International Journal of Environmental Sciences Vol. 4 No. 1. 2015. Pp. 7-13

Full Length Research Paper

Determination of Uranium and Thorium Concentration in Ground Water Samples by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and the Associated Dose Contribution

[1,2]M.H.Nassef* and [2]H.M. Diab

[1]Faculty of Engineering, King Abdulaziz University, P.O. Box 80204, 21589, Jeddah, Saudi Arabia.
[2]Nuclear and Radiological Regulatory Authority, Cairo, Egypt.
**On leave from NRRA*

**Corresponding Author: H.M. Diab*

Abstract
Eighteen ground water samples were collected from different locations of the Sadat city which located 93 km from Cairo, Egypt. Inductively Coupled Plasma Mass Spectrometry (SF-ICP-MS) has been used to measure uranium and thorium content in the collected samples. Compared to gamma spectrometry, the ICP-MS method permits using smaller sample size, fewer sample preparation steps and shorter measurement times due to higher sensitivity. The levels of uranium concentration ranged from 0.062 to 2.12 µg/l with a mean value of 0.871 µg/l. The levels of thorium concentration ranged from 0.070 to 51.2 µg/l with a mean value of 7.87 µg/l. The obtained results werecompared with the limits given by the World Health Organization (WHO) to identify samples which are acceptable to be used for drinking purposes, to that needs chemical treatment to be acceptable.The annual absorbed doses were estimated in mSv/y. The averageannual estimated effective dose of uranium and thoriumforan adult is$7\times10^{3}$and 8.2×10^{3} µSv/y respectively. These values were compared with the international safe limit values recommended for drinking water. The total annual effective dose (9.9×10^{3}) µSv/y was lower than the WHO recommended limit (0.1 mSv/y).

Keywords: *Uranium in water, Thorium in water, ICP-MS technique, Annual effective dose*

Introduction

Now days the quality of drinking water is an important issues worldwide. Environmental radiation protection program is essentially aims to limit radiation dose to the public to be as low as reasonably achievable (ALARA). Water is an important factor of transfer of radionuclide's to human, therefore it is useful to measure natural radionuclide concentrations in drinking water(Ahmad et al., 2004) Also, it is important to assess the population exposure to radiation by the consumption of water. The radionuclide concentrations in groundwater depend on many factors such as, the kind of mineral derived from aquifer rocks, the chemical composition of the water, and the soil ions retention time (Yussuf et al., 2012; Gilkeson et al., 1987; Andreo et al., 1999). Drinking water guidelines for radionuclide's are established based on a reference dose level of 0.1 mSv annually. This limit is 10% of the public dose limit recommended by the International Commission on Radiological Protection (ICRP), and the International Atomic Energy Agency (IAEA and is consistent with the reference level set by the World Health Organization.A level of 0.1 mSv represents less than 5% of the annual dose from natural background radiation (ICRP 1990; IAEA 1996; WHO 2008; GCDW 2009).

The United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR, 2000)has reported that the average worldwide exposure to natural sources in foods and drinking water (ingestion exposure) is 0.12 mSv annually from Uranium and Thorium.Uranium is a very toxic heavy metal and is of very small dose conversion factor, therefore, it has to be regulated and controlled. The World Health Organization gives a limit of (15 µg/l) for Unatural(WHO,2004) , while in the USA and Canada the maximum level is 20 and 30 µg/l, respectively. It is difficult to detect thorium isotopes (^{232}Th, ^{230}Th, and ^{228}Th,) in drinking water as a result of their low solubility in water (Ivanovich et al., 1992).

ICP-MS is an experimental technique usually used for trace analysis (µg/L) of elemental species in aqueous solutions. Instrument detection limits (IDLs) are typically in the pG/L to µg/L range, depending on elemental sensitivity and potential matrix effects(Jarvis et al., 1992).Sector field ICP-MS provides a sensitive technique and fast determination of long-lived radio-nuclides in environmental samples (James et al.,2005; Becker et al., 2003). The ICP-MS technique is not convenient to concentrations of dissolvedsolids that exceed 0.2%, as these solids can saturate the detector and produce solid deposition onthe system sampling interface components (EPA, 1992).The method used is suitable to analyze low activity samples, so that minimal special shielding is required.

In the present work the concentration levels of natural radionuclides (uranium and thorium) in well water from Sadat city, Egypt was determined using SF-ICP-MS mass spectrometry technique. The annual effective dose (mSv/y) to the public consuming the water was estimated.

Materials and Methods

Description of the study area

Sadat city is located in the north-west of Cairo at the point 93 km in Cairo-Alexandria road with a total area of 500 km^2. Sadat city was built as residential, industrial, and agriculture city. The main water source for drinking water is the ground water in the city.

Experimental procedure

Ground water sample collection

A total of eighteen ground water samples was collected from the ground water wells distributed in the city. The samples were collected inthe clean-washedpolypropylene bottles and then transferred to the laboratory for analysis. About 40 ml of samples was recommended for SF-ICP-MS analysis. Figure 1, shows the collected samples locationsin the studied area.

Ground water sample preparation for SF-ICP-MS analysis of uranium and thorium

The samples were filtered through 0.45µm filters and acidified to pH less than 2using ultra-pure HNO3. The samples were directly nebulized into the instrument using an MCN6000. The concentration of uranium and thorium of the samples was measured in the high resolution sector field SF-ICP-MS (Finnegan Element2) technique at the Woods Hole Oceanographic Institution, USA.

Estimation of the effective dose

The annual effective dose to an individual due to intake of uranium and thorium from the groundwater wells were estimated by the National Council on Radiation Protection & Measurements (NCRP, 1991) andare given by the following formula:

$$D_w = C_w . CR_w . D_{cw}$$

Where:

D_w:is the annual effective dose (nSv/y) from consumption of drinking water, C_w:is the activity concentration of radio-nuclides in the ingested water (Bq/l), CR_w: is the annual intake of drinking water (liters per year), and D_{cw}:is the ingested dose conversion factor for radio-nuclides (mSv/Bq).

To calculate the annual effective dose, it is very known that the daily intake of drinking water is 2 L/Day for age class > 17 years (Desideri et al., 2007).

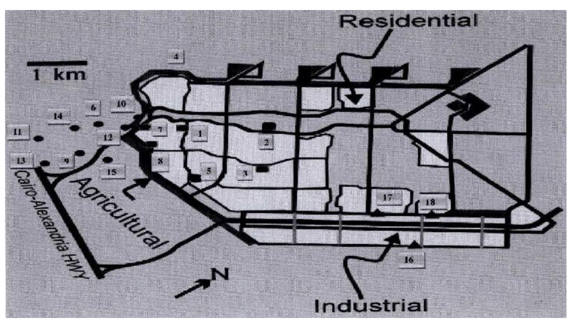

Fig. 1. Map of The study area of Sadat city showing the locations of the collected ground water samples.

Results and Discussion

Uranium and thorium concentration in ground water wells of Sadat city

The activity concentrations of uranium and thorium in the analyzed samplesusing SF-ICP-MS mass spectrometry techniqueand their descriptions are shown in Table1. It was found that, the uranium concentration ranged from 0.002 Bq/l to 0.0259Bq/l with an average value of 1.0 Bq/l. Most of the values of uranium concentrations samples were compared with the recommended limit (15µg/l) (WHO, 2004; WHO, 2008)and it was lower thanthe recommendedsafe limit for different international authorities as shown in Table 2. The slight variation in uranium concentration may be due to the interactions with colloidal organics in the agricultural and residential area. The uranium concentrations in the samples were compared with the worldwide results as shown in Table 3. Uranium is soluble in water, it can be measured by both SF-ICP-MS mass spectrometry and HPGe. The activity concentrations of ^{238}U (^{226}Ra) and ^{232}Th in the water samples in Sadat city in Egypt were analyzed by gamma ray spectrometry and the obtained concentrationswere less than the detection limits of the gamma spectrometers (0.7 and 0.6 Bq/l) for U and Th respectively (Nassef et al., 2005).

The thorium concentration ranged from 0.0015 Bq/l to 0.0915 Bq/l with an average value of 0.0198 Bq/l. Thorium concentrations up to 51.2µg/l were observed in the collected samples coming from Industrial and agricultural area. Water type derived from the Eastern

Nile Delta area are characterized by low ^{226}Ra levels and relatively high ^{228}Ra activity, likely due to the muddy agricultural nature of that area, (Lasheen et al., 2007) which is subjected to water from several surface resources for irrigation. From this point of view, the slight increase of ^{228}Ra may be attributed to the same reason. As thorium is insoluble in water, thorium transport within a particulate matter rather than solutions and can be measured from the ^{228}Ra series. Thorium does not have a WHO health-based drinking water guideline, so, it is a potential public health challenge. In the widespread presence and independent distribution of other metals besides thorium must be taken into consideration for drinking water strategies involving well switching or home-scale water treatment. Table 4 summarized the average values of thorium concentrations in drinking water, groundwater, tap water World Wide. Figure 2, shows the specific activity (Bq/l) for uranium and thorium in the studied samples

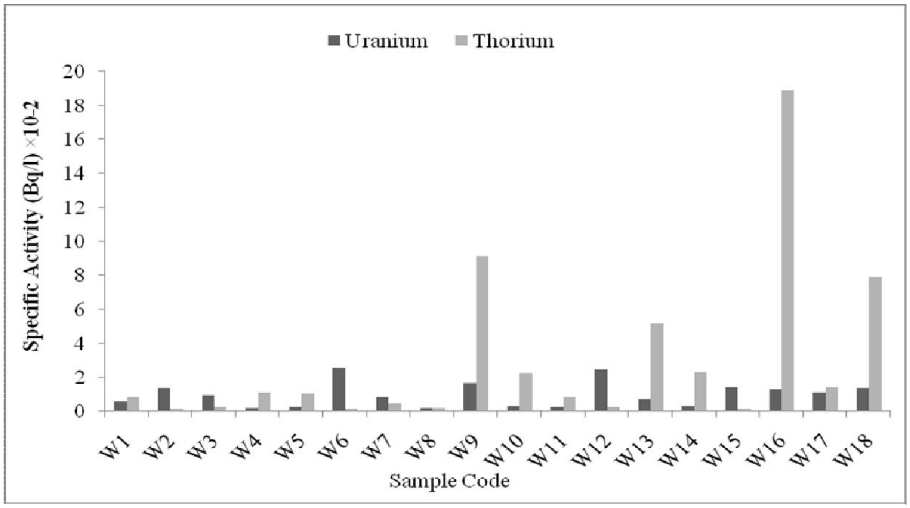

Fig. 2. The specific activity (Bq/l) of uranium and thorium in ground water wells of Sadat city.

Table 1. Measured values of Uranium and Thorium concentration (µg/l &Bq/l), and the specific activities in ground water samples of Sadat city.

Sample Code	Location	Area Classification	Uranium (µg/l)	Thorium (µg/l)	Uranium Bq/l (×10^{-2})	Thorium Bq/l (×10^{-2})
GW_1	Hassan Alam	Residential area	0.476	2.33	0.59	0.86
GW_2	MS	Residential area	1.11	0.461	1.36	0.17
GW_3	US	Residential area	0.796	0.715	0.97	0.27
GW_4	D	An agricultural area	0.175	2.94	0.21	1.09
GW_5	N	Residential area	0.206	2.78	0.25	1.03
GW_6	I	An agricultural area	2.12	0.395	2.59	0.15
GW_7	1	Residential area	0.678	1.23	0.83	0.46
GW_8	Mubarak	Residential area	1.65	0.552	0.20	0.20
GW_9	SH	An agricultural area	1.36	24.7	1.66	9.15
GW_{10}	93.5	An agricultural area	0.270	6.16	0.33	2.28
GW_{11}	95	An agricultural area	0.218	2.23	0.27	0.83
GW_{12}	2	An agricultural area	2.02	0.070	2.47	0.26
GW_{13}	3	An agricultural area	0.062	14.1	0.76	5.22
GW_{14}	M	An agricultural area	0.246	6.17	0.30	2.29
GW_{15}	Mahmoud Amin	An agricultural area	1.17	0.454	1.43	0.17
GW_{16}	AH	Industrial area	1.09	51.2	1.33	18.9
GW_{17}	R	Industrial area	0.912	3.86	1.12	1.43
GW_{18}	Delta	Industrial area	1.11	21.3	1.36	7.89

.

Table 2. Uranium recommended safe limit for different international authorities.

S.N.	Recommended safe limit	Organization-Reference
1	1.9 µg/l	ICRP-1979
2	30 µg/l	WHO-1993
3	9.0 µg/l	UNSCEAR-2000
4	30 µg/l	US EPA-2003
5	15 µg/l	WHO-2004

Table 3. World-wide uranium concentration in drinking and groundwater samples.

S.N	Country	Range of uranium concentration in unit of Bq/l in drinking and ground water samples (Mean value)	Reference
1	New York*	0.000367-0.000977	Fisenne et al., 1986
	USA*	(0.03055)	EPA, 1990
	USA*	2-10	Cothern et al., 1986
2	Ontario,Canada	0.000611-0.05134 (0.004889)	Moss et al., 1985
3	Argentina	0.000489-0.1345 (0.01589)	Bomben et al., 1996
4	China	0.001-0.93	Weihai et al., 2001
5	Japan	(0.000011)	Nozaki et al., 1970
6	Central Australia	0.2445	Hostetler et al., 1998
7	Norway	0.2445	Frengstad et al., 2000
8	South Greenland	0.00611-0.0122	Brown et al., 1993
	Italy	0.00021-0.103	Guogand et al., 2007
9	Italy*	0.00017-0.089	Desideri et al., 2007
10	Denmark	0.55	Ulback et al., 1984
11	Turkey	0.002934-0.2157	Kumru et al., 1995
12	India*	0.0779- 0.5294(0.2339)	Sandeep et al., 2011
	India*	0.0132-0.24056	Joga et al., 2008
13	Malaysia	0.0182 0.0266	Yussuf et al., 2012
14	Egypt, **(Present study)**	0.002-0.0259 (0.01)	

**Another study*

Table 4. Range and average values of thorium concentrations in units of Bq/l in drinking water, groundwater, and tap water samples worldwide and the present study.

S.N	Country	Range of Thorium concentration in unit of Bq/l (average value)	Reference
1	Malaysia	0.0389 drinking 0.0645 minerals	Yussuf et al., 2012 Yussuf et al., 2012
2	Turkey	0.018-0.073	Yasar et al., 2011
3	Egypt	0.003-0.019	Rafat et al., 2010
4	Egypt, **(Present study)**	0.0015-0.0915 (0.0198)	

Committed effective dose estimation for adult due to drinking water intake

The annual consumption rate of drinking water assumed to be 731L/yr, which was taken from the WHO Guidelines for Drinking Water Quality (WHO, 2004). The dose coefficients of the concerned uranium and the rate of the annual intake, and thorium was given from ICRP, 1996using the conversion factor as shown in Table 5.

Using the isotopic activity concentration results in each water sample, the estimated annual effective doses to the adult population for drinking water were obtained and given in Table 6. It was found that the total doses of all the analyzed drinking water samples were in the range from0.000163 to 0.00213nSv/y with a mean value of 0.000704nSv/y from uranium intake, and from 0.000529 to 0.0596nSv/y with a mean value of 0.00920 nSv/y from thorium intake. All the obtained values are below the reference level of the effective dose (0.1mSv/y) recommended by WHO, 1996 and UNSCEAR, 2000. Table 7 shows the annual effective dose of uranium and thorium from this study compared with the available corresponding data from different publications.
The average annual effective dose of this study (0.0099 (nSv/y)) was found to be below the WHO recommended safe limit 0.1mSv $y^{-1}$and does not show any significant health impact.

The values of uranium concentration in all the studied samples are within the international recommended value of the safe limit of uranium concentration in drinking water. About 27 % of the studied samples show thorium relatively high contents and the total annual effective dose was found to be below the WHO safe limit. The use of groundwater samples for drinking purposes that has been investigated show acceptable radiation exposure (internal exposure) compared with the recommended value by UNSCEAR, WHO, ICRP (0.12 mSv/year, 0.1 mSv/year, 1.0 mSv/year) respectively. Continuous assessment is recommended for each category especially for the age from 10 to 17 years old, because of the lack of information about this category.

Table 5. Present the dose conversion factor $DC_{w.}$

Radionuclides	Ingested dose conversion factor (mSv/Bq)
Uranium	1.1×10^{-10}
Thorium	4.3×10^{-10}

Table 6. Annual effective dose of uranium and thorium in groundwater samples.

S.N.	Sample Code	Annual effective dose (nSv/y)	
		U ($\times10^{-3}$)	Th ($\times10^{-3}$)
1	GW1	0.474	2.70
2	GW2	0.109	0.53
3	GW3	0.779	0.85
4	GW4	0.169	3.43
5	GW5	0.201	3.24
6	GW6	2.080	0.47
7	GW7	0.667	1.45
8	GW8	0.161	0.63
9	GW9	1.330	28.8
10	GW10	0.265	7.17
11	GW11	0.217	2.61
12	GW12	1.990	0.82
13	GW13	0.611	16.40
14	GW14	0.241	7.19
15	GW15	1.150	0.53
16	GW16	1.070	59.4
17	GW17	0.901	4.49
18	GW18	1.090	24.8

Table7. Annual effective dose of uranium and thorium in groundwater samples worldwide and the present study

S.N	Samples	Country	Annual effective dose (nSv/y)		Reference
			Uranium	Thorium	
1	Drinking	Malaysia	0.0015	0.0122	Yussuf et al., 2012
2	Mineral	Malaysia	0.0021	0.0203	Yussuf et al., 2012
3	Drinking **(Presentstudy)**	Egypt	0.0007	0.0092	

Conclusion
The presented work provides useful information about the ingestion of the most important radionuclides in a ground water wells at Sadat City in Egypt. These measurements give a good estimation for the concentrations of radionuclides in well water using a rapid

method for analysis of uranium and thorium using ICP-MS. This technique is a rapid, sensitive, and reliable technique for measuring uranium and thorium concentration in groundwater samples compared to conventional techniques such as gamma spectrometry or alpha spectrometry.

The values of uranium concentration in all the studied samples are within the international recommended value of the safe limit of uranium concentration in drinking water. The total annual effective dose is below the reference level of the effective dose (0.1mSv/y) recommended by WHO. This method offers the flexibility of adding other elements of geochemical interest in the future

Acknowledgement
The author would like to thank Prof. Dr.Robyn Hannigan, Director, Graduate Program in Environmental Sciences, Arkansas State University Judd Hill Chair of Environmental Sciences, Arkansas State University -USA, for her kind help and assistance in analyzing the samples by SF-ICP-MS technique. Also, I would like to thank Mr. LaryBall for laboratory assistance at Hole Oceanographic Institute USA.

References
Ahmad Taufek Abdel Rahman, Ahmad TermiziRamli, AbdKhalik Wood:. Analysis of the concentrations of natural radionuclides in rivers in kotatinggi district, Malaysia. Journal of nuclear and related technologies, vol. 1, No.1, June (2004).

Andreo, B; Carrasco, F.: Application of geochemistry and radioactivity in the hydro geological investigation of carbonate aquifers. Sierras Blanca and Mijas southern Spain. Applied Geochemistry. 14, 283–299, (1999).

Becker, J. S.: Mass spectrometry of long-lived radionuclides. SpectrochimActa, B 58, p1757– 1784, (2003).

Bomben, A.M; Equillor, H.E; Oliveria, A.A.: ^{226}Ra and natural uranium in Argentina bottled mineral waters. Radiat. Prot. Dosim., 67: 221-224, (1996).

Brown, A; Steenflet, A; Kunzzenorf, H.: Uranium districts defined by reconnaissance geochemistry in South Greenland. J.Geochem. Explor., 19: p127-145, (1993).

Cothern, C.R; Lappenbush, W.L; Jacqueline, M.: Drinking water contribution to naturalbackground radiation. Health Physics, Vol. 50, p.33-47, (1986).

Desideri, D; Meli, M. A.; Feduzi, L.; Roselli, C.; Rongoni, A.; Saetta, D.: ^{238}U, ^{234}U, ^{226}Ra, ^{210}Po Concentrations of bottled mineral waters in Italy and their dose contribution. Journal of Environmental Radioactivity, 94, p 86-97, (2007).

Fisenne, Isabel M; Welford, G.A.: Natural uranium concentration in soft tissues and bone of New York City residents. Health Physics, 50, p739-746, (1986).

Frengstad, B; Skrede, A.K; Banks, D; Krog, J.R; Siewers, U.: The chemistry of Norwegian groundwater: III. The distribution of trace elements in 476 crystalline bedrockgroundwaters, as analysed by ICP-MS techniques Sci.Tot.Environ., 31, p 21-40, (2000).

Gilkeson, R. H; Cowart, J.B.: On radon in ground water. In Proc. NWWA conf. Chelsea: Lewis,p.403, (1987).

Guidelines for Canadian Drinking Water Quality: Guideline Technical Document Radiological Parameters. Federal-Provincial-Territorial Committee on Drinking Water, ISBN 978-1-100-16767-1, (2009).

Guogand, Jia ;Torri, G.: Estimation of radiation doses to members of the public in Italy from intakes of some important naturally occurring radionuclides (238U, 234U,^{235}U, ^{226}Ra, ^{228}Ra, ^{224}Ra and ^{210}Po in drinking water. Appl. Radiat. Isot. ApplRadiatIsot, 65(7), p 849-57, (2007).

Hostetler, S; Wischusen, J; Jacobson, G.: Groundwater quality in the Papunya-Kintore region, Northern Terrtory. Canberra, Australian Geological Survey Organisation, (1998).

International Atomic Energy Agency (IAEA),: International basic safety standards for protection against ionizing radiation and the safety of radiation sources. Vienna, Austria, (1996).

International Commission on Radiological Protection Publication, (ICRP),:Limits for Intake of Radionuclides by Workers. PergamonPress,Oxford, .U.K, 30, (1979).

International Commission on Radiological Protection, (ICRP),: recommendations of the ICRP. Annals of the ICRP,21(1.3).Oxford, Pergamon Press (Publication 60). (1991a ,1990).

International Commission on Radiological Protection, (ICRP),:Age-dependent dose to members of the public from intake of radionuclides: part 5 Compilation of ingestion and inhalation dose coefficients. ICRP Publ No. 72,Oxford: Pergamon press, (1996).

Ivanovich, M; Harmon R.S.: Uranium series disequilibrium, application to earth, marine and environmental sciences, 2nd ed. Oxford, Clarendon press, (1992).

James Cizdziela; Dennis Farmerb; Vernon Hodgec; KazumasaLindleya; Klaus Stetzenbacha.: ^{234}U/^{238}isotope ratios in groundwater from Southern Nevada:a comparison of alpha counting and magnetic sector ICP-MS. Science of the total environment, vol. 350, n^{o}1-3, p 248-260, (2005).

Jarvis K.E., Gray A. L., and Houk R. S. Handbook of Inductively Coupled Plasma Mass Spectrometry. Chapman and Hall, New York (1992).

Joga, S; Harmanjit, S; Surinder S; Bajwa, B.S.: Estimation of uranium and radon concentration in some drinking water samples. Radiation Measurements. 43, p 523-526, (2008).

Kumru, M.N.: Distribution of radionuclides in sediments and soils along the Buyuk Menderes River. Proc. Pakistan Acad. Sci., 32, p 51-56, (1995).
Lasheen, Y.F., Seliman, A.F., and Abdel-Rassoul, A. A.: Simultaneous measurement of ^{226}Ra and ^{228}Ra in natural water by liquid scintillation counting. Journal of Environmental Radioactivity. 95: 86-97, (2007).
Moss M.A.: Chronic low level uranium exposure via drinking water-clinical investigations in Nova Scotia. Thesis, Dalhousie University, Halifax, Novia Scotia, (1985).
Nassef. M.H.: Evaluation of the radioactivity levels of some Egyptian industrial cities (Sadat and 6th October. Ph.D. Thesis, Physics Department. Faculty of Science-Cairo University, Egypt (2005).
Nozaki, T; Ichikawa, M; Sasuya, T; Inarida, M. J.: Neutron activation analysis of uranium in human bone, drinking water and daily diet. J. Radio anal. Chem., 6: p33-40, (1970).
Rafat, M; Khalil, F.A; El Fayoumi, M.A.K.: Natural radioactivity and chemical concentration in Egyptian groundwater. Environ Monit Assess. DOI 10.1007/s10661-010-1367-x, (2010).
Sandeep Kansal; RohitMehra; Singh, N.P.: Uranium concentration in ground water samples belonging to some areas of Western Haryana, India using fission track registration technique. Journal of Public Health and Epidemiology, Vol. 3(8), p 352-357, (2011)
United States Environmental Protection Agency,(US EPA).: Occurrence and exposure assessment for uranium in public drinking water supplies. Report prepared by Wade Miller Associates, Inc. for the Office of Drinking Water, 26, (1990).
United Nations Scientific Committee on Effects of Atomic Radiation, (UNSCEAR),: Report to the General Assembly. Vol. I. : Sources and Effects of Ionizing Radiation, New York. United Nations, (2000).
United States Environmental Protection Agency,(US EPA).: Test Methods for Evaluating Solid Wastes. Physical/Chemical Methods, 3rd Edition, Proposed Update II, SW-846. Office of Solid Waste and Emergency Response. Washington, DC. Available from the National Technical Information Service, Springfield, Virginia, (1992)
United States Environmental Protection Agency, (US EPA),: Review of RSC analysis. Report prepared by Wade Miller Associates, Inc. for the US Environmental Protection Agency. Health Phys., 45, p361, (2003).
Ulback, K; Klinder, O.: Radium and Radon in Danish Drinking Water. Radiation Protection Dosimetry, Vol.7, No.1-4, p 87-89, (1984).
United Nations Scientific Committee on Effects of Atomic Radiation, (UNSCEAR),:Report to General Assembly. Annex B: Exposure from Natural Radiation Sources. and, Report to General Assembly. With Scientific Annexes. Sources and Effects of Ionizing Radiation. United Nations Sales Publications No.E.00.IX.3 Volume I: Sources and No. E.00.IX.4 (Volume II: Effects). United Nations, New York, (2000).
World Health Organization (WHO): Guidelines for Drinking Water quality" Recommendations, 2nd ed., vol.1, Geneva, (1993).
World Health Organization.: Guidelines for drinking water quality. 2nd edition, Vol.2, Geneva, Switzerland, (1996).
World Health Organization, (WHO),: Uranium in Drinking water. Background document for development of WHO Guidelines for Drinking Water Quality, Geneva, (2004).
World Health Organization,(WHO),:Guidelines for Drinking Water quality, Recommendations, Third ed., vol.1. WHO, Geneva, (2004).
World Health Organization, (WHO),: Guidelines for drinking water quality, 2nd edition, addendum to volume 2: Health criteria and other supporting information, Geneva, (2008).
Weihai, Z; Takao, I; X.T.Y.: Occurrence of Rn-222, Ra-226, Ra-228 and U in Groundwater in Fujian Province, China. Journal of Environmental Radioactivity, vol.53, p11-120, (2001).
Yasar, K; Nevzat, D; Ugur, C.: Radiochemical characterization of mineral waters in the Eastern Black Sea Region, Turkey. Environ. Monit Assess, 182, p 415-422, (2011).
Yussuf, N.M; Hossain, I; Wagiran, H.: Natural radioactivity in drinking and mineral water in jphorBahru (Malaysia). Scientific Research and Essay, Vol.7(9), p.1070-1075, (2012).

(Article Received: 15 July 2014; Published on: 15 January 2015)