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Radioactivity in the Southern East Baghdad Oilfield from the Reservoir to the Surface Environment

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Abstract:
Naturally occurring radioactivity was evaluated in the reservoir rock, surface soil samples, and oil production waste at the East Baghdad South (EBS) Oil Field. The radioactivity of uranium-238 (and radium-226), thorium-232, and potassium-40 were calculated in core samples from four geological formations: Al-Zubair, Al-Khasib, Tanuma, and Hartha Formations, which represent the oil reservoirs in the study area in addition to the natural GR and SGR logs for the oil well in EBS were calculated. The radioactivity of the above-mentioned nuclides was also measured for surface soil samples and waste samples from the site of the oil production industry at the EBS oilfield. The measurements included all the stages of oil production from the collection of crude oil from the wells stage to the storage of the manufactured oil. It also included measurements of radioactivity in samples for some sites outside the industry and near the oil wells in the region. Total radioactivity was measured in count/second and the exposure dose rates were also measured at all the above sites. Relatively high concentrations of uranium-238 and radium-226 were found in rock core samples of some geological units within the oil reservoir formations which will certainly move with the oil to the surface and collect with waste (such as sludge) when oil is produced. Although, some sites have higher Ra-226, Th-232, and K-40, in the sludge samples and oily soil, such as in the 1st separator stage, water separation (Desalter) stage, and near the waste pit, these locations are acceptable if they are compared with other oilfields worldwide. The gamma absorbed doses calculated inside the EBS oil industry were higher than the global average of (59) nGy/h where Ra-226 is the main contributor in these doses, on the other hand, external hazard index (Hex) values less than unity so they are acceptable according to UNSCEAR. Radiation dose values in some places in the study area exceed the values recommended by ICRP, UNSCEAR, and IAEA (1 mSv/y) for the public but less than the values recommended for workers (20 mSv/y). generally, the site of EBS- oilfield does not show radioactive contamination or significant radioactive hazards, as it is a new facility, and safety instructions are still strictly applied, and the removal of waste immediately before its spread by the activity of the workers in the facility.

Keywords: NORM, Radioactivity, EBS oil field, Radiation doses.

النشاط الإشعاعي من المكمن النفطي إلى البيئة السطحية في حقل نفط شرق بغداد الجنوبي

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الخلاصة :

تم تقييم النشاط الإشعاعي الذي للنويدات المشعة المتواجدة طبيعيا في صخور الخزان وعينات التربة السطحية ومخلفات إنتاج النفط في حقل نفط شرق بغداد الجنوبي (EBS). تم حساب النشاط الإشعاعي لليورانيوم 238 (والراديوم 226) ،الثوريوم 232 والبوتاسيوم 40 في عينات لباب من اربعة تكوينات جيولوجية هي الزبير والخصيب وتنومة وهارثة والتي تمثل المكامن النفطية في منطقة الدراسة. فضلا عن قياس قيم غاما الكلية GR و طيف اشعة SGR الطبيعية لابار النفط في الحقل. تم أيضًا قياس النشاط الإشعاعي للنويدات المذكورة أعلاه لعينات التربة السطحية وعينات المخلفات النفطية من موقع صناعة إنتاج النفط في الحقل. وشملت القياسات جميع مراحل إنتاج النفط من مرحلة تجميع النفط الخام من الآبار إلى تخزين النفط المصنّع في الحقل. كما تضمنت الدراسة قياس النشاط الإشعاعي في عينات لبعض المواقع حول موقع مصنع النفط وبالقرب من آبار النفط المنتجة في منطقة الدراسة. تم قياس معدلات جرعة التعرض في جميع المواقع المذكورة أعلاه. تبين من خلال الدراسة هناك تركيزات عالية نسبيًا من اليورانيوم 238 والراديوم 226 في عينات اللباب الصخري لبعض الوحدات الجيولوجية ضمن تكوينات المكامن النفطية وهذه التراكيزستنتقل بالتأكيد مع النفط إلى السطح وتتجمع مع المخلفات (مثل الحمأة) عند إنتاج النفط .وعلى الرغم من أن بعض المواقع لديها مستوى عالي نسبيا من Ra-226 و Th-232 و K-40 ، في عينات الحمأة والتربة الملوثة بالنفط ، كما هو الحال في المرحلة الأولى لفصل النفط، مرحلة فصل المياه (إزالة الملوحة) ، وبالقرب من حفرة النفايات ، فإن هذه المواقع مقبولة إذا ما قورنت مع حقول النفط الأخرى في حول العالم. كانت جرعات جاما الممتصة المحسوبة داخل مصنع النفط EBS أعلى من المتوسط العالمي البالغ (59) نانوغرام / ساعة حيث يعتبر Ra-226 هو المساهم الرئيسي في هذه الجرعات. من ناحية أخرى فان قيم مؤشر المخاطر الخارجي (Hex) اقل من الوحدة (unity) لذا فهي مقبولة وفقًا لـ UNSCEAR وتتجاوز قيم جرعة الإشعاع في بعض الأماكن في منطقة الدراسة القيم الموصى بها من قبل ICRP وUNSCEAR والوكالة الدولية للطاقة الذرية (1 ملي سيفرت / سنة) للجمهور ولكن أقل من القيم الموصى بها للعاملين (20 ملي سيفرت / سنة). بشكل عام ، لا يُظهر موقع EBS- حقل نفط تلوثًا إشعاعيًا أو مخاطر إشعاعية كبيرة ، حيث إنه منشأة جديدة ، ولا تزال تعليمات السلامة مطبقة بصرامة ، وإزالة النفايات فورا قبل انتشارها نتيجة نشاط العمال في المنشأة.

Introduction:

Gamma rays recorded by gamma logs are related to the presence of naturally occurring radioactive material (NORM) in clay and the ions associated with them [1]. Radioactivity of K-40, Th-232, and U-238 are recorded in the gamma log tool (GR) then added together, and converted to an American Petroleum Institute (API) unit [1]. For standard GR logs, the value measured is calculated from thorium in ppm, uranium in ppm, and potassium in percent. There is a clear difference between radioactivity in the different rock formations in the oil well wall. Shale rocks have almost highly radioactivity than sandstone and carbonate rocks. This difference in radioactivity between shales and sandstones/carbonates allows the gamma tool to distinguish between shales and non-shales. Attention must be taken in some cases in the interpretation of GR. Due to the mass of uranium concentration in the calculation, anomalous concentrations of uranium can cause clean sand reservoirs to appear shaly. Sandstone can contain uranium, potassium feldspar, clay filling, or rock fragments that cause it to have higher-than-usual gamma radiation. Limestones have very low concentrations of U, Th, and K, and give very low gamma-ray responses. The laboratory radioactivity measurement of core samples collected within the drilling of the oil well should give the same results as the well-logging after wellbore influence corrections.

The gas and oil industries in the oil fields are one of the most important sources of contamination by natural radionuclides. Some naturally occurring radioactive materials (NORM), the most important of which is radium-226, rise to the earth's surface with crude oil.

The concentration of radioactive radionuclides increases through the stages of oil and gas production, produced water, and in all sludge and scale deposits in the subsurface and/or surface production facilities [2]. Cleaning or maintaining equipment rise the contamination in the site in addition to higher indoor radon levels in nearby buildings [3, 4].

The international community has been considering disposal options for NORM wastes to make negligible a public radiological impact, therefore, it is necessary to take radiological measurements and collect data related to the concentrations of radionuclides in the surface soil, oil-contaminated soils, and oil and gas production waste at the oil field production site, and to trace the radioactivity of those nuclides from their source in the oil reservoir to the last stage of oil production and storage. This data will be important as a database for monitoring the level of radioactive contamination and taking the necessary actions according to the instructions of the relevant authorities, such as the IAEA, issued in this regard.

Currently, data on the radioactivity levels in oil and gas at the Southern East Baghdad (EBS) oilfields is unavailable. This is because there have not been any radiological surveys of the facilities and the surrounding areas. The current study aims to identify the various radionuclides associated with NORMs in core rocks, crude oil, and petroleum waste from the EBS Oilfield.

Study area:

East Baghdad oilfield is located east of Baghdad city. It is spreading 60 km long and 12 km wide. The site is under the concession of the EBS field and covers an area of 822 km^2. East Baghdad oil field is subdivided geographically into six areas from northwest to southeast; respectively North Extension, Al-Taji, Al-Rashdiya, Urban, South 2, and South 1 areas. East Baghdad southern area includes both south 2 and south1 [5], (Figure 1)

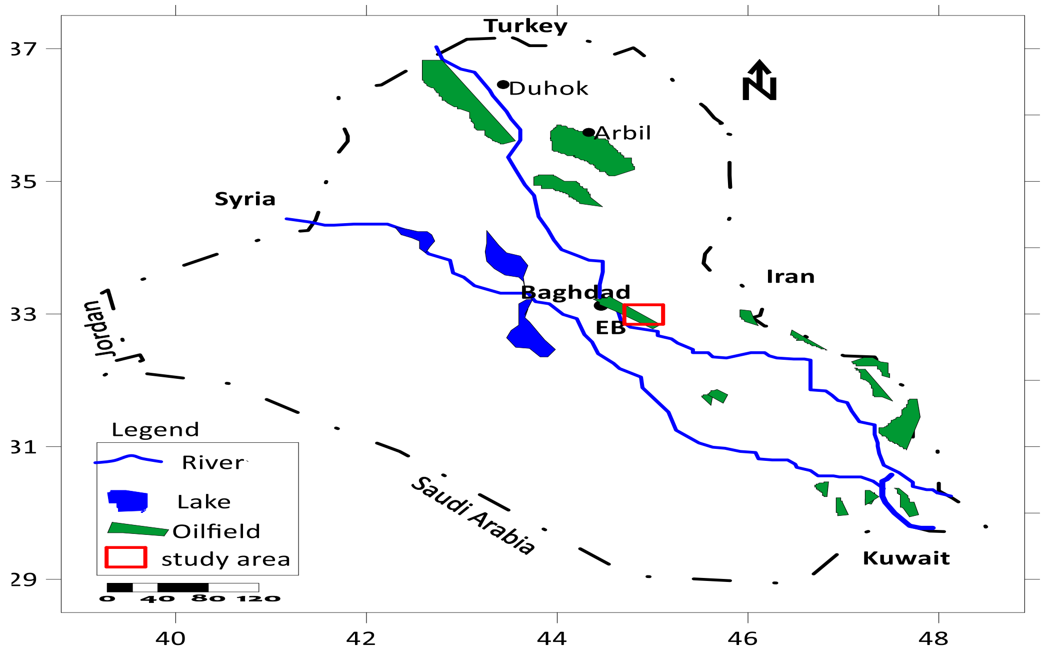


Figure 1: Map of Iraq showing the location of the East Baghdad (EB) oilfield; modified from [6]. The study area represents the southern part of the EB oilfield.

Geological setting of EBS oilfield area:

The EBS area is flat with about 33m elevation above sea level. The surface of the study area is covered by quaternary deposits of about 30m carried and deposited by the Tigris River and the Euphrates River [6].

The EB field represents a faulted, NW-SE trending structure, with oil production to date coming mainly from the late Cretaceous Tanuma Formation and the fractured Khasib carbonates Formation and from the early Cretaceous Zubair sandstone Formation. Oil has been successfully tested in other Cretaceous reservoirs; the Hartha carbonates, Mishrif/Rumaila carbonates, Nahr Umr clastics, and Ratawi mixed clastics /carbonate, and there is also have been good oil shows in other Cretaceous reservoirs. [6], (Figure 2).

The geological column, as shown in Figure 2, represents a stratigraphic section of the East Baghdad Oil Field. Oil Reservoirs in the study area contain three formations; they are Zubair Formation, Khasib Formation, and Tanuma Formation. Hereinafter brief description of these formations.

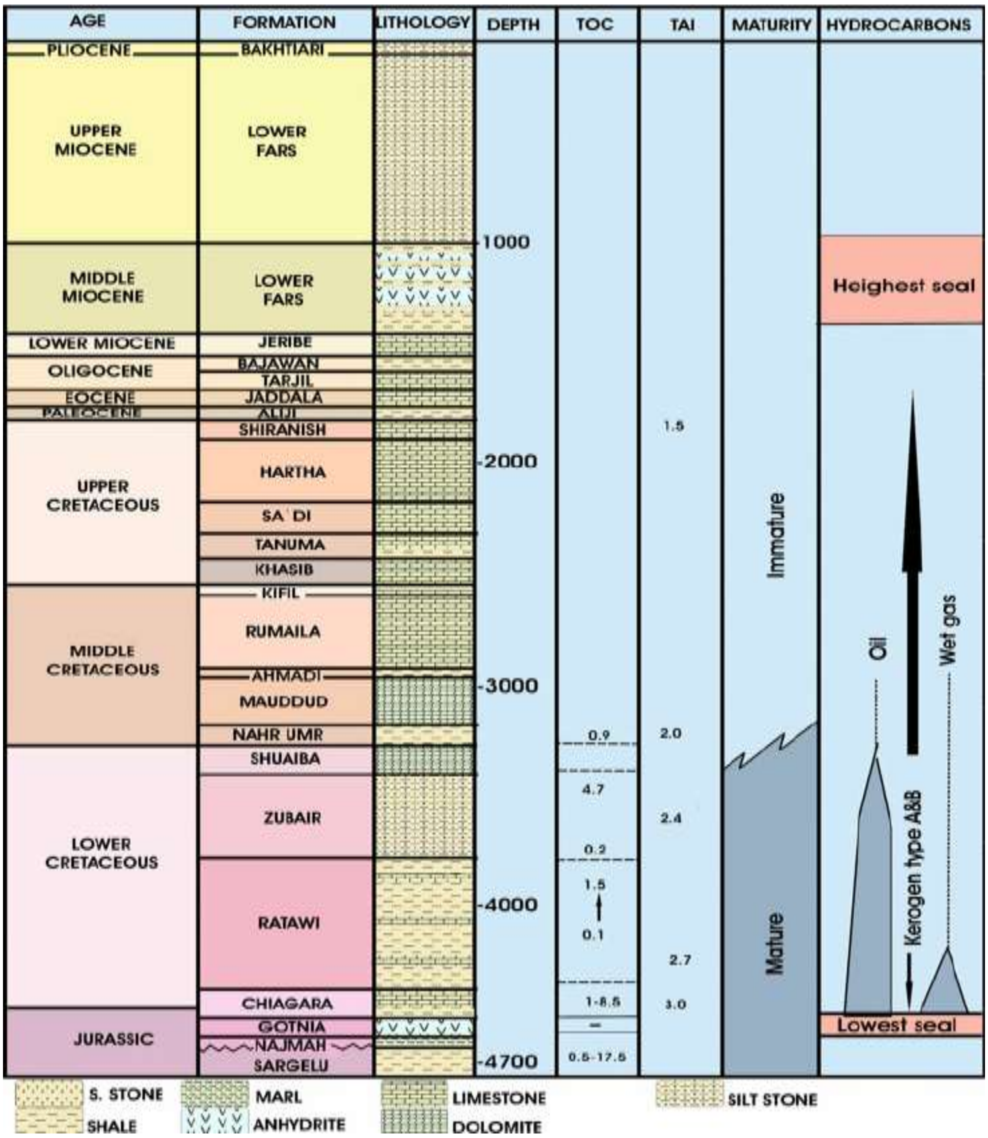


Figure 2: Lithological column in the study area (left), zoom of the cretaceous period lithology in EBS showing the main oil reservoir formations [6]

The Zubair Formation is essentially composed of alternating shale and sandstone with some siltstone. The variation in lithology displays some regularity, towards the shore where the amount of politic component rapidly decreases. In the west of the sedimentary basin, the formation contains more and more shale and becomes almost purely shaley near the Dujaila area in eastern Iraq [7].

The contacts of the formation are mostly gradational and conformable [7]. In the east Baghdad area, the Zubair Formation is a fine to more-grained, texturally mature, well to moderately, sorted quartz arenite. It was derived from a provenance area dominated by acid igneous rocks [8].

It is the most proximal unit of the late Turonian- early companion sequence [7]. The lower part (20m) of the formation consists of dark grey and greenish-grey shales, and grey, fine-grained, argillaceous limestone. The upper part (30m) comprises grey, fine-grained, argillaceous limestone [9]. The thickness of the formation is highest in southern Iraq. Al Khasib Formation is thickest in the Tigris subzone of the Mesopotamian zone. Its thickness in E-Baghdad well is 108m [7].

The Tanuma Formation comprises black, fissile shale with limestone at the top. In Dujiala and Bazurgan wells in eastern Iraq, the formation consists mainly of marl and chalky limestone. The thickness of the Tanuma Formation in SE Iraq reaches 60m but wedges out in all directions. Tanuma Formation was deposited in the restricted shallow basin in a partly euxinic environment [7].

Materials and method:

Three well–logging data for the gamma radioactivity were used in this study. Two wells (EBSK-2-8 and EBSZ-10) with total gamma (GR) in the API unit and the third is the Total Gr with spectrum GR (SGR) record of well EBS38 in the API unit for the total gamma radioactivity and in ppm for Th-232 and U-238 and in percent (%) for K-40 (Figure 3). The SGR log of well EBS38 was used to sample total GR and SGR for U-238, Th-232 and K-40 for selected depth (Three depths from S7-toer to follow the values of the radioactivity in the reservoir formations and compare these values with the other logs in the other two wells and with the radioactivity in the environmental samples selected from different stages of the oil and gas production.

Six rock samples (core) were collected by ESB from wells EBSK8-2 and EBSZ-10 provided to the current study. These wells are located in the East Baghdad Oilfield and the core samples represent the following geological formations: Hartha, Khasib, Tanuma, and Zubair (Figure 2). The samples are weighted around 100-500 g and they are kept in nylon bags with all the necessary information (Code No., formation name, depth, and lithology). The depth of the rock samples is indicated on the well-log records (Figure 3).

Thirteen (13) samples were collected from the different stages of oil production inside the EBS oilfield. Each sample was collected and sealed in a plastic bag of 3kg capacity within its information (sample number, Coordinates, date, and type). The samples represent sludge (SL), soil (SE), crude oil (CO), waste oil (WO), wastewater (WW), and evaporates water (EW). In addition, 10 surface soil samples were collected from different locations near the oil wells in EBS Oilfield (Figure 4 and Table 1). These soil samples were taken at a depth down to 3 cm from the surface and covered an area of 1m [10]. The sampling was done by using a small shovel. There was some difference in the volume of samples due to the soil density.

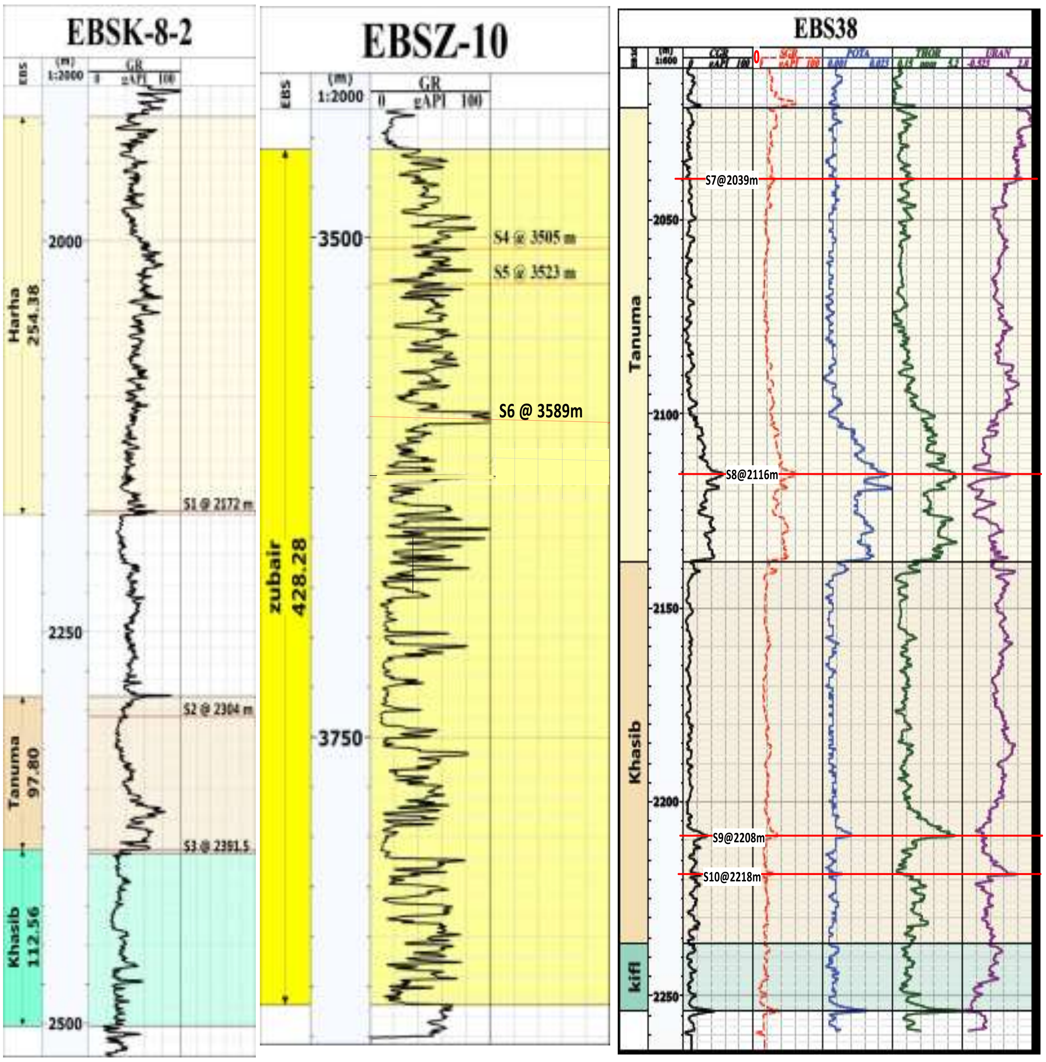


Figure 3: Gamma well logs of three wells in the study area. Total GR for EBSK-8-2 and EBSZ-10 for Hartha, Khasib, Tanuma, and Zubair Formations and GR and SGR for Tanuma and Khasib Formation of well EBS38

Table 1: samples collected from inside the EBS oil industry and the surrounding area.

Sample No.	Code No	Material	Location of Sample	Coordinate (decimal degree)	
				East	North
1	SE1	Oily Soil	First Stage (Manifold)	44.569254	33.325635
2	SL2	Sludge	1st Separator	44.569014	33.324752
3	SE3	Oily Soil	2nd Separator	44.570165	33.325306
4	SE4	Oily Soil	1st Desalter	44.570517	33.325306
5	SE5	Oily soil	2nd Desalter	44.570491	33.324536
6	SL6	Sludge	Waste pit	44.571268	33.324626
7	SE7	Soil	Flare	44.571018	33.324209
8	SE8	Soil	Near well EB33H	44.56635	33.320635
9	SE9	Oily Soil	Waste pit well EB33H	44.566376	33.320485
10	CO10	Crude Oil	Crude oil from well EB33H	44.566376	33.320485
11	WO11	Waste Oil	Evaporate Water	44.571731	33.323625
12	WW12	Waste Water	Near well EB33H	44.571948	33.323239

13	EW13	Evaporate Water	Waste pit well EB33H	44.571129	33.323348
14	SE14	Soil	EBS38N well	44.57008	33.31092
15	SE15	Oily soil	EBS38N waste pit	44.57008	33.31092
16	SE16	Soil	EBS21H well	44.57589	33.31563
17	SE17	Soil	EBSK-4-5 WELL	44.561863	33.333353
18	SE18	Soil	EBST-2-2H WELL	44.55609	33.3241
19	SE19	Soil	EBSK-2-3	44.55283	33.33164
20	SE20	Soil	EBST-4-1H WELL	44.553766	33.331782
21	SE21	Soil	EB 38 WELL	44.564414	33.338427
22	SE22	Soil	EB 4 WELL	44.568565	33.331739
23	SE23	Soil	EBSK-4-9 WELL	44.567697	33.329325

GPS with an accuracy of 3m is used to determine the sampling location. Radiation exposure dose rates were measured in all locations of sampling. Geiger Mueller Counter type GMC-3000 and RADEYE PRD from Thermo SCIENTIFIC are used for measuring radiation exposure dose rate in microsievert per hour (μSv/ h). The devices measure ambient doses between 0.01-1000μSV/h. in addition, InSpector™ 1000 Digital HandHeld Multichannel is used to measure the exposure rate in mR/h (milliRoentgens per hour) in the same sites above.

Sampling preparing:

The samples (surface soil, sludge, sediments, and, core samples) were heated in an electric oven at a fixed temperature of 105 ºC a sufficient time to make sure they were dry. The next step is removing any bulks of pebbles by using a sieve of (1mm). The last step represents crushing and powdering all of the samples and preparing them for the radioactivity measurements. All samples (surface soil, rock sample, sediment, sludge, scale, crude oil, and formation water) are then thoroughly homogenized. 0.5-1 kg of each sample is taken and stored for 25 days in a completely sealed Marinelli beaker to achieve equilibrium between radon and its daughters [10].

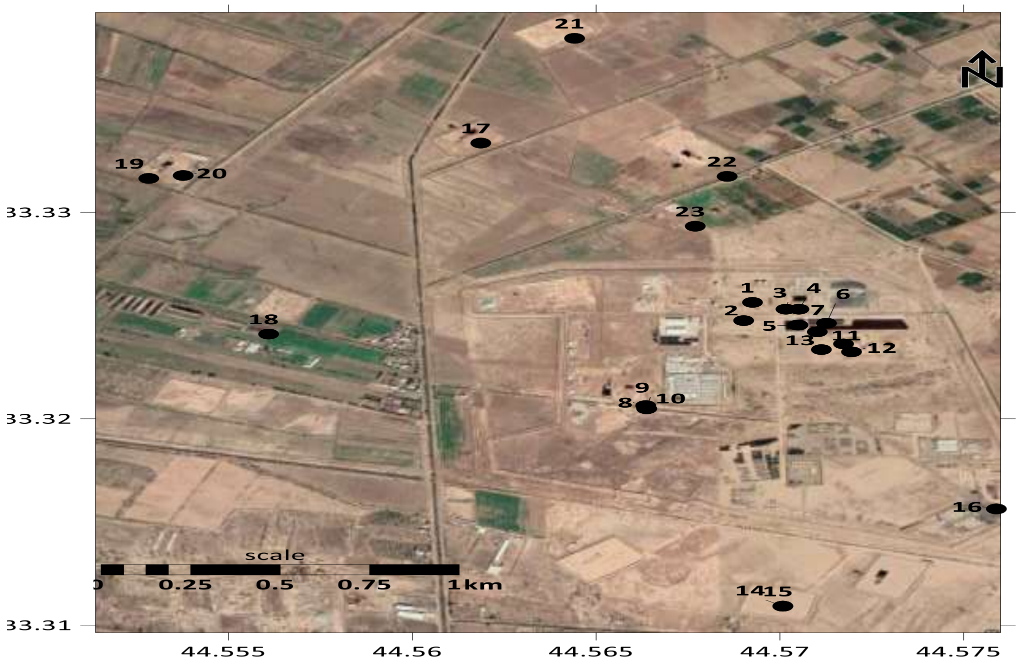


Figure 4: Sampling and radiation readings locations inside the ESB oil and gas industry and surrounding wells

Radioactivity measurement:

For analyzing the radioactivity in the samples, a Gamma Spectrometry System based on HPGe was used. Radioactivity in the samples is measured in Bq/kg for Radium-226, Th-232, and K-40. Gamma-ray photo peaks at several energies are used to calculate the specific activities. The gamma-ray lines at 180.5 of Ra-226 and/ or at 295.2 keV and 351.9 keV from ^{214}Pb and at 609.3 keV and 1764.5 keV from ^{214}Bi were used to determine the specific activity of ^{226}Ra. The gamma-ray lines of 338.4 keV, and 911.2 keV from ^{228}Ac, the 727.3 keV from ^{212}Bi, and 583.2 keV and 2614.5 keV from ^{208}Tl were used to determine the specific activity of ^{232}Th. The specific activity of ^{40}K was measured directly by its gamma-ray line at 1460.8 keV. To make the efficiency calibration and the energy calibration a standard source of a multi-energy made by the American Canberra Company was used. For measuring the activity of the samples a Marinelli geometrical shape was used. The measurements were done in the laboratories of the Radiation Protection Center/ Ministry of Health and Environment/Iraq.
Core samples and sludge sample SL2 (table -1)) were sent to Bureau Veritas Laboratories-Canada to measure the activity of U-238, U-235, Th-232, and K-40 using the Neutron Activation Analytical method (NAA).

Gamma Absorbed Dose Rate (GADR)

The outdoor air-absorbed dose rates of gamma rays emanating from terrestrial radionuclides, ^{226}Ra, ^{232}Th, and ^{40}K, were measured in the sampling locations assuming that the other radionuclides can be ignored as their contributions are expected to be negligible to the total dose from the environmental background according to the following equation [11]

The dose D(nGy/h) =0.462CRa+0.621CTh+0.041CK ....(1)

Where CRa, CTh, and CK are the measured radioactivity of ^{226}Ra, ^{232}Th, and ^{40}K respectively.

External Hazard Index (Hex)

The external hazard index (Hex) is defined as [12]:

Hex = CRa/370+CTh/259+CK/481 ……………………………………….…… (2)

Where CRa, CTh, and CK are the measured radioactivity in (Bq/kg) of ^{226}Ra, ^{232}Th, and ^{40}K respectively. The value of this index must be less than unity for the radiation hazard to be negligible [12]. Hex equal to unity corresponds to the upper limit of Raeq 370 Bq/kg [12].

Results and discussion

Radioactivity in reservoir formations:

The well-log data of the selected cores at depths as indicated on logs of the wells EBSK-8-2 and EBSZ-10 in (Figure 2) reveal that the GR values range between 40 API (for S2)- more than 100 API (for S6). The radioactivity of U-238, Th-232, and K-40 in the core samples measured by NAA are listed in (Table 2).

When calculating the GR in API unit from the values of the measured radioactivity of the core samples, using 1API = 4Th(ppm) + 8U(ppm) + 16K (%) [1], after converting radioactivity from Bq/kg to ppm for U-238 (1ppm= 12 Bq/kg) and Th-232 (1ppm = 4Bq/kg) and for K-40 (310 Bq/kg = 1% from the total K.) [13, 14], as listed in (Table 2), the calculated API values are very close to values in the logs with shifting about 0.5m in the depths.

The radioactivity in core samples reveals that Zubair Formation (S6) with a depth of 3589m has a high concentration of U (280 Bq/kg) compared with the other samples of the same formation although all samples are shale. The other formations have lower radioactivity in their core samples.

Measuring the radioactivity in the same samples using a gamma spectrometer showed that sample S6 of Zubair Formation had high radioactivity of radium-226 (831 Bq/kg), while the values of radium-226 for other samples ranged between 95 (S4) in well EBS-8-2 to 231 Bq/kg (S2) in EBSZ-10. As for potassium-40, the highest value is 4171 Bq/kg in Al-Hartha (S1) well EBS-2-8, - while the activity of thorium-232 did not exceed 25 Bq/kg.

Table 2: Radioactivity of TH-232, U-238, and K-40 for core samples using NAA

Nuclide	Unit	S1 KHASIB Limestone	S2 TANUMA Limestone	S3 HARTHA Limestone	S4 ZUBAIR Shale	S5 ZUBAIR Shale	S6 ZUBAIR Shale
Th-232	Bq/kg	4	3	5	22	15	7
	ppm	1	0.75	1.25	5.5	3.75	1.75
U-238	Bq/kg	15	10	16	13	19	280
	ppm	1.25	0.83	1.33	1.1	1.58	23.3
K-40	Bq/kg	210	130	22	120	290	160
	ppm	0.67	0.42	0.71	0.38	0.94	0.52
Depth	m	2171	2304	2391.5	2505	2523	2589
GR	API	70	40	42	80	60	>100

On the other hand, the radioactivity of the samples from the log of the well EBS38, as shown in Table 3, showed that U-238 is from 0.47-2.13 ppm, thorium is from 0.7-4.5 ppm, and potassium is from (0.6-2.19) %. These values reflect the radioactivity (GR) in the API unit for each sample according to their depths. The GR ranged between 29-64 API. Relatively high radioactivity at a depth of 2116m represents Tanuma Formation

Table 3: Radioactivity of the rock formation in well EBS38 sampled from the GR and SGR

ID	Formation	Depth (m)	Th-232 (ppm)	U-238 (ppm)	K-40 %	GR (API)
S7	Tanuma	2039	1.5	2.13	0.8	30
S8	Tanuma	2116	4.5	1.47	2.19	64
S9	Khasib	2208	4.19	0.47	1	35
S10	Khasib	2218	0.7	2.11	0.6	29

The measurements, whether using the neutron activation method or gamma spectra analysis, and those derived from the logs showed that some geological units of the oil reservoir formations display relatively high radioactivity in the reservoir rocks represented in uranium, thorium, and potassium. Recently, although there are 97 drilled wells, the industry produces about 10000 oil Barrels per day from 40 produced wells. The EBS oilfield proved to hold 7 billion barrels of recoverable reserve and is believed to have a production potential of 40,000 barrels per day. It is known that pumping oil from the reservoir to the surface in oil production will bring with it radium-226 and its daughters, while uranium will remain in the reservoir rocks [2, 15, 16]. Likewise, thorium and its daughters and potassium will move with the oil and associated water to the surface when pumping crude oil. This may cause the accumulation of these nuclides in the pipes or leak out through the connections of the pipes or the valves, or other activities in the stages of oil and gas production in the oil field.

Radioactivity in the oil and gas industry

The activity of Ra-226, Th-232, and K-40, using gamma spectroscopy, in soil and oil production waste inside and outside the industry in addition to radiation dose rates, and external hazard index is listed in (Table 4). Colored classed post maps are plotted using Surfer -16 to represent the distribution of Ra-226, Th-232, K-40, and dose rates in the study area (Figure 5).

Ra- 226 was found to be ranged between (24-153.1) Bq/kg. The relatively high activities for Ra-226 were found in oil-contaminated soil near the 1st separator stage inside the industry, near the water treatment stage, and near the waste pit near well EBS38N. It is logical results that radium has a max level in sediment samples collected from the final stage of water treatment because most of the radium is dissolved in formation water and transferred with the associated oily water then it is deposited as salts with other elements such as barium and is being enhanced upon unique conditions (due to change in temperature, pressure, acidity, etc.) (15, 17], especially with increasing salinity [18]. The variation in Ra-226 in the different stages of oil production may be attributed to the amount of ^{226}Ra in the subsurface [19]. Figure 5 showed that most of the sampling locations have Ra-226 more than the world average (32 Bq/kg) in soil [11], which may indicate the dispersion of radium resulting from oil and gas production processes over most areas of the study area. About 30% of the locations have Ra-226 more than 100 Bq/kg. So it should take into consideration monitoring these sites, especially the sites with red and blue colored circles (more than 100 Bq/kg).

The activity of Th-232 ranged between (3-83.7) Bq/kg. The maximum radioactivity is 83.7 Bq/kg in the sludge sample near 1st separator stage, which may be contaminated with Thorium deposited within the processes of production of oil, while the minimum is 3 in crude oil from the oil wells ESB33H and waste oil. More than 37% of the sampling locations have Th-232 of more than (45) Bq/kg the world average of thorium-232 in soil [11], most of them inside the oil and gas industry (blue and cyan circles). It is worth noting that thorium and its daughters move with the oil to the earth's surface with crude [2] and are deposited inside or outside the pipelines when an oil leak occurs or during the processing and production of oil and gas (3, 4, 16].

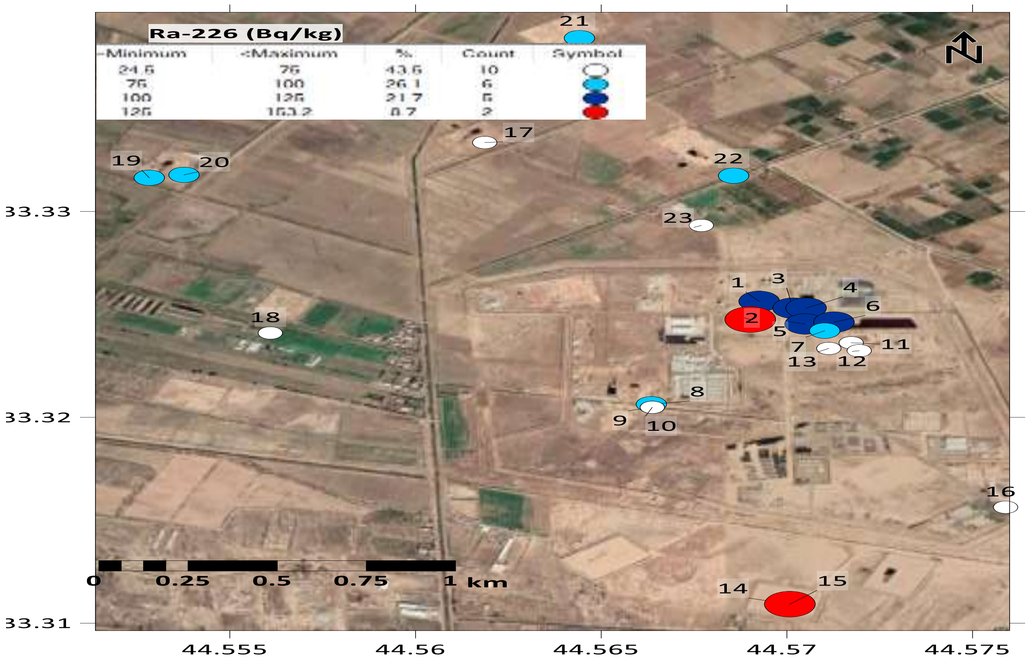
All the locations have K-40 more than the world average (410 Bq/kg) in soil [11] except 4 samples of oil and wastewater (locations No.10, 11,12,13) near the well ESB33H. The relatively high concentration of potassium (higher than the world average) in the soil of the study area may due to the nature of the surface soil in the study area which mostly is clayey soil in addition to the contamination caused by the oil production.

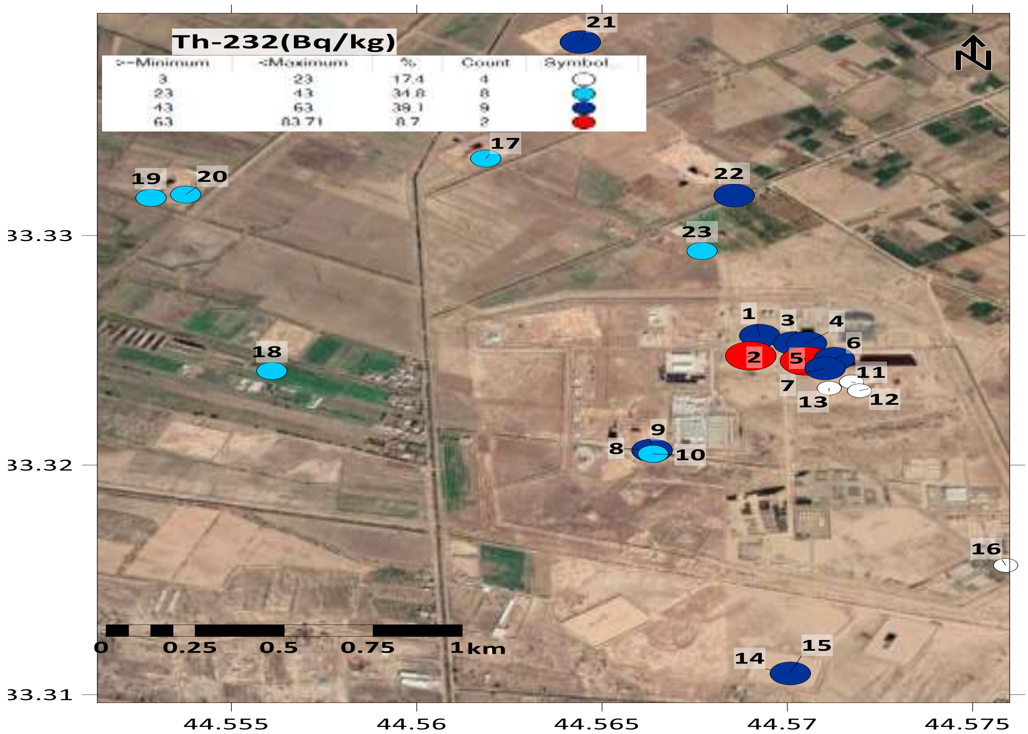
The results of the radioactivity of the samples inside and around the oil and gas industry were logical and consistent with the results of the radiological analysis of the rock cores from the reservoir formations and the data extracted from the wells logs of the wells in the study area. The radioactivity in the studied locations is acceptable if they are compared with other oilfields worldwide (Table 5).

The ambient exposure dose values near the sampling locations shown in Table 2 are consistent with the values of NORMs in the locations. The doses range between (0.05-0.13) μSv/h (71.4-185.7) nGray/h by applying a dose conversion factor of 0.7 Sv/Gy) with average (0.092±0.02) μSv/h (129.8±31.9) nGy/h. The maximum value is recorded near the 1st Separator stage, and the waste pit, inside the oil production industry, where sludge has been leaked and deposited. It is logical a result due to these sites have high concentrations of radium-226. All values of the ambient exposure dose are above the worldwide average value of 58 nGy/h [1]. On the other hand, the range of the annual effective dose is about (0.4-1.1) mSv/y, so the max values recorded near the 1st Separator stage, and the waste pit are below the max value of (20 mSv/y) recommended by UNSCEAR for workers [18].

Table 4: radioactivity in Bq/kg, radiation dose rates, and external hazard index in the study area

Sample No.	Code No	Radioactivity (Bq/kg)			Dose rate (µSv/h)	Measured total Dose rate (nGy/h)	Annual effective dose (mSv/y)	D (nGy/h)	Hex
		Ra-226	Th-232	K-40					
1	SE1	105	50.8	836.6	0.11	157.1	1.0	114.3	0.7
2	SL2	153.1	83.7	1264.2	0.13	185.7	1.1	174.5	1.0
3	SE3	116.6	54.2	855.2	0.09	128.6	0.8	122.6	0.7
4	SE4	106	54	838	0.1	142.9	0.9	116.9	0.7
5	SE5	118.6	68.8	1010	0.12	171.4	1.1	138.9	0.8
6	SL6	100	59.6	852.8	0.13	185.7	1.1	118.2	0.7
7	SE7	97.8	54	838	0.09	128.6	0.8	113.1	0.6
8	SE8	99	51	740	0.12	171.4	1.1	107.7	0.6
9	SE9	67	31.2	203	0.11	157.1	1.0	58.7	0.3
10	CO10	28	31.2	18.8	0.08	142.9	0.8	33.1	0.2
11	WO11	28	18.8	1	0.07	128.6	0.8	25.2	0.2
12	WW12	24	3	221.6	0.08	157.1	0.8	22.3	0.1
13	EW13	24.6	3	221.6	0.07	142.9	0.7	22.3	0.1
14	SE14	53.8	38	790	0.06	128.6	0.8	80.4	0.5
15	SE15	135	52.2	1033	0.09	128.6	0.9	137.1	0.8
16	SE16	74	22.6	630	0.08	114.3	0.7	74.1	0.4
17	SE17	53	33.6	495	0.09	128.6	0.8	65.6	0.4
18	SE18	60	34.1	495	0.05	71.4	0.4	69.2	0.4
19	SE19	96	35	698	0.06	85.7	0.5	94.7	0.5
20	SE20	91	26	670	0.07	100.0	0.6	85.7	0.5
21	SE21	97	44.1	713	0.08	114.3	0.7	101.4	0.6
22	SE22	86	62	780	0.06	85.7	0.5	110.2	0.6
23	SE23	72	36	651	0.06	85.7	0.5	82.3	0.5


Ra-226 (Bq/kg)
Minimum | <Maximum | % | Count | Symbol
24.5 | 75 | 43.5 | 10
75 | 100 | 26.1 | 6
100 | 125 | 21.7 | 5
125 | | 8.7 | 2
0 0.25 0.5 0.75 1 km
33.33
33.32
33.31
44.555 44.56 44.565 44.57 44.575


Th-232(Bq/kg)
>=Minimum | <Maximum | % | Count | Symbol
3 | 23 | 17.4 | 4
23 | 43 | 34.8 | 8
43 | 63 | 39.1 | 9
63 | 83.71 | 8.7 | 2
0 0.25 0.5 0.75 1km
33.33
33.32
33.31
44.555 44.56 44.565 44.57 44.575

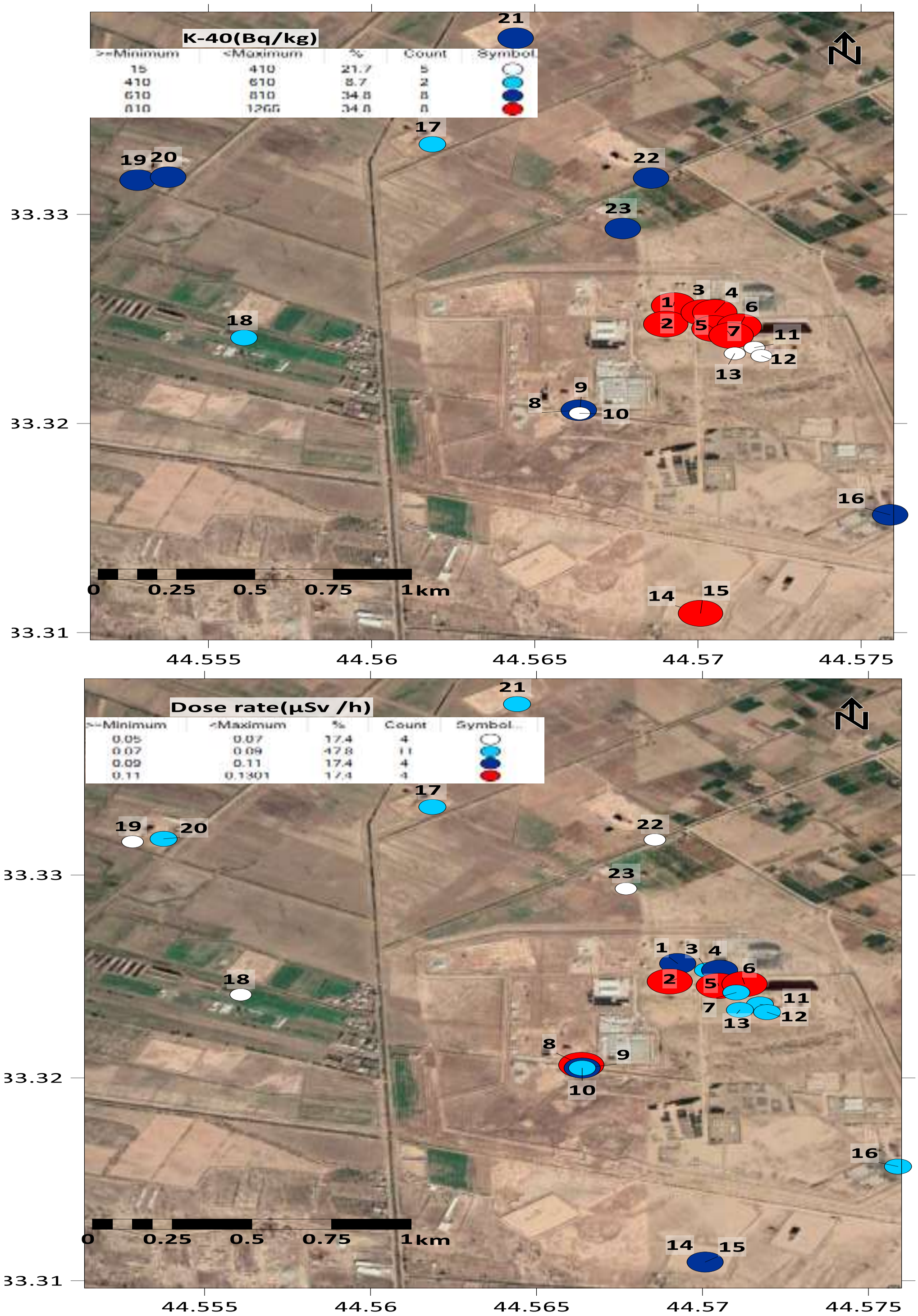


Figure 5: Distribution of Ra-226 (upper left), Th-232 (Upper Right), K-40 (below left), and Dose rates (below right) in the sampling locations in the study area. Color of the circles as indicated in the legend in the figure. Larger red-colored circles have higher values.

Table 5: Comparison between radioactivity (Bq/kg) of NORM in the current study with other studies

NO.	Sample Type	Ra-226	Th-232	K-40	Reference
1	Worldwide average(soil)	32	45	410	[18]
2	Oman NORM(Sludge)	547	271	118	[21]
3	China (Surface soil)	12	16	746	[22]
4	OGP (Crude oil)	$800\text{-}4*10^5$	1-70	-	[16]
5	IAEA (Sludge)	$5\text{-}8*10^5$	2-10	-	[2]
6	Iraq NORM(Sludge)	74.7	377	104	[23]
7	Iraq NORM(Sludge)	1.8-252	7-79	12-529	[24, 25]
8	Iraq NORM (Crude Oil)	2-6	2.9-5.5	3-36.0	
9	Iraq (Surface soil)	3.7-43	6.7-23	216-595	
10	Iraq (sludge)	6.8-14.4	2-38		
11	Iraq (oily sediment)	79	252		
12	Iraq (sludge)	68.7-312.8	23.5-140.8	309.3-800.8	[26]
13	Iraq (Soil)	49.8-97.6	18.5-42.7	204.1485.6	
14	Oily Soil	67-118.6	31.2-68.8	203-1010	Current study
15	Sludge	100-153.1	-59.6-83.7	852.8-1264.2	
16	Crude Oil	28	31.2	18.8	
17	Wastewater	24	3	221.6	
18	Soil	53-96	26-62	85.7-124.6	

Gamma Absorbed Dose Rate (D)

The D in nGy/h was calculated based on equation (1). The range of D is (22.3-174.5) nGy/h with an average of (89.9±40.1) nGy/h. The minimum gamma absorbed dose rate is 22.3 nGy/h near sampling location No.12 (wastewater sample), The value D at this site was calculated from the measured radioactivity for the three radionuclides (Ra-226, Th-232, and K-40) only, as it appeared that their radioactivity in this sample was not highly radioactive (Table 5), so the calculated gamma absorbed doses were low. While the highest value calculated for the gamma absorbed dose rate was (174.5) nGy/h at site No. 2 with high radioactivity for Ra-226, Th-232 and K-40. Other locations with relatively high concentrations of Ra-226 have high values of D.

It is worth noting that most of the calculated rates of gamma absorbed doses were higher than the global average of (58) nGy/h [18] (Figure 6A), which necessitates periodic monitoring of the study area site in anticipation of any increase in the values of radioactivity, especially the radioactivity of radium-226. Ra-226 is the main contributor in gamma absorption doses as appears in Figure-6b.

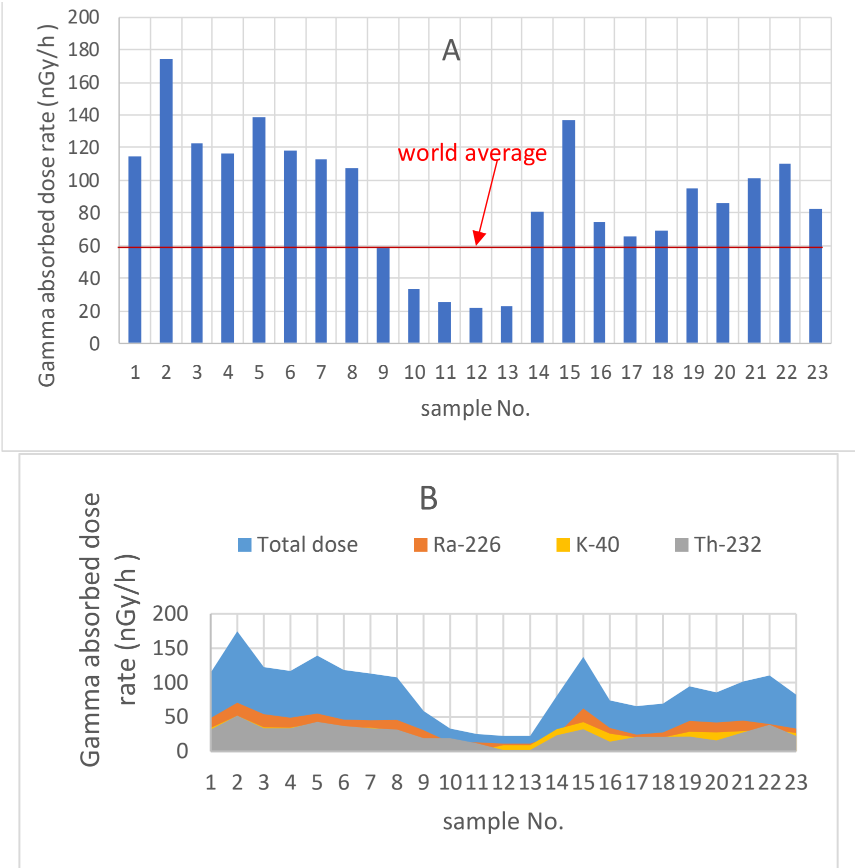


Figure 6: Absorbed doses rates (a) due to exposure to gamma rays emitted from Ra-226, Th-232 and K-40 in sampling locations. (b) Contribution of Ra-226, Th-232, and K-40 in total absorption dose rates in sampling locations.

External Hazard Index (Hex)

Hex is calculated using equation (2), the range is (0.1-1.0) with an average of (0.5±0.23). The minimum value is in locations No.10 and 11 because these sites (oil samples) have low radioactivity of Ra-226, Th-232, and K-40 while the maximum value of Hex is in location No.2 (1^{st} separator stage in the oil industry). This is a logical result that this site has high radioactivity of Ra-226 and other radionuclides (Table 2). All values of Hex are lower than the unity except those of site 1 (Figure 7), so, most Hex values are acceptable and have no hazard [11,18].

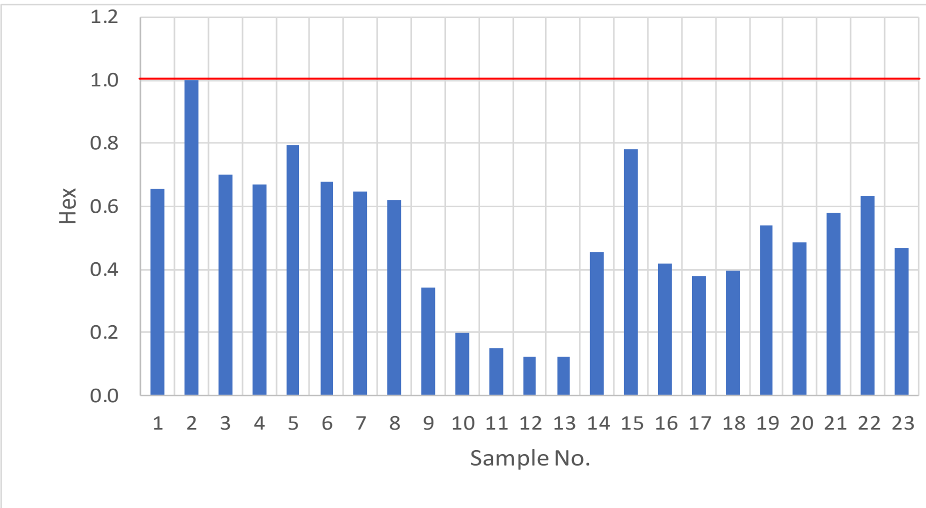


Figure 7: Hex caused by NORM for samples in the study area

Conclusion:

Oil production industries and oil fields are one of the most important sectors of NORM contamination, so it is necessary to perform an environmental radiological survey to create the base map and then monitor these sectors to track any increase in radioactivity resulting from oil production and associated activities.

The radiological survey and the assessment of NORM in ESB Oilfield southern Baghdad in Iraq
in current study conclude the following:

1. Measurements of natural radioactivity (NORM) in the rock core of the oil reservoir formations from which oil is produced in the EBS oil field, or from the natural GR and SGR logs for the oil well in EBS, showed that there is relatively high radioactivity in some units within the oil reservoir formations. It is certain that the radionuclides belonging to the uranium-238 series, starting from radium-226 and its daughters, will be transported with oil to the surface, as is the case with thorium and its daughters, and potassium-40. With crude oil processing operations and oil production in the field, it may cause the accumulation of these radionuclides in locations along the production stages.
2. Even if, most of the places within the ESB oil industry have relatively high Ra-226, Th-232, and K-40 concentrations (above the worldwide average in soil), the studied locations are acceptable if they are compared with other oilfields worldwide.
3. The places that have higher Ra-226, Th-232, and K-40, in the sludge samples and oily soil, among the other places within the processing stages of oil and production within EBS are 1st separator stage, water separation (Desalter) stage, and near the waste pit. Radiation levels measured after the water separation stage are, consequently, lower than those observed in other stages.
4. Most of the rates of gamma absorbed doses calculated inside the EBS oil industry were higher than the global average of (59) nGy/h recommended by UNSCEAR [18]. Ra-226 is the main contributor to these doses.
5. All the locations inside and outside of the oil production industry have external hazard index (Hex) values less than unity so they are acceptable according to Beretka and Mathew, [11]; UNSCEAR [18] and Sam and Abbas [12].
6. The places, within the study area, having relatively highly contaminated with NORM and high radiation doses should be monitored more frequently to ensure that no more radiation doses are present due to exposure to these materials.
7. The result of the assessment of ESB in the current study does not mean that these locations are radiologically safe forever, Notification, for radiation protection these locations should be periodically monitored and the basic control procedures should be taken into consideration by workers when dealing with NORM.
8. Radiation dose values in some places in the study area exceed the values recommended by UNSCEAR [18], and IAEA [2] (1 mSv/y) for the public but less than the values recommended for workers (20 mSv/y). So as long as the values of the radiation doses are still within these ranges, there is no significant hazard due to external radiation exposure provided that workers should use the correct personal protective equipment and minimize the exposure time to reduce the values of doses as low as possible according to ALARA principles.
9. Sludge and oily soil are the main sources of NORM accumulation on surface production facilities in study areas. The separators and Desalter (water treatment) stages are the higher places where NORMs accumulate. Leakages of oil from pipes and valves as sludge or salts (scale) are the main causes of this accumulation.
10. In general, the site of the study area does not show radioactive contamination or significant radioactive hazards, as it is a new facility, and safety instructions are still strictly

applied, and due to the removal of waste immediately before its spread by the workers in the facility.

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