Measuring the specific concentration of the radioactive isotopes of ^{40}K, ^{137}Cs and (^{224}Ra, ^{226}Ra, ^{228}Ra) for selected samples from Basrah Governorate and the northwest of the Arabian Gulf

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Abstract

The specific concentration of radioisotopes of Potassium ^{40}K; Cesium ^{137}Cs and Radium (^{224}Ra ,^{226}Ra, ^{228}Ra) have been identified for soil, sediment, fish samples (Liza abu, Liza klunzingeri, Brachirus orientalius, Tylosurus crocodilus, Cyprinus carpio and Acanthopagrus arabicus) and kladophora as well as snails in the stations: Qurmat Ali; Al sadir Teaching Hospital; Umm Qasr Port and and Arabian Gulf 1 in 2016. The present study aims to detect the impact of both Chernobyl reactor explosion, Fokushima reactor destruction and the oil industries in the study region environments. The results of the soil and sediment analysis showed that there is an impact of Chernobyl accident. There are observed concentrations for the ^{137}Cs; in addition to the effect of the oil industries in the soil, sediments, and Acanthopagrus arabicus fish and Kladophora crusbate plant. This was proved by measuring the concentrations of Radium isotopes in the amounts above the allowable rates globally and locally. The results of the current study showed that the rates of Potassium 40 were the most prominent in fish samples and the Kladophora crusbate plant, which represents the predominant radiation activity and it is within the permitted natural range. The results of this study can be considered as a basis for monitoring of the future changes.

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Keywords: Specific concentration of radioisotopes, potassium isotopes, cesium isotopes, radium isotopes, Gamma spectrometry analysis.

قياس التركيز النوعي للبوتاسيوم ^{40}K والسيزيوم ^{137}Cs ولنظائر الراديوم المشعة (^{224}Ra, ^{226}Ra, ^{228}Ra) لعينات مختارة من محافظة البصرة وشمال غرب الخليج العربي.

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الخلاصة

جرى تعيين التركيز النوعي للنظائر المشعة لكل من البوتاسيوم ^{40}K والسيزيوم ^{137}Cs ولنظائر الراديوم (^{226}Ra,^{228}Ra ,^{224}Ra) لعينات التراب والرسوبيات والاسماك (خشني, بياح, مزلك, مخيط, سمتي و شعم) وكذلك نبات الكلادوفورا اضافة الى القواقع في بيئات شط العرب وميناء ام قصر والمياه الساحلية العراقية في منطقة السد الخارجي – شمال غرب الخليج العربي في عام 2016. تهدف الدراسة الحالية الكشف عن تأثير كل من حادثة انفجار مفاعل تشرنوبل وحادثة انفجار مفاعل فوكوشيما في اليابان وكذلك الصناعات النفطية في بيئات منطقة الدراسة. اوضحت نتائج تحليل التراب والرسوبيات ان هناك وجود تأثير لحادثة تشرنوبل اي ان هناك تراكيز مرصودة لنظير السيزيوم 137 ، إضافة الى وجود تأثير للصناعات النفطية في كل من التراب والرسوبيات واسماك الشعم ونبات الكلادوفورا حيث تم اثبات ذالك من خلال رصد تراكيز لنظائر الراديوم بمقادير فوق النسب المسموح بها عالميا ومحليا. كما وان نتائج الدراسة الحالية أوضحت ان نسب البوتاسيوم 40 كانت الابرز في عينات الاسماك ونبات الكلادوفورا والذي يمثل النشاط الاشعاعي الغالب وهو ضمن النسب الطبيعية المسموح بها . وبالإمكان اعتبار نتائج هذه الدراسة كأساس لمراقبة التغيرات المستقبلية.

الكلمات المفتاحية: التركيز النوعي للنظائر المشعة, نظائر البوتاسيوم, نظائر السيزيوم, نظائر الراديوم, التحليل باستخدام مطياف كاما.

1. Introduction

The environment is generally exposed to a continuous stream of pollutants of various kinds, some of which result from natural activities but mostly from human activities. Radiation pollutants are subject to the reactions and transitions within the environment. Where they are concentrated, transferred from one part to another and integrated into ecological activities. In particular, the seas are the most concentrated reservoirs of radioactive contaminants. Therefore, significance of the seas from ecological studies is no less than that of other parts of the earth and the atmosphere [10]. Since the beginning of World War II, various researchers have been interested in conducting extensive research to understand the chemical and physical properties of radioactive materials which attributed to natural and anthropogenic sources that are affected the general population [1]. The naturally occurring radioactive material (NORM) belong to one of the natural radiation decay chains: the uranium ^{238}U series, the thorium ^{232}Th series and the actinium ^{235}U series, which accompanies potassium ^{40}K decay [11]. The natural radioactive sources are found in varying concentrations from one region to another on the surface of the plant. They may be concentrated as a byproduct of some industries, such as the phosphate fertilizer industry and the oil and gas industry, in addition to the combustion of fossil fuels in the electricity industry. The human body naturally contains specific amounts of these radioactive isotopes, most notably Potassium ^{40}K. Potassium ^{40}K is a natural isotope that contributes to the largest part of the radiation dose entering people bodies. The decay of the three radiation chains leads to the production of other natural radioactive isotopes, which are characterized by physical and chemical properties that differ from their radionuclide characteristics. Among these dates, the Radium element Ra and these dates have a shorter half -life. These elements emit different types of ionizing radiation in the environment and energy rates are different from the parents [3]. Radiation decay is the emission of particles or electromagnetic radiation from the nucleus of the atom (for radioactive nuclei). Particles are divided into the rays of alpha particles (the nucleus of helium atom) or the radiation of beta particles, whereas the electromagnetic radiation is a beam of Gamma radiation. When any type of ionizing radiation collides with the atom, it is ionized, thereby damaging living cells that exposed to the radiation, and this damage increases the risk of cancer. If the exposure to Radium radiation is externally, the rate of damage is less because the range of alpha particles is too small to penetrate the skin, and the beta particles do not exceed the surface layer of the skin. Radium, dissolved in water, concentrated in biota and dissolved in the soil, damages internal living cells and thus increases the risk of cancer, primarily bone cancer and sinus cancer [8]. It should be noted that the risks incurred are dependent on the way the body metabolizes. The United States Environmental Protection Agency (USEPA) has established a standard for the maximum concentration level MCL contamination of the radium-Ra element in public drinking water supply stations because of the health risks associated with the handling of these radioactive materials. The MCL that determined by (USEPA) for the total radium ^{228}Ra and ^{226}Ra is 5 pCi / L and for the alpha particles is 15 pCi / L [17]. This leads to a cancer risk of 1 to 20,000 in the case of 2 liters of contaminated water per day for 70 years.

There are many studies for the estimation of the concentration of radium isotopes ^{228}Ra, ^{226}Ra, ^{224}Ra [16, 2, 5, 13]. The anthropogenic radioactive elements are primarily produce from nuclear tests, nuclear power plants, various medical and agricultural uses, scientific research, and the explosion of reactors such as the Chernobyl reactor explosion.

The most important nuclear fission products are the strontium ^{90}Sr , its half-life is 28.8 years, and the cesium ^{137}C , its half-life is

30 years. They have long half-life and similarity in their chemical composition. The strontium ^{90}Sr is similar to calcium, which they belong to group (1) in the periodic table, while cesium ^{137}C is similar to potassium ^{40}K belonging to group (2) of the periodic table, as potassium is the main element in the composition of muscle cells and then the pollution is relatively larger [9]. In the body of a man weighing 70 kg, the potassium content is about 160 g, equivalent to the decay of 4,900 nuclei of potassium ^{40}K per second [15]. Similar chemical elements can compete with each other when moving from soil to plant to man.

The objective of the research is studying the concentration of the anthropogenic radionuclides in a number of environments to monitor the level of radiation activity produced after the Chernobyl explosion. In addition to that, studying of concentrations of the natural nuclides in the water environment of southern Iraq, which may contain isotopes that coming from the remnants of oil industries and other industries. So, the aim of the present study is to conduct a radiological survey of samples from the aquatic environment in addition to soil and sediments to determine the samples in which radionuclides are concentrated and to be adopted as bioactive radionuclides.

2. The study region

The study region is located in the south of Iraq within the sedimentary plain. It is located between longitudes (73^{o} 480') (17^{o} 470') east, and latitudes (57^{o} 300') (81^{o} 290') north. The study region includes selected regions of Basrah Governorate, Shat Al-arab and the coastal water in the outer bar north-west of the Arabian Gulf (i.e. Arabian Gulf 1), as shown in figure (1). Shat Al-arab is an estuary formed from the confluence of the Tigris and Euphrates rivers. These rivers meet in the region of Qurmat Ali, the northern entrance of the Basrah, which is about 200 km long. It also consists of the Al-karcha river, which flows in Shat Al-arab north of the Basrah through the marshes, and Al-karun river, which flows in this estuary - in south of Basrah. The sources of these two rivers are located in Iran. In addition to other permanent or seasonal tributaries flowing into one of those rivers. Shat Al-arab identifies the interactive relationship with salty sea water in both tidal conditions (i.e. flood-tide and ebb-tide), going north during flood-tide and south during the ebb-tide [6]. Arabian Gulf is a shallow stretch of the Indian Ocean between Arabian peninsula and southwestern Iran. It covers an area of about 241,000 km^2 and is about 990 km long and its width ranges from a maximum of 340 km to a minimum of 55 km in the Strait of Hormuz. It is bordered by Iran from the north, northeast; while from the south-east and south are Oman and United Arab Emirates. Furthermore, it is bordered from the southwest and west by Saudi Arabia and Qatar. Kuwait and Iraq are located on its northwestern tip, while Bahrain lies within the waters of the western Gulf in northern Qatar.

The waters of the Gulf rarely exceed 90 meters depth, and in very few areas may reach depths of more than 110 meters at its entrance and in isolated places in the south-eastern part. The Gulf is asymmetric in depth. The deepest water lies along the Iranian coast and most of its areas are about 35 meters deep. There are many islands, most of which are salt domes, accumulations of coral and skeletal debris of fine marine animals. The rate of tides varies in the Arabian Gulf and rises to 3.0 to 3.4 m in the northwest. The movement of the surface water in the Gulf is the counter clockwise, and is characterized by a vertical movement. Surface water, when entering from Indian Ocean, is evaporated and thus becomes more dense and drowns within the body of the Gulf to emerge from the Gulf into the Strait of Hormuz to the Indian Ocean as deep water currents under the surface currents entering the Gulf body [7].

3. Collection of samples

Samples were collected during the month of June 2016 to November 2016, from the selecting regions. The samples were collected according to the recommendations and procedures of the International Atomic Energy Agency (IAEA). A group of at least 6 soil samples were taken for an area of at least 10 m^2 and to the 4 corners per each site, at a depth of (0-15 m). The mud sediments were collected from Shat Al-arab and Arabian Gulf using the grap sampler, while the kladophora as well as snails were collected manually, whereas, the fish were purchased from fishermen within the study region.

4. Preparation of samples

The samples were prepared after transfer to the marine radiation pollution laboratory. The samples were dried after purification from impurities and suspended materials in a drying oven within 48 hours at 105 ° C. They were then grinded and sifted with 2 mm sieve. Each sample weighing 500 g was then placed in plastic bags with an indication to the type and location of the sample.

5. Samples measurement

After preparation, the samples were sent to the Ministry of Science and Technology / Central Laboratories to measure the level of radiation concentrations using Gamma Rays Spectrometry. The system uses a high-purity Germanium detector that has an analytical capacity of 1.8 KeV in the energy of 1332 KeV, with an efficiency of 40%. The system uses Gamma Vission-32 software, which is supplied by Ortec company to extract data from the resulting spectra.

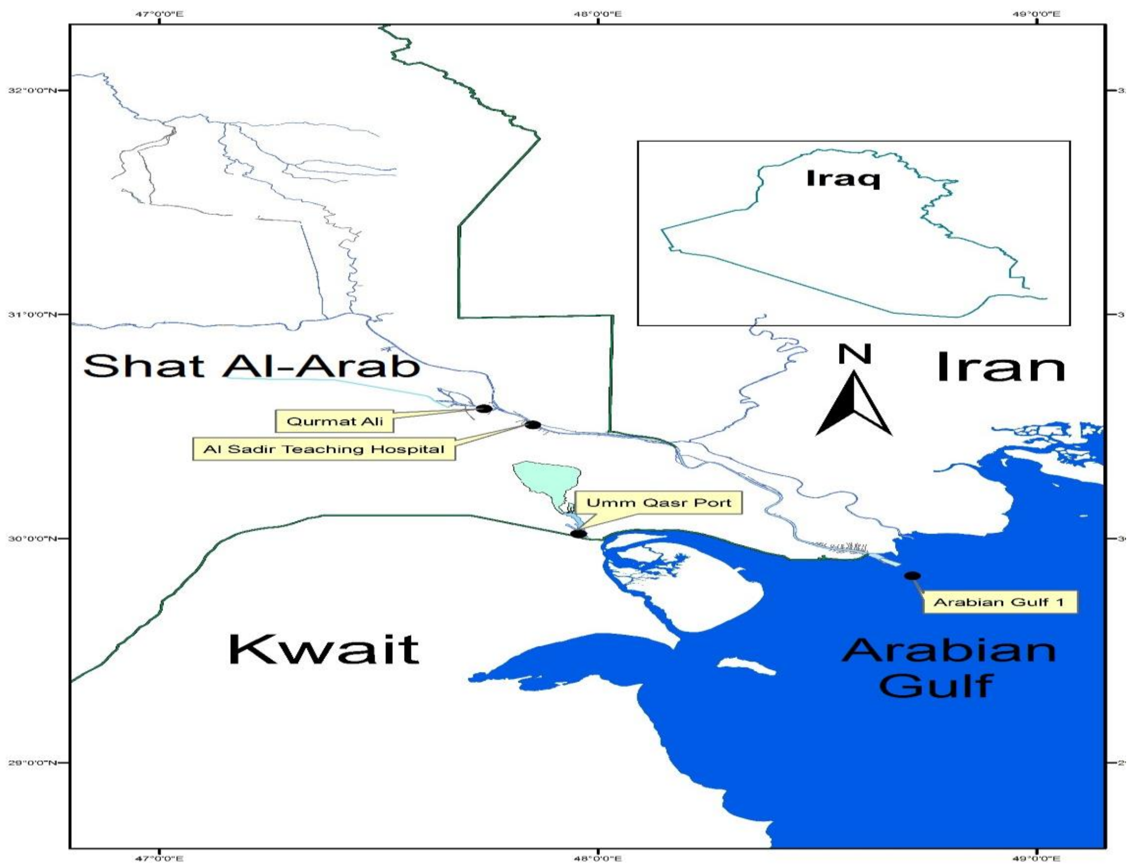

Figure (1): Map of study region.

6. Results and discussion

6.1 Specific concentration of Potassium ^{40}K

Potassium is one of the most important mineral elements in the earth's crust. The natural potassium has three isotopes (^{39}K, ^{40}K, ^{41}K). Potassium ^{40}K has a half-life of 1.3 x 10^9 y and emits gamma and beta particles, whereas, its content in the total potassium is approximately 0.01178% [14]. Since ^{40}K is the most effective in the earth's crust and does not belong to the ^{238}U, ^{235}U and ^{232}Th radiation series, its study is one of the fundamental principles of natural radiation background.

After sampling and laboratory preparation, the gamma spectrums of the samples are studied. The peak of concentration of potassium ^{40}K is determined at energy of 1460 KeV. The specific concentration is calculated after determining the specific intensity of ^{40}K and the efficiency of the detector. Table (1) shows the specific concentration of potassium ^{40}K in all samples, while the figure (1) shows the comparison of the specific concentration . The results showed that the highest concentration of potassium ^{40}K concentration was for (Liza abu, Liza klunzingeri, Brachirus orientalius, Cyprinus carpio and kladophora plants). This may be due to weak mixing and circulation in the study region in comparison with open sea water, which increases the concentration of the mentioned isotope in the above samples. These ratios are within the internationally permissible limits of this compound in comparison to [12]. ^{40}K has affinity to biological materials and sands also.

Table (1): The specific concentration A_s for the potassium ^{40}K in the studied samples

Specific Concentration A_s (Bq/Kg)	Coordinates	Sampling Regions	Sample Type	Symbol	Seq.
370.9	48^0 43' 1'' E 29^0 50' 2'N	Iraqi coastal water/Outer bar	Soil	S1	1
397.9	47^0 57' 8'' E 30^0 1' 24'' N	Umm Qasr / Opposite Port	Soil	S2	2
337.6	47^0 51' 11'' E 30^0 30' 49.7'' N	Al Sadir Teaching Hospital/Opposite	soil	S3	3
360.8	48^0 43' 1'' E 29^0 50' 2'N	Iraqi coastal water/Outer bar	Sediments	S4	4
370	47^0 57' 8'' E 30^0 1' 24'' N	Umm Qasr / Opposite Port	Sediments	S5	5
367	47^0 51' 11'' E 30^0 30' 49.7'' N	Al Sadir Teaching Hospital/ Shat Al-arab	Sediments	S6	6
762	47^0 51' 11'' E 30^0 30' 49.7'' N	Al Sadir Teaching Hospital/ Shat Al-arab	Liza abu Fish, (Heckel, 1843)	F7	7
914	47^0 57' 8'' E 30^0 1' 24'' N	Umm Qasr Port	Liza klunzingeri Fish,(Day,1888)	F8	8
654	48^0 43' 1'' E 29^0 50' 2'N	Iraqi coastal water	Brachirus orientalius Fish, (Bloch and Schneider, 1801)*	F9	9
368	48^0 43' 1'' E 29^0 50' 2'N	Iraqi coastal water	Tylosurus crocodilus Fish, (Peron and Lesueur,1821)*	F10	10
1180	47^0 44' 23.6'' E 30^0 34' 45.5'' N	Shat Al-arab/ Qurmat	Cyprinus carpio	F11	11

		Ali	Fish, (Linnaeus, 1758)*		
500	47^0 37' 29.1" E 31^0 34' 11.8" N	Umm Qasr Port	Acanthopagrus arabicus Fish, (Iwatsuki, 1013)*	F12	12
708	47^0 44' 23.6" E 30^0 34' 45.5" N	Shat Al-arab/ Qurmat Ali	Kladophora crusbate*	B13	13
280	47^0 44' 23.6" E 30^0 34' 45.5" N	Shat Al-arab/ Qurmat Ali	Lymena (Radix) anricularia Snails (Linnaeus, 1758)*	B14	14

* Each name of an animal or plant is followed by the name of the scientist that discovers it.

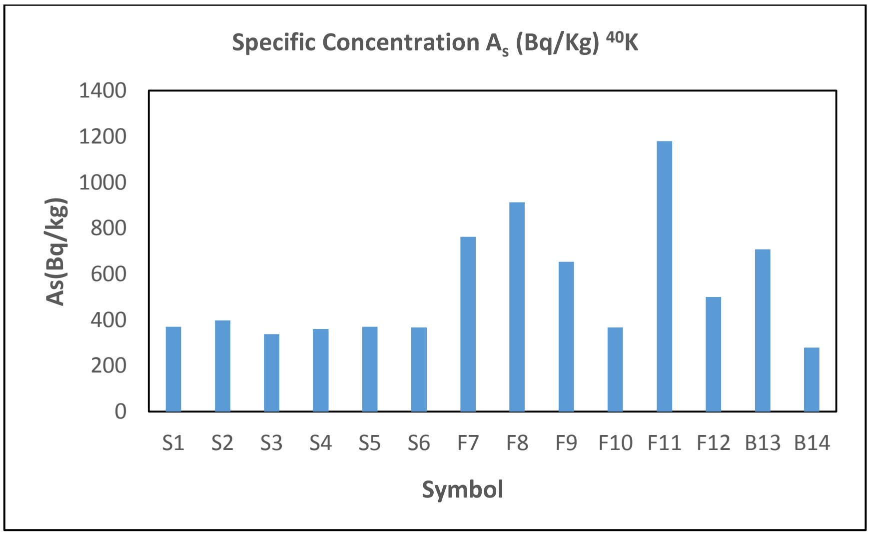

Figure (2): Comparison of the specific concentration of ^{40}K in the study region samples.

6.2 Specific concentration of Radium (^{224}Ra, ^{226}Ra, ^{228}Ra) and Cesium (^{137}Cs)

Samples were collected from the study region, after their preparation, were sent to the Ministry of Science and Technology / Central Laboratories. The specific concentrations of the above elements as shown in table (2), were compared to figures (3), (4), (5), (6).

Table (2): The specific concentration A_s for the (^{224}Ra, ^{226}Ra, ^{228}Ra, ^{137}Cs) in the studied samples

Specific Concentration A_s (Bq/Kg) ^{228}Ra	Specific Concentration A_s (Bq/Kg) ^{226}Ra	Specific Concentration A_s (Bq/Kg) ^{224}Ra	Specific Concentration A_s (Bq/Kg) ^{137}Cs	Sampling Regions	Sample Type	Symbol	Seq.
15.3	29.15	6.9	2.9	Iraqi coastal water/Outer bar	Soil	S1	1
15.4	23.3	9.7	1.5	Umm Qasr / Opposite Port	Soil	S2	2
14.23	33.22	12.8	1.7	Al Sadir Teaching Hospital/Opposite	soil	S3	3
14.94	27.35	11.27	N.D*	Iraqi coastal water/Outer bar	Sediments	S4	4

15.2	30.84	9.24	1.6	Umm Qasr / Opposite Port	Sediments	S5	5
17.8	30.62	12.9	4.7	Al Sadir Teaching Hospital/ Shat Al-arab	Sediments	S6	6
14.95	15.59	4.74	N.D*	Al Sadir Teaching Hospital/ Shat Al-arab	Liza abu Fish, (Heckel, 1843)	F7	7
N.D*	10.22	3.36	N.D*	Umm Qasr Port	Liza klunzingeri Fish,(Day,1888)	F8	8
N.D*	10.16	3.36	N.D*	Iraqi coastal water	Brachirus orientalius Fish, (Bloch and Schneider, 1801)*	F9	9
18.59	10.77	5.54	N.D*	Iraqi coastal water	Tylosurus crocodilus Fish, (Peron and Lesueur,1821)*	F10	10
N.D*	5.66	3.24	N.D*	Shat Al-arab/ Qurmat Ali	Cyprinus carpio Fish, (Linnaeus, 1758)*	F11	11
3.12	27.45	9.0	N.D*	Umm Qasr Port	Acanthopagrus arabicus Fish, (Iwatsuki, 1013)*	F12	12
1.1	57.45	14.0	N.D*	Shat Al-arab/ Qurmat Ali	Kladophora crusbate*	B13	13
N.D*	4.5	0.45	N.D*	Shat Al-arab/ Qurmat Ali	Lymena (Radix) anricularia Snails (Linnaeus, 1758)*	B14	14

Note: N.D * means that the concentration in the sample is less than the sensitivity of the system, * each name of an animal or plant is followed by the name of the scientist that discover it.

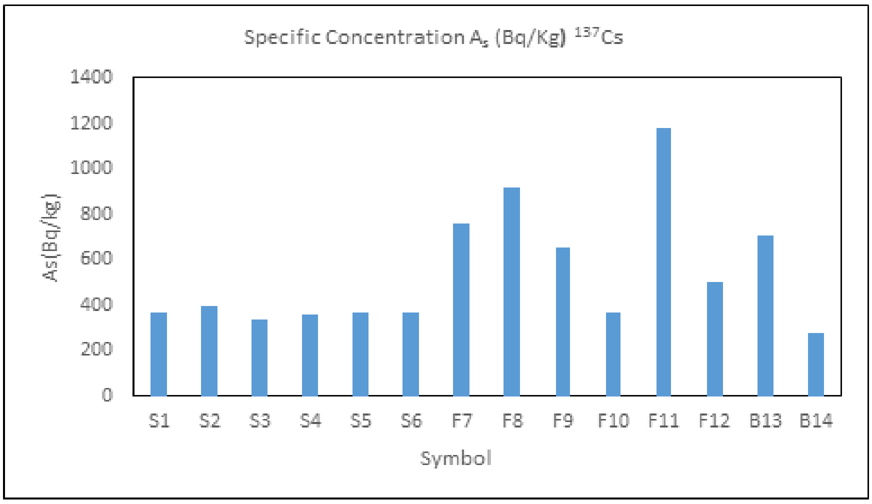

Figure (3): Comparison of the specific concentration of ^{137}Cs in the study region samples

The current results show that the highest concentration of Cesium ^{137}Cs was found in soil and sediments samples. This may be due to the raining during the Chernobyl accident. Where, the water and sediments of the study region are less mixed with the open marine waters due to the weak mixing and circulation in this region. The concentration of the mentioned isotopes in the above samples is increasing. On the other hand, the deposition of cesium 137 on the surface of the soil is affected by weather conditions and the nature of the study region as well as the degree of correlation of these radionuclides with the soil compounds over time [1]. Many studies have showed that levels of radionuclides vary from place to place depending on the prevailing wind speed, the size of radionuclide-bearing particles and climatic conditions. Therefore, the levels of anthropogenic radionuclides caused by raining, Cesium 137, should be determined in order to identify the radiation dose of the general population.

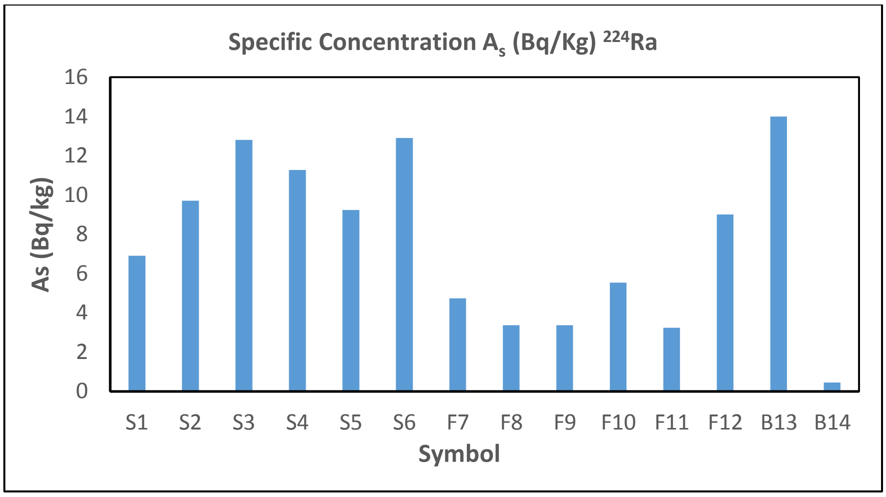

Figure (4): Comparison of the specific concentration of ^{224}Ra in the study region samples.

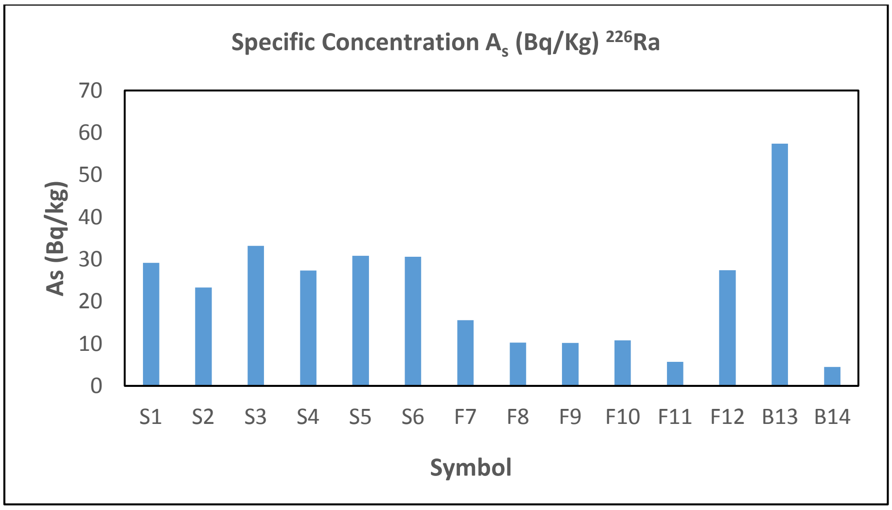

Figure (5): Comparison of the specific concentration of ^{226}Ra in the study region samples.

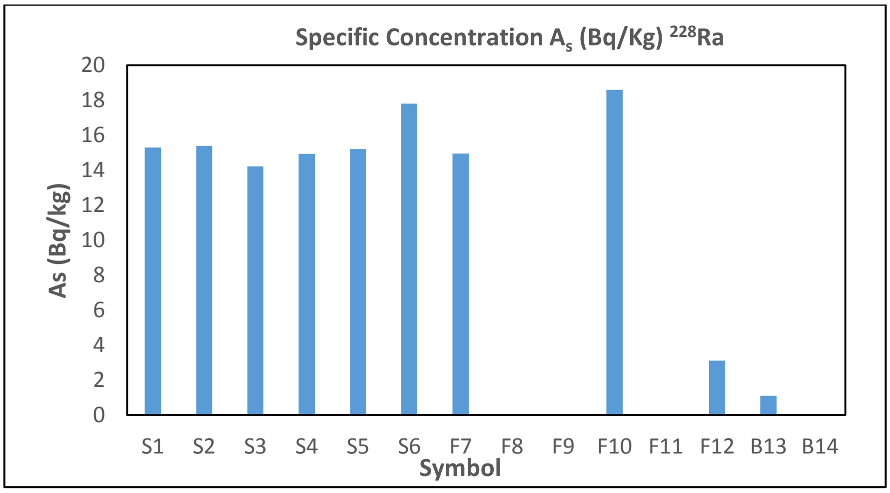

Figure (6): Comparison of the specific concentration of ^{228}Ra in the study region samples.

Where, the soil holds more than 90% of the cesium 137 caused by raining in the surface layer (0-20 cm) [1]. However, the percentage of these concentrations in terms of health is within the permissible limits in comparison with [4, 12].

The results of radium isotops ^{224}Ra, ^{226}Ra and ^{228}Ra show that the highest concentration was in soil and sediment samples, as well as in Acanthopagrus arabicus fish and kladophora crusbate plant. This may be due to the dumping of water accompanying the oil industry near the banks of the study region. These values are higher than the maximum pollution values proposed by USEPA [17, 4]. It should be noted that the impact of oil industries in general is significant to the environment in the sampling region.

7. Conclusions and recommendations

The results of the current research showed that there is a clear impact of the Chernobyl explosion, Fokushima accident and that the measured rates in the study region are among the world's allowable rates according to concentrations of cesium 137 isotopes. However, there is a clear impact of the oil industries on Shat Al-arab environment and the port of Umm Qasr and Iraqi coastal waters in the region of the outer bar as indicated by concentrations of radium isotopes, which we conducted in the soil and sediments, fish and plants of the study region. Potassium 40 concentrations in the studied samples were within the normal limits and were more pronounced in fish samples and kladophora crusbate plants. When comparing the results of the following research with studies conducted in other parts of Iraq and the world, it was noted that the values obtained were consistent with some other studies and that some differences may be due to the nature of marine physical properties. The study recommends monitoring the dumping of human and industrial waste in the study region.

8. References

[1] Al-Masri, M., (2005), Inventory of Cesium 137 Located in Syrian Soils and Estimation of Extrusion Rates and Dosage, Syrian Atomic Energy Commission, KPC 601. (In Arabic).

[2] Chisté, V., M.-M. Bé, and Dulieu, C. (2007). Evaluation of decay data of radium-226 and its daughters. International Conference on Nuclear Data for Science and Technology, EDP Sciences.

[3] Durrance, E. M. (1986). "Radioactivity in geology: principles and applications."

[4] Godyń, P., Dołhańczuk-Śródka, A., Ziembik, Z., and Moliszewska, E. (2014). "Estimation of the committed radiation dose resulting from gamma radionuclides ingested with food." Journal of radioanalytical and nuclear chemistry 299(3): 1359-1364.

[5] Hsieh, Y.-T., Geibert, W., van Beek, P., Stahl, H., Aleynik, D., and Henderson, G.M., (2013). "Using the radium quartet (228Ra, 226Ra, 224Ra and 223Ra) to estimate mixing rates and trace sediment inputs in Loch Etive, Scotland." Limnology and Oceanography 58(3): 1089-1102.

[6] Janabi, H., (2017), Shat Al-alarab symbolism and deteriorating reality. (In Arabic).
/http://iraqieconomists.net/ar/2012/02/08/

[7] Knowledge, (2017). Arabian Gulf. (In Arabic).
http://www.marefa.org/

[8] Mays, C. W., Rowland, R.E., and Stehney , A.F. (1985). "Cancer risk from the lifetime intake of Ra and U isotopes." Health physics 48(5): 635-647.

[9] Mollah, A. S., Husain, S.R. , and Rahman, M.M. (1986). "Environmental gamma radiation from deposited fallout 137 Cs." Indian Journal of Pure and Applied Physics 24(4): 211-212.

[10] Othman, A., and Yasin, T. (1997), Determination of the level and sources of radioactive contamination in the Syrian coast, Syrian Atomic Energy Commission, KPC 153. (In Arabic).

[11] Radiation, U. N. S. C. o. t. E. o. A. (2000). Sources and effects of ionizing radiation: sources, United Nations Publications.

[12] Rasheed, M. Yousuf, H. I. H., and Ahmed, K.h. (2008). "Determination of the Specific Activity of Cs137and K40in Environmental Nineveh Governorate." Journal of Al-Rafidain Research Science 19(2): 205-220.

[13] Rodellas, V., Garcia-Orellana, J., Trezzia, G., Masquéacde, P., Stieglitz, T. C., Bokuniewiczg, H., Cochran, J.K., and Berdalet, E. (2017). "Using the radium quartet to quantify submarine groundwater discharge and porewater exchange." Geochimica et Cosmochimica Acta 196: 58-73.

[14] Rosén, K. (1991). Effects of potassium fertilization on caesium transfer to grass, barley and vegetables after Chernobyl. The Chernobyl fallout in Sweden.

[15] Samat, S. B., Green, S., and Beddor, A. H. (1997). "The activity of one gram of potassium." Physics in medicine and biology 42(2): 407-433.

[16] Szabo, Z., DePaul, V. T., Kraemer, T. F. and Parsa, B. (2005). Occurrence of radium-224, radium-226, and radium-228 in water of the unconfined Kirkwood-Cohansey aquifer system, southern New Jersey, U. S. Geological Survey.

[17] U.S. Environmental Protection, A. (2000b). "National Primary Drinking Water Regulations; Radionuclides; Notice of data availability; Proposed rule: Washington, D.C., Office of Water." U.S. Environmental Protection Agency EPA-815-2-00-003.