.26	0.19	0.15	0.10
	10	0.00	0.00	0.00	0.00	0.00	0.00
	12	0.00	0.00	0.00	0.00	0.00	0.00
	13	0.00	0.00	0.00	0.00	0.00	0.00
	14	0.00	0.00	0.00	0.00	0.00	0.00
	17	0.77	0.74	0.39	0.31	0.33	0.23
	18	2.67	1.30	0.69	0.51	0.40	0.26
	19	0.79	1.47	0.91	1.07	1.86	0.72
	20	0.63	0.62	0.37	0.39	0.60	0.25
	21	1.03	0.50	0.27	0.20	0.15	0.10
	22	0.08	1.05	0.68	0.87	1.64	0.61
	23	0.03	0.05	0.02	0.02	0.01	0.01
	24	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.24	0.39	0.20	0.12	0.07	0.12
	27	0.00	0.00	0.00	0.00	0.00	0.00
	28	0.00	0.00	0.00	0.00	0.00	0.00
	29	0.00	0.00	0.00	0.00	0.00	0.00
Lakes	3	0.13	0.21	0.10	0.06	0.04	0.06
	9	0.65	0.39	0.20	0.15	0.11	0.09
Springs	2	0.19	0.94	0.58	0.67	1.17	0.49
	11	0.00	0.00	0.00	0.00	0.00	0.00
	16	0.00	0.00	0.00	0.00	0.00	0.00
	29	0.00	0.00	0.00	0.00	0.00	0.00
	30	0.80	1.88	1.18	1.42	2.52	0.97
NSSAS	4	0.00	0.00	0.00	0.00	0.00	0.00
	15	0.56	2.64	1.63	1.90	3.26	1.27
Min		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Max		**3.30**	**2.64**	**1.63**	**1.90**	**3.26**	**1.27**
Average		**0.43**	**0.48**	**0.28**	**0.28**	**0.43**	**0.19**

The estimated hereditary effect to adult per year varied from 0.03E-6 to 178E-6 with its associated lifetime hereditary effect in adult of 2.02E-6 to178.25E-6. This means that in terms of the lifetime fatality cancer risk to adult approximately 49 out of 10,000 may suffer some form of cancer fatality and for the lifetime hereditary effect approximately 178 out of 1000,000 may suffer some hereditary effects. The negligible cancer fatality risk value recommended by WHO is in the range of 1.0 × 10-6 to 1.0 × 10-4 (ie 1 person out of 1 million to10,000 persons suffering from some form of cancer fatality is considered trivial) [6]. Comparing the estimated results of the lifetime fatality cancer risk in the present Study with the acceptable risk factor.

3.2 Radioactivity Correlation between Water and Soil

To identify the impact of the natural radioisotopes in the water to the environment, correlation between radioisotopes in water and surrounded soil is conducted.

The specific activity concentration of ^{226}Ra, ^{224}Ra and ^{40}K in measured soil samples were ranged from 8.5±1.5 Bq.kg^{-1} to 104.5± 16.1 Bq.kg^{-1}, from < 0.6 to 67.8± 13.9 Bq.kg^{-1} and from 82.9 ± 6.0 Bqkg^{-1} to 1969.4 ± 80.7 Bqkg^{-1} respectively [2].

As shown in figure 2 (A,B,C) a very poor negative correlation -0.06, -0.05, and -0.04 between ^{226}Ra in water samples and ^{226}Ra in soil samples, ^{232}Th in water samples and ^{232}Th in soil samples, and ^{40}K in water samples and ^{40}K in soil samples respectively. The correlation obtained results indicates a neglected or a very low impact from water to soil in Siwa Oasis.

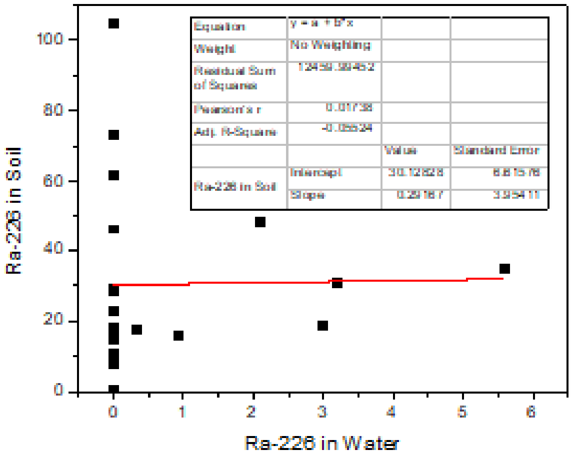

Fig.2. A

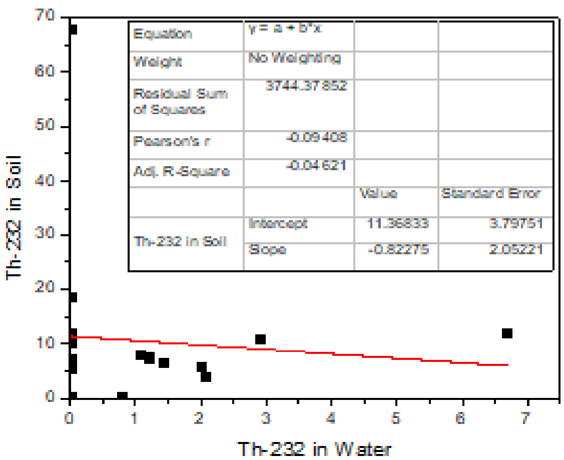

Fig. 2. B

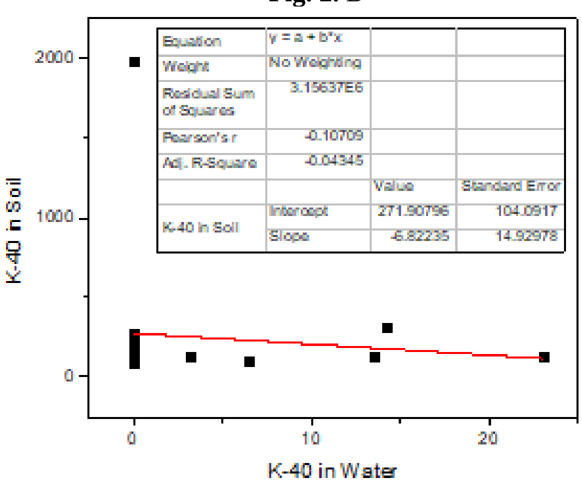

Fig. 2. C

Fig.2: Correlation between ^{226}Ra (A), ^{232}Th (B), and ^{40}K (C) in water and soil.

3.3 Comparison of Radioactivity Concentrations in Waters with Literature.

Table 3 summarizes the values of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations in drinking water for other countries and those from Egypt. As can be seen from table 3. In Egypt, the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K reaches up to 11.1 Bq.l^{-1}, 6.7 Bq.l^{-1} and 23 Bq.l^{-1} respectively. Internationally, the values of ^{226}Ra, ^{232}Th and ^{40}K activity concentration from <D.L. to 49 Bq.l^{-1}, <D.L. to 23 Bq.l^{-1} and <D.L. to 376.02 Bq.l^{-1} respectively. It shown that the activity in ground water can reach up to 49 Bq.l^{-1} for ^{226}Ra, 23 Bq.l^{-1} for ^{232}Th, 376.02 Bq.l^{-1} for ^{40}K which is nearly 4.5, 2.1, 16.3 times Egyptian values in this survey.

The Dissolution and leaching are the major processes which add radioactive isotopes to groundwater from its bedrock. Apart from radioactive decay, during the emission of ionizing radiation, the nucleus of a radioactive element is subject to recoil, which may transfer the daughter product directly to the pore space or may lose its position within the crystalline structure of a mineral, facilitating its further removal from the rock matrix via leaching or dissolution [13]. So it can be explained the variation of natural radioactive isotopes concentration in global world is due to the variation of those isotopes in aquifers rocks.

Table 2: Estimated Cancer Risks and Hereditary Effects of Adult Member of the Public.

Sample Code	Fatality cancer risk per year	Estimated Lifetime cancer Risk	Severe hereditary Effects per year	Estimated lifetime hereditary Effects
1	17.50E-6	12.25E-4	0.6 E-6	44.54E-6
8	5.25E-6	3.67E-4	0.1 E-6	13.36E-6
17	12.42E-6	8.69E-4	0.45E-6	31.61E-6
18	14.13E-6	9.89E-4	0.51E-6	35.96E-6
19	39.87E-6	27.91E-4	1.45E-6	101.49E-6
20	13.59E-6	9.51E-4	0.49E-6	34.60E-6
21	5.46E-6	3.82E-4	0.20E-6	13.89E-6
22	33.64E-6	23.55E-4	1.22E-6	85.62E-6
23	0.79E-6	0.55E-4	0.03E-6	2.02E-6
26	6.37E-6	4.46E-4	0.23E-6	16.21E-6
3	3.39E-6	2.37E-4	0.12E-6	8.62E-6
9	4.76E-6	3.33E-4	0.17E-6	12.12E-6
2	26.72E-6	18.71E-4	0.97E-6	68.02E-6
30	53.35E-6	37.35E-4	1.94E-6	135.81E-6
15	70.03E-6	49.02E-4	2.55E-6	178.25E-6

Table 3: Comparison of radioactivity concentration in drinking water from global studies.

Country	Water Type	Ra-226		Th-232		K-40		Ref.
		Min	Max	Min	Max	Min	Max	
Egypt- Siwa	GW	<D.L.	5.6	<D.L.	6.7	<D.L.	25.6	1
Assuit								
Group A	GW	7.00E-05	5.40E-04	5.00E-05	5.00E-04	3.25E-03	7.21E-03	14
Group B	GW	1.05E-03	1.27E-02	1.47E-03	9.91E-03	8.09E-03	5.25E-02	14
Sidfa and El-Ghanayim	GW	4.61E-02	4.12E-01	5.51E-02	1.06E-01	5.03E-02	1.68E+00	15
Egypt-Elba	GW	1.60E+00	1.11E+01	2.10E-01	0.97	9.7	23	16
Egypt-Qana	GW	4.30E-01	3.51E+00	2.70E-01	2.16			17
Sudan-Kadugli	GW	7.70E-03	1.43E-02	<0.01e-3	3.90E-02			18
Sudan-Kadugli	LW	8.50E-03	1.65E-02	<.01E-3	3.90E-04			18
Nigeria-Abeokuta	GW	2.58	6.77	<D.L.	4.50E+00	<D.L.	2.71E+02	19
Nigeria-Abeokuta	SW	<D.L.	9.71E+00	1.00E-01	8.02E+00	<D.L.	8.77E+01	19
Nigeria-Achet	GW	9.36E+00	2.25E+01	9.85E+00	2.39E+01	174	3.76E+02	20
Nigeria	BW	2.22E+00	1.55E+01	4.00E-02	7.04E+00	5.70E-01	3.41E+01	21
Nigeria-Ndokwa East, Delta State	SW	<D.L.	4.49E+00	<D.L.	1.00E+01	3.07E+00	3.49E+01	22
Brazil-Sao Paulo	GW	<2.2e-3	2.35E-01	<3.7e-3	1.31E-01			23
Brazil	BW	<D.L.	6.47E-01	1.20E-02	7.41E-01			24
Austria	GW	<D.L.	2.00E-02	<D.L.	1.00E-02			25
Austria	TW	<0.1e-3	7.94E-02	<D.L.	2.70E-02			26
Iran-Mahallat	GW	<D.L.	1.62E+00	<D.L.	6.20E-01	5.32E+00	1.36E+01	27
Libya-Northeast	GW	7.00E-02	1.00E-01	5.00E-02	9.00E-02	1.12E+01	1.19E+01	28
Libya-Northeast	TW	6.50E-02	1.38E-01	5.50E-02	1.77E-01	9.30E-01	5.60E+00	28
Yamen-Aden	GW	2.20E-04	2.67E-03	1.50E-04	2.72E-03	7.87E-03	2.60E-02	29
Yamen-Ass-Alh	GW	2.01E+00	6.55E+00	1.07E+00	2.93E+00	<D.L.		30
Yamen-Juban	GW	2.25E+00	3.45E+00	3.00E-01	1.43E+00	2.67E+01	4.37E+01	30
Yamen-Dempt	SW	1.19E+00	5.48E+00	<D.L.	2.17E+00	5.64E+00	2.25E+01	30
Finland		1.00E-02	4.90E+01					30
U.S		4.00E-04	1.80E-03					30
France		7.00E-03	7.00E-01					30
Germany		1.00E-03	1.80E+00					30
Italy		2.00E-04	1.20E+00					30
Poland		1.70E-03	4.50E-03					30
Poland	GW	1.30E-02	8.08E-01					30
Spain		< 2.00E-2	4.00E+00					30
Jordan	HS	3.80E+00	6.80E+00	1.42E+00	2.37E+00	2.32E+01	3.48E+01	30
Tunisia	SW	3.40E-02	3.90E+00					32
Bangladesh	BW	1.88E+00	4.97E+00	1.42E+00	9.72E+00	1.09E+01	3.21E+01	33
Saudi Arabia-Western Province	GW-BW-TW	<D.L.	2.50E+00	<D.L.	3.30E+00	<D.L.	3.39E+02	34

From radiation protection point of view, 57% of water resources in Siwa Oasis are acceptable for drinking and 100% for irrigation. The result of the estimated fatal cancer risk to adult per year in each of the drinking water sampled ranged from 0.79E-6 to 0.70E-4 with the associated lifetime fatality cancer risk from 0.55E-4 to 49.02E-4. The estimated hereditary effect to adult per year varied from 0.03E-6 to 178E-6 with its associated lifetime hereditary effect in adult from 2.02E-6 to 178.25E-6.

The obtained results indicates a very poor negative or neglected correlation between radioactivity in soil and water, which means a very low impact from water to soil in Siwa Oasis.

The radioactivity concentration in ground water can be reaches 49 Bq.l^{-1} for ^{226}Ra, 23 Bq.l^{-1} for ^{232}Th, and 376.02 for ^{40}K which is nearly 4.5, 2.1, 16.3 the Egyptian groundwater radioactivity concentration in this work survey.

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