

Sa'ad R. Yousif<sup>1</sup>, Ali Abid Abojassim<sup>2,\*</sup>, Anes Hayder<sup>2</sup><sup>1</sup> University of Kufa, Faculty of Science, Department of Geology, Kufa, Iraq<sup>2</sup> University of Kufa, Faculty of Science, Department of Physics, Kufa, Iraq

\*Corresponding author: ali.alhameedawi@uokufa.edu.iq

MAPPING OF NATURAL RADIOACTIVITY IN SOIL SAMPLES  
OF BADRA OIL FIELD PROJECT USING GIS PROGRAM

The study focuses on measuring the values of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  natural radionuclides in soil samples in Badra oil field area (Iraq). Also, the radiological risk data were calculated for all samples in this study. The technique used in this study was gamma-ray spectrometry with NaI(Tl) detector. The averages of specific activity are: 24.7 Bq/kg for  $^{238}\text{U}$ , 13.6 Bq/kg for  $^{232}\text{Th}$ , and 538.9 Bq/kg for  $^{40}\text{K}$ . Besides, the estimations of radiological effects like the radium equivalent ( $Ra_{eq}$ ), the absorbed dose rate ( $D_r$ ), external hazard index ( $H_{ex}$ ), internal hazard index ( $H_{in}$ ), representative gamma hazard index ( $I_\gamma$ ) and the total annual effective dose equivalent (AEDE) are 85.5 Bq/kg, 42.1 nGy/h, 0.23, 0.30, 0.66 and 0.26 mSv/y respectively. When comparing the results in the study area with the world mean values specified by the UNSCEAR, OCDE and ICRP, the study terminates that the limits of health risk are safe and may not menace the workers at these locations due to these radionuclide limits. The values were subjected to GIS environment under the WGS1984 coordinate system for the sake of results' coordination, and processed in Inverse Distance Weighted interpolation as the best processing.

*Keywords:* natural radioactivity, Badra oil field, geographic information system (GIS), gamma ray spectroscopy.

### 1. Introduction

Natural radioactivity is widespread and present in different geological formations of various rocks. The necessity of this study is focused to the radiation effect, where it has a great interest and importance in health physics, therefore evaluation of natural radioactivity in sediments is so necessary to assess the quantity of change in the radioactive setting with time due to the radioactive effect dissemination [1]. The soil is one of human food sources and the most important contributors to the radiation exposure. Hence, there is an essential necessity to study the dissemination of natural radioactivity in the sediments and soil [2]. The Naturally Occurring Radioactive Materials (NORM) consider biochemical and geochemical indicators that are associated with geological processes such as earthquakes and volcanic eruptions affect on the environment [3]. It is well known that even if a small amount of these radionuclides due to the gamma ray exposure of the body and irradiation of lung tissues from inhalation of radon and its daughters occur, the harmful biological effects are produced [4]. So, the knowledge of definitive dose limits of natural radioactive materials is crucial for the sake of measuring radiation levels caused by their persistence in land, air, water, food, building, etc. to estimate exposure and protection of humans [5]. Since soil presents the main providers to radioactive setting, it is essential to determine the radioactivity content of the soil over the world. The mentioned

natural radioactivity usually comes from the existence of the  $^{238}\text{U}$ ,  $^{232}\text{Th}$  series and  $^{40}\text{K}$  during the deterioration of sediments due to weathering and deposition [6]. Gamma radiation, emitted from these naturally occurring radionuclides, represents the main external source of irradiation of the human body, while the internal exposure is due to inhalation of radon gas and its short-lived decay products. The average specific activity of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  is 30, 33 and 400 Bq/kg, respectively [7]. The natural environmental radioactivity resulted from gamma-radiation relies principally on geological conditions, and they disperse at varied levels of radionuclides in the soils and sediments of the world [8]. Many worldwide studies of contamination have been interested in the measurement of the specific activity of natural radioactivity [9 - 12].

All samples in this work were submitted to the processing of Geographic Information System (GIS) for deciphering the results using Inverse Distance Weighted (IDW) interpolation that dictates cell values to cluster set of sample points in a linearly weighted combination, where this method presumes that the variable being mapped decreases in influence with distance from its sampled location.

It is evident that no studies have been carried out on the study area and no baselines of concentration of natural and anthropogenic radioisotopes have been reported. Therefore, this study can be considered the first in this field. In this context, cancer incident cases have been reported with some workers who are

working in more than 12 hrs. The aim of the study is measuring the natural radioactivity in soil samples from some locations of Badra Oil Field Project, Wasit Governorate, Iraq as well as to assess the radiological risks from background radiation through calculating the radium equivalent ( $Ra_{eq}$ ), the absorbed dose rate ( $D_r$ ), external ( $H_{ex}$ ), internal ( $H_{in}$ ) hazard indexes, radioactivity level index ( $I_r$ ), the total annual effective dose equivalent (AEDE) and Excess Lifetime Cancer Risk (ELCR) of the soil samples collected from the study area.

## 2. The study area

Badra lies near the Iraqi-Iranian border within Wasit Governorate [13], 180 km southeast Baghdad (Fig. 1) within longitudes ( $32^{\circ} 98' - 33^{\circ} 05'$ ) E and latitudes ( $45^{\circ} 01' - 46^{\circ} 27'$ ) N with an area more than 3500 km<sup>2</sup>. It is located next to the site of the ancient Sumerian city Deer. Badra Oil Field which, after a discovery well was drilled in 1979, has remained unexploited until 2011. Badra oil field is estimated to hold reserves of about three billion barrels of crude oil [14]. The Iraqi oil field extends about 16 km long and 6 km wide. The oilfield area is mapped for natural radioactivity to estimate the risks that may affect on the public health.

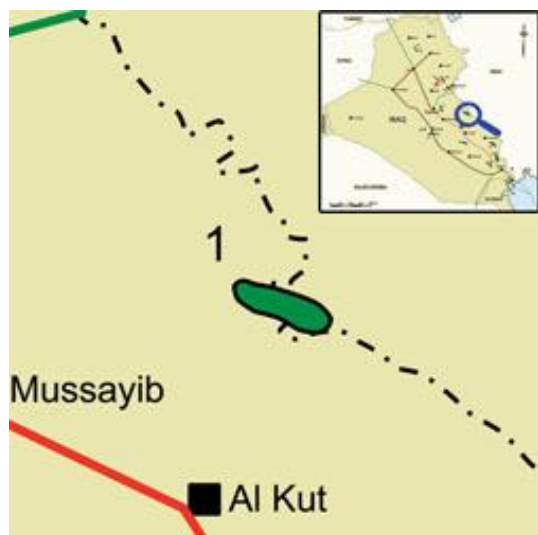


Fig. 1. Location of the study area.

## 3. Geology of the study area

The study area is a part of the Foothill Zone and Mesopotamian Zone within unstable shelf, which is characterized by a broad concave and convex folds affected by the epirogenic movements that began in the Cretaceous period and have an utmost effect in lower Pliocene [15].

Geological formations that exposed in the study area, range from Euphrates (L. Miocene) that is composed of limestone ( $CaCO_3$ ) and dolomite ( $CaMg(CO_3)_2$ ) and exposed in a relatively limited area at northeastern border of the study area. The upper contact of Euphrates Formation underlies conformably the clastic formations of continental environment, that are Fat'ha (M. Miocene), Injana (U. Miocene), Muqdadiyah (Pliocene) Formations, in addition to Quaternary Sediments (Pleistocene and Holocene) that dispersed through the entire area [16] (Fig. 2).

The topography of Iraq is unique in its kind, where all the rains falling on Iraq migrate towards the Mesopotamian depression where the study area lies, whether via valley floods or infiltration to the ground aquifers. The Euphrates and Dammam Formations are important ground water aquifers. They are close to the Euphrates River basin, and are rich in immense quantities of ground water that is subjected to high pressures.

In general, the Upper Miocene – Pliocene cycle is characterized by sediments laid down during the paroxysmal phases of the orogenic uplift of the epigeosynclinal and (later on) epiplatform mountain belts of Iraq [18].

The cycle is characterized by the progressive change from the marine sedimentation into the lacustrine and fluvial one. This change was simultaneously accompanied by the gradational coarsening of the clastics including varied minerals and chemical constituents laid down during the cycle [18]. The concentrations of the minerals and chemical constituents varied due to the variance in the depositional environments mentioned above. They are accompanied to the following Tertiary Formations of aquatic environmental genesis and Quaternary Deposits:

**Euphrates Formation (Early Miocene):** Dolomitic limestone, dolostone and limestone, fossiliferous, 45 m thick, interfinger with Ghar Formation (sandstone and other clastics) at the upper part.

**Al-Mukdadiyah Formation:** The formation according to [19] comprises of fining upward cycles of pebbly sandstone, sandstone and mudstone, and it is believed to be deposited in a fluvial environment in a rapidly subsiding foredeep basin.

**The Quaternary Deposits:** The Quaternary deposits comprised of Pleistocene and recent deposits. They include alluvial deposits, which consist of a mixture of gravel, sand, silt, clay, and conglomerates of post Pliocene deposits. They show no sign of bedding or stratification [20].

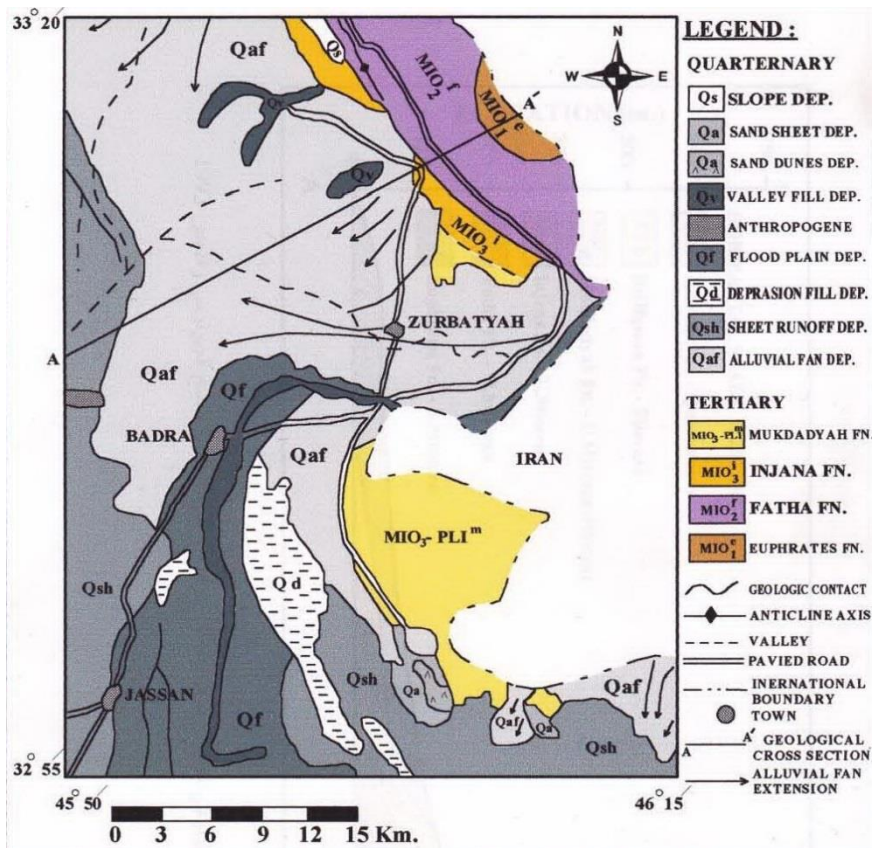


Fig. 2. Geologic map of the study area [17]. (See color Figure on the journal website.)

**4. Materials and method**

**4.1. Collection and preparation of samples**

Ten soil samples were collected from Badra oil field project in Kut Government. The collected

samples were taken from places as in Fig. 3 with depth of 15 cm. Table 1 shows the sampling locations in the study area. Each soil sample was preserved in a plastic pouch and classified according to its collected site.

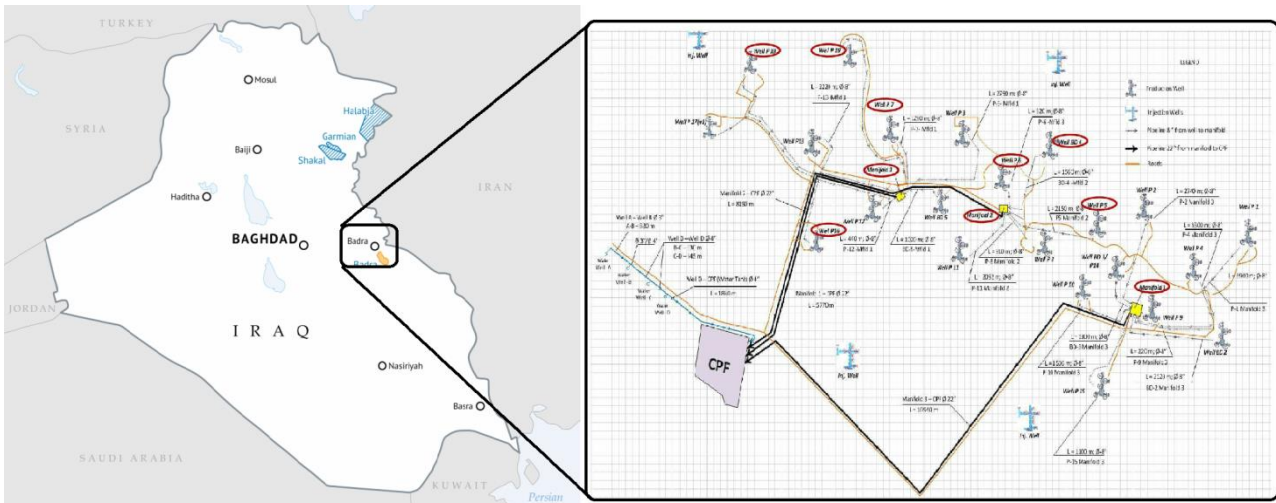


Fig. 3. The locations of the samples distributed on the map of Badra oil field project. (See color Figure on the journal website.)

All samples were dried by the effect of heat of the sun in order to remove surplus wetness, samples were crushed, using an electric mill, to get homogeneity. The samples were sieved, and for the sake of keeping them without wetness, they were put

in an electric oven for about one hour so as to reach a constant weight. Work has been done for experimental measurements in the Nuclear Physics Laboratory, Department of Physics, Faculty of Science, University of Kufa. Then the samples were

packed in a Marinelli beakers (1 L) of constant volume, in order to obtain a geometric homogeneity round the detector. Then the net weights were measured and registered using a digital weighing balance, and then the plastic Marinelli beakers were closed by a tape and stored for about four weeks before counting to obtain secular equilibrium [12].

**Table 1. Locations of the soil samples collected from different districts of Badra oil field project**

Sample code	Coordinates	
	Longitude	Latitude
BD4	46.090431	33.059519
MF1	46.056383	33.057816
MF2	46.079592	33.051854
MF3	46.104662	33.032871
P5	46.097705	33.047008
P6	46.08140	33.057258
P7	46.056883	33.066161
P16	46.034618	33.053723
P18	46.028249	33.074063
P19	46.047857	33.0762

**4.2. Experimental setting**

Gamma-ray spectrometer system contains scintillation detector NaI(Tl) with dimensions of 3"×3", provided by Alpha Spectra, Inc.-12I12/3, connected with a MCA ORTEC-DigiBase multi-channel analyzer of 4096 channels coupled with Analog to Digital Convertor (ADC) unit through interface. The MAESTRO-32 software is used in this work for all spectroscopic measurements and analysis on the data.

**5. Calculations**

**Specific Activity.** The specific activity of a sample is an activity per unit mass (Bq/g or Ci/g). The specific activity of each sample is estimated using the following equation [12]:

$$A \left( \frac{Bq}{kg} \right) = \frac{(N - B)}{t \cdot \epsilon \cdot I_\gamma \cdot m}, \quad (1)$$

where *B* represented the background counts; *N* is the gross counts (sample plus background); *t* represented the counting time (*s*); *I<sub>γ</sub>* is the probability of gamma emission; *m* is the sample weight (kg), and *ε* is the absolute efficiency of the detector at particular gamma energy.

In this study, for the energy and absolute efficiency calibration of the NaI(Tl) detector we used the three radionuclides, <sup>60</sup>Co, <sup>137</sup>Cs and <sup>22</sup>Na in mixed sources, for detection time period of 10800 s.

**Radium Equivalent Activity (Ra<sub>eq</sub>).** Ra<sub>eq</sub> is used to obtain the sum of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K activities, it is called Radium equivalent activity in Bq/kg units, and is given by the following equation [21]:

$$Ra_{eq} \left( \frac{Bq}{kg} \right) = A_U + 1.43A_{Th} + 0.077A_K, \quad (2)$$

where *A<sub>U</sub>*, *A<sub>Th</sub>* and *A<sub>K</sub>* are the specific activities of the radionuclides <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K respectively.

**Absorbed Dose Rate (D<sub>r</sub>).** This index, due to gamma radiations in air at 1 m above the ground surface for the uniform distribution of the naturally occurring radionuclides <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K, is used for the illustration of terrestrial radiation, and is usually expressed in nGy/h. It is calculated by the following equation [22]:

$$D_r = 0.462A_U + 0.604A_{Th} + 0.0417A_K. \quad (3)$$

**External Radiation Hazard Index (H<sub>ex</sub>).** The external hazard index is used to evaluate the biological hazard of natural gamma radiation, and it is calculated by the following equation [9]:

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}. \quad (4)$$

**Internal Radiation Hazard Index (H<sub>in</sub>).** The internal exposure due to radon and its daughter products is quantified by H<sub>in</sub> which is calculated by following relation [11]:

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810}. \quad (5)$$

**Representative Level Index (I<sub>γ</sub>).** I<sub>γ</sub> for the soil is used to calculate the level of gamma radiation hazard associated with natural gamma emitters in the soil. It was estimated using the following relation [23]:

$$I_\gamma = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500}. \quad (6)$$

**Annual Effective Dose Equivalent (AEDE).** To evaluate the effective dose rates from the absorbed dose, we used the conversion coefficient in air to effective dose (0.7 Sv/Gy), and values of 0.2 for the indoor occupancy factor and 0.8 for the outdoor occupancy factor, and the conversion coefficient from absorbed dose in air to effective dose [22 - 25]:

$$AEDE_{indoor} \left( \frac{mSv}{y} \right) = [D_r \cdot 8766 \cdot 0.2 \cdot 0.7] \cdot 10^{-6}, \quad (7)$$

$$AEDE_{outdoor} \left( \frac{mSv}{y} \right) = [D_r \cdot 8766 \cdot 0.8 \cdot 0.7] \cdot 10^{-6}. \quad (8)$$



## 6. Results and discussion

The results of the specific activity for the study area are illustrated in Table 2 and Fig. 4 for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in 10 soil samples collected from Badra oil field project at Kut Government. The specific activity of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in this region varies from  $20.9 \pm 1$  Bq/kg to  $29.4 \pm 1$  Bq/kg with average value  $24.7$  Bq/kg, from  $9.3 \pm 1$  Bq/kg to  $17.8 \pm 1$  Bq/kg with average value  $13.6$  Bq/kg, and

from  $456.2 \pm 5$  Bq/kg to  $685.8 \pm 7$  Bq/kg with average value  $538.9$  Bq/kg respectively. The results of the specific activity of  $^{238}\text{U}$  and  $^{232}\text{Th}$  of soil samples collected from this region were within the world average except for  $^{40}\text{K}$ , for which all the samples were higher than the world averages. The world averages are  $33$  Bq/kg,  $45$  Bq/kg and  $420$  Bq/kg for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  respectively, recommended by UNSCEAR, 2008 [22].

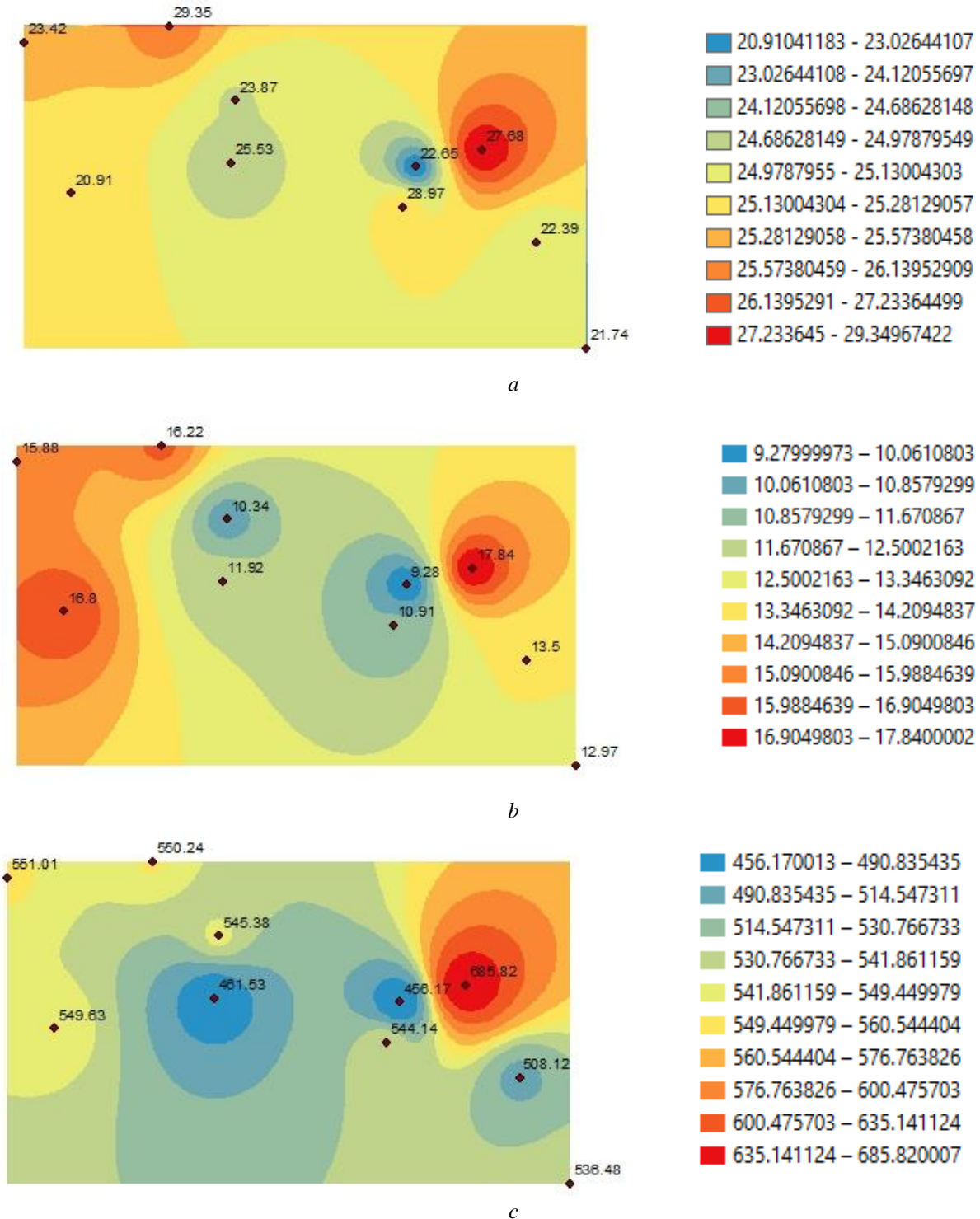


Fig. 4. The choropleth maps of the values of specific activity of (a)  $^{238}\text{U}$ , (b)  $^{232}\text{Th}$  and (c)  $^{40}\text{K}$ . (See color Figure on the journal website.)

Table 2. Results of specific activity for the study area, Bq/kg

Sample code	$^{238}\text{U}$		$^{232}\text{Th}$		$^{40}\text{K}$	
	Average	$\pm$ Error	Average	$\pm$ Error	Average	$\pm$ Error
BD4	27.7	1	17.8	1	685.8	7
MF1	25.5	1	11.9	1	461.5	6
MF2	29.0	1	10.9	1	544.1	6
MF3	21.7	1	13.0	1	536.5	5
P5	22.4	1	13.5	1	508.1	6
P6	22.7	1	9.3	1	456.2	5
P7	23.9	1	10.3	1	545.4	6
P16	20.9	1	16.8	1	549.6	6
P18	23.4	1	15.9	1	551.0	6
P19	29.4	1	16.2	1	550.2	6
Average	24.7		13.6		538.9	

The specific activities of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  have different values in each area of the study; this difference can be attributed to a difference in the geographical nature of each region such as soil type (clay or sand). The specific activities of  $^{232}\text{Th}$  in all studied samples are lower than the specific activity of  $^{238}\text{U}$ . The results shown in Table 2 demonstrated the specific activities of  $^{40}\text{K}$  are relatively higher in all samples. The reason for the higher concentration of  $^{40}\text{K}$  is likely treatment of industrial and agricultural regions, where the samples were collected, by

chemical fertilizers, which usually contain high concentrations of potassium. In addition, the study area is located within Foothill and Mesopotamian Zones of fertile soils, which are related with geologic formations of marine environment and quaternary alluvium deposits, which consist of mixture of gravel, sand, silt, clay. The mean values of specific activity of  $^{238}\text{U}$  and  $^{232}\text{Th}$  in the studied sites are within the world permissible limits [22], but the average values of  $^{40}\text{K}$  in all locations were higher than the world permissible limits [22].

Table 3. Results of radiological parameters due to NORM in soil samples

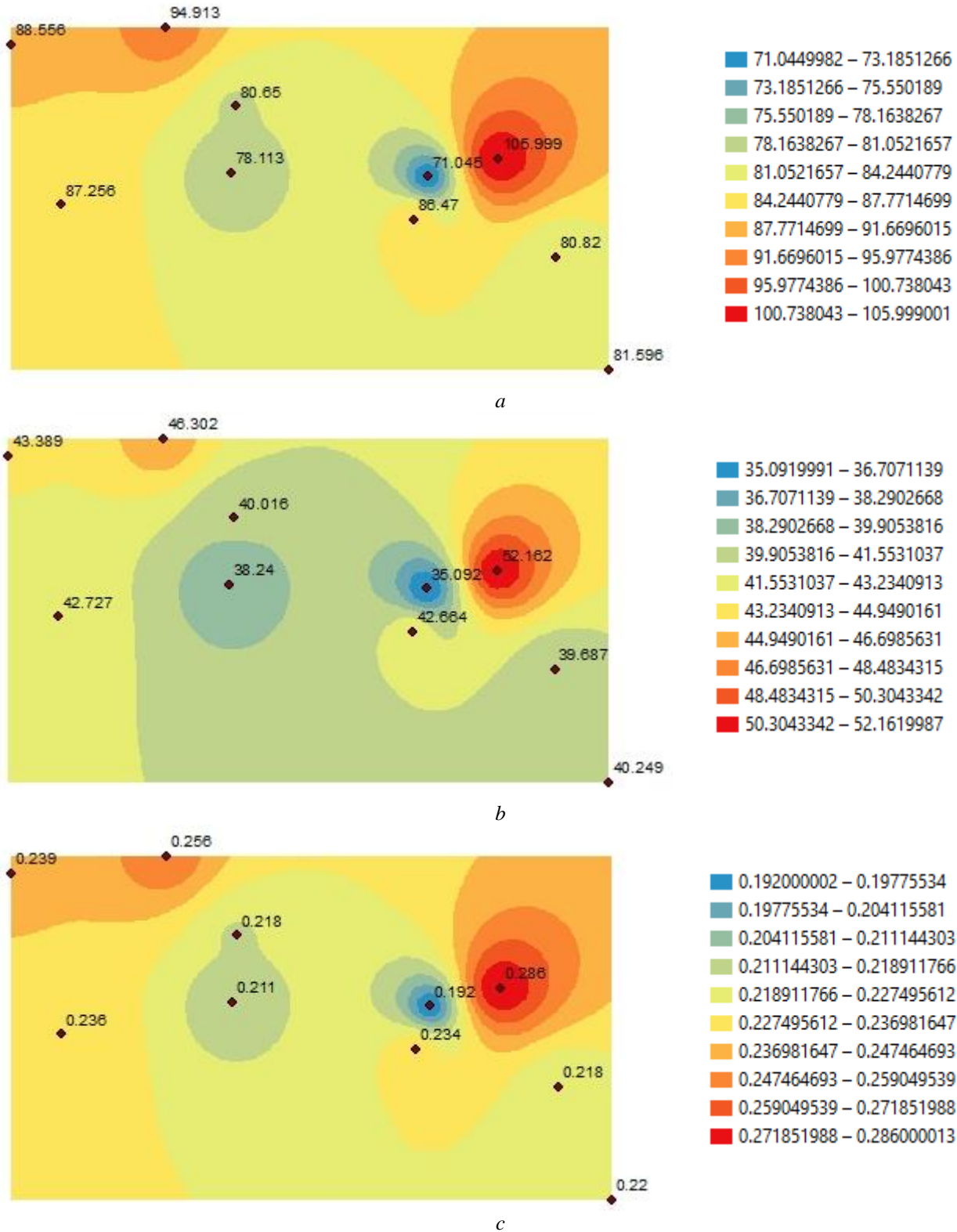
Sample code	$R_{a_{eq}}$ , Bq/kg	$D_r$ , nGy/h	$H_{ex}$	$H_{in}$	$I_\gamma$	AEDE, mSv/y
BD4	106.0	52.2	0.29	0.36	0.82	0.32
MF1	78.1	38.2	0.21	0.28	0.60	0.23
MF2	86.5	42.7	0.23	0.31	0.67	0.26
MF3	81.6	40.2	0.22	0.28	0.63	0.25
P5	80.8	39.7	0.22	0.28	0.62	0.24
P6	71.0	35.1	0.19	0.25	0.55	0.22
P7	80.7	40.0	0.22	0.28	0.63	0.25
P16	87.3	42.7	0.24	0.29	0.67	0.26
P18	88.6	43.4	0.24	0.30	0.68	0.27
P19	94.9	46.3	0.26	0.34	0.73	0.28
Average	85.5	42.1	0.23	0.30	0.66	0.26

Table 3 and Fig. 5 show the radiological risks ( $R_{a_{eq}}$ ,  $D_r$ ,  $H_{ex}$ ,  $H_{in}$ ,  $I_\gamma$  and AEDE) of studied soil samples. The results of  $R_{a_{eq}}$  show that the values lie between 71.0 to 106.0 Bq/kg with an average value of 85.5 Bq/kg. The minimum and maximum values were found in samples P6 and BD4 respectively. The acceptable value is 370 Bq/kg [26]. Therefore, the maximum value in this study lies in the acceptable

level. The values of  $D_r$  ranges from 35.1 to 52.2 nGy/h with an average value of 42.1 nGy/h. The population-weighted value of the absorbed dose rate in outdoor calculated by UNSCEAR 2000 was 57 nGy/h [24] which is higher than our average value. The range values  $H_{ex}$ ,  $H_{in}$  and  $I_\gamma$  were 0.19 to 0.29 with an average 0.23; 0.25 to 0.36 with an average 0.30; and 0.55 to 0.82 with an average 0.66

respectively. The results for  $H_{ex}$ ,  $H_{in}$  were lower than 1 depending on the report of radiation protection [27]. The average value of  $I_\gamma$  also was less than the world average value which is  $I_\gamma < 1$  [27]. The minimum and maximum values of AEDE (indoor + outdoor) were 0.22 and 0.32 mSv/y respectively. The mean values

of annual effective dose (AEDE) (indoor + outdoor) were lower than the permissible world limits (0.08 + 0.42 = 0.50) mSv/y respectively [27]. According to above results and comparing to world limit, the Badra oil field project can be considered as a safe area.



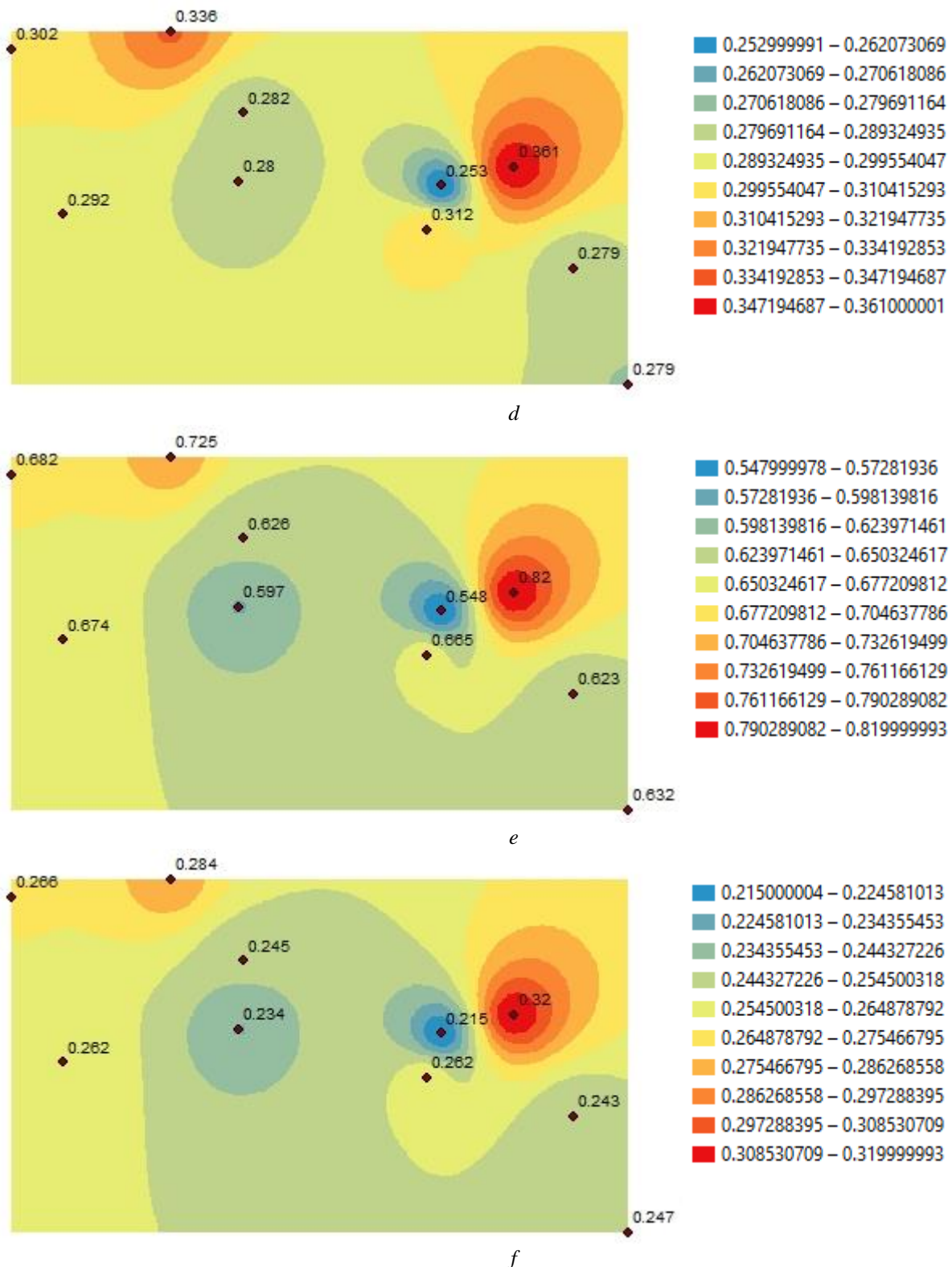


Fig. 5. The choropleth maps that illustrates the radiological risks (a)  $R_{a_{eq}}$ , (b)  $D_r$ , (c)  $H_{ex}$ , (d)  $H_{in}$ , (e)  $I_\gamma$  and (f) AEDE for soil samples in the study area. (See color Figure on the journal website.)

### 7. Conclusions

The specific activity values of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  in Badra oil field project are within the world average values which have been identified by specialized scientific committees and organizations such as

UNSCEAR, 2008. The results of the radiation risks ( $R_{a_{eq}}$ ,  $D_r$ ,  $H_{ex}$ ,  $H_{in}$ ,  $I_\gamma$ , and AEDE) are acceptable within the global limits (UNSCEAR, 2000; UNSCEAR, 2008; OECD and ICRP reports). Hence, it can be concluded that no harmful radiation effects are posed to the population who live in the study area.



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Саад Р. Юсіф<sup>1</sup>, Алі Абід Абоджассім<sup>2,\*</sup>, Анес Хейдер<sup>2</sup>

<sup>1</sup> Університет Куфи, факультет природничих наук, кафедра геології, Куфа, Ірак

<sup>2</sup> Університет Куфи, факультет природничих наук, кафедра фізики, Куфа, Ірак

\* Відповідальний автор: ali.alhameedawi@uokufa.edu.iq

### КАРТУВАННЯ ПРИРОДНОЇ РАДІОАКТИВНОСТІ ЗРАЗКІВ ҐРУНТУ НАФТОВОГО РОДОВИЩА БАДРА З ВИКОРИСТАННЯМ ПРОГРАМИ ГІС

Дослідження фокусується на вимірюванні активності природних радіонуклідів  $^{238}\text{U}$ ,  $^{232}\text{Th}$  і  $^{40}\text{K}$  у зразках ґрунту в районі нафтового родовища Бадра (Ірак). Значення радіологічних ризиків були також розраховані для всіх зразків. Методом, що використовувався в цьому дослідженні, була гамма-спектрометрія з детектором NaI(Tl). Середні значення питомої активності дорівнюють 24,7 Бк/кг для  $^{238}\text{U}$ , 13,6 Бк/кг для  $^{232}\text{Th}$  і 538,9 Бк/кг для  $^{40}\text{K}$ . Крім того, було розраховано радіологічні показники, такі як еквівалент активності радію ( $Ra_{eq}$ ), потужність поглиненої дози ( $D_r$ ), індекс зовнішньої небезпеки ( $H_{ex}$ ), індекс внутрішньої небезпеки ( $H_{in}$ ), індекс репрезентативної гамма-небезпеки ( $I_\gamma$ ) і загальна річна ефективна еквівалентна доза (AEDE), – 85,5 Бк/кг, 42,1 нГр/год, 0,23, 0,30, 0,66 і 0,26 мЗв/рік відповідно. При порівнянні активностей у досліджуваному районі зі світовими середніми значеннями, визначеними НКДАР, ОЕСР та МКРЗ, зроблено висновок, що ризику для здоров'я і загроз персоналу через радіонукліди у цих місцях немає. Для координації результатів картування значень здійснювалось за допомогою геоінформаційної системи (ГІС) у системі координат WGS1984 з використанням методу зворотних зв'язаних відстаней для кращої інтерполяції.

*Ключові слова:* природна радіоактивність, нафтове родовище Бадра, геоінформаційна система (ГІС), гамма-спектроскопія.

Саад Р. Юсіф<sup>1</sup>, Али Абид Абоджассим<sup>2,\*</sup> Анес Хейдер<sup>2</sup>

<sup>1</sup> Університет Куфы, факультет естественных наук, кафедра геологии, Куфа, Ирак

<sup>2</sup> Університет Куфы, факультет естественных наук, кафедра физики, Куфа, Ирак

\* Ответственный автор: ali.alhameedawi@uokufa.edu.iq

### КАРТИРОВАНИЕ ЕСТЕСТВЕННОЙ РАДІОАКТИВНОСТИ ОБРАЗЦОВ ҐРУНТА НЕФТЯНОГО МЕСТОРОЖДЕНИЯ БАДРА С ИСПОЛЬЗОВАНИЕМ ПРОГРАММЫ ГИС

Исследование фокусируется на измерении активности естественных радионуклидов  $^{238}\text{U}$ ,  $^{232}\text{Th}$  и  $^{40}\text{K}$  в образцах почвы в районе нефтяного месторождения Бадра (Ирак). Значения радиологических рисков были также рассчитаны для всех образцов. Методом, который использовался в этом исследовании, была гамма-спектрометрия с детектором NaI(Tl). Средние значения удельной активности равны 24,7 Бк/кг для  $^{238}\text{U}$ , 13,6 Бк/кг для  $^{232}\text{Th}$  и 538,9 Бк/кг для  $^{40}\text{K}$ . Кроме того, рассчитаны радиологические показатели, такие как эквивалент активности радия ( $Ra_{eq}$ ), мощность поглощенной дозы ( $D_r$ ), индекс внешней опасности ( $H_{ex}$ ), индекс внутренней опасности ( $H_{in}$ ), индекс репрезентативной гамма-опасности ( $I_\gamma$ ) и общая годовая эффективная эквивалентная доза (AEDE), – 85,5 Бк/кг, 42,1 нГр/ч, 0,23, 0,30, 0,66 и 0,26 мЗв/год соответственно. При сравнении активностей в исследуемом районе с мировыми средними значениями, определенными НКДАР, ОЭСР и МКРЗ, сделан вывод, что риска для здоровья и угроз персоналу из-за радионуклидов в этих местах нет. Для координации результатов картирование значений осуществлялось с помощью геоинформационной системы (ГИС) в системе координат WGS1984 с использованием метода обратных взвешенных расстояний для лучшей интерполяции.

*Ключевые слова:* естественная радиоактивность, нефтяное месторождение Бадра, геоинформационная система (ГИС), гамма-спектроскопия.

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