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Research paper

Gamma activity in Tigris river water and Rustumai wastewater treatment plant

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Abstract

The activity level of 226Ra, 232Th and 40K radionuclides at selected locations of Tigris River and Rustumai water treatment plant (before and after treatment) has been determined by using NaI(Tl) gamma spectrometry. The results show that the total average activity values were 44.3Bq kg−1 and 789.6Bq kg−1 for 226Raand 40K, respectively. These values are higher than the world recommended values given by UNSCEAR, while the total activity concentration of 232Th was within the world recommended value of 30 Bq.kg-1. Radiological hazard indices such as: radium equivalent activity in Bq.kg−1, annual equivalent dose in Sv.y−1, external and internal hazard indexes, representative gamma index, dose rate in nGy.h−1 and annual effective dose equivalent (outdoor and indoor) in mSv.y−1 were calculated. The calculated indices were below the world recommended values, hence they have no serious effects on people health and environmental species and the Tigris River water can be considered un-harmful for the environment and humans as they are within the world median limits. In the case of Rustumai wastewater treatment plant samples for untreated and treated samples, the average activity concentrations of the three radionuclides were higher than the world recommended values.

Keywords: *Absorbed Dose; Equivalent Dose; Gamma Spectroscopy; Radioactivity; Wastewater.*

1. Introduction

Water quality is a significant factor of ecological researches. The presence of radioactivity in surface water is essentially due to the presence of limited amounts of radioactive isotopes in the earth's crust such as uranium, thorium and radium, besides potassium. Different human exercises may also increase the level of natural radioactive materials in the environment. These radioactive materials can reach surface waters by various channels from each of the processes or exercises. Rivers can be polluted by surface overflow of rainwater which conveys radionuclides from urban communities, mine waste, soil weathering and agricultural areas [1]. Moreover, another type of water contamination is due to geological formation of soil containing radioactive components referred to as Naturally Occurring Radioactive Materials (NORM). NORM can be conveyed to rivers by rain and floods [2]. The drainage of treated wastewater into the river may also affect the level of the radioactive materials in the river's water.

Quick development of populace, urbanization, improvement of sanitation administration and shortage of fresh water increment the interest for the reuse of treated wastewater [3-6]. Wastewater repurpose is a fundamental aspect of water needs which improve the keeping of freshness of water in addition to diminishing the ecological contamination and the absolute supply costs. Improvements in innovation motivate the developing countries to have the potentials towards the wastewater reuse [7,8]. Irrigation with treated wastewater ought to be run cautiously so as to diminish the negative environmental effects and can be increasingly beneficial to the environment [9].

Radioactivity in drinking water is one of the significant manners by which radionuclides gets into the human body, which may thusly cause radiation-induced disorder [10]. In developed countries, estimation of radioactivity is in every case part of their water quality assurance. So many countries are now adopting the guideline activities recommended by the World Health Organization [11] of concentration for drinking water quality.

Consequently, people ought to know that long time exposure to uranium, radium and thorium can cause many acute illnesses [2]. Learning on the circulation of radioactivity present in normal substances empowers the people to evaluate any conceivable risk to human due to radiation by the utilization of such radioactive materials.

The Tigris River has upheld numerous Mesopotamia civic establishments throughout history and keeps on playing animated performance in providing valuable water for drinking, irrigation, and industry to the Iraqi individuals. The investigation of the naturally occurring radioactivity of Tigris river water is significant, and the determination of dose rates will be of some enthusiasm to local health.

Rustamai wastewater treatment plant (RWWTP) was based on the Diyala River (44°52'69.98"E, 33°27'38.82"N). After treatment, the seepage is released in the Diyala River which thus brings about the Tigris River.

The goal of this exploration is to quantify gamma activities in the region under investigation by utilizing NaI (Tl) gamma ray spectrometry and to estimate their potential hazardous impacts on the Baghdadi inhabitants.

2. Materials and methods

2.1. Study area

The River Tigris stems from Eastern Turkey in the Taunus Mountains. The overall length of Tigris River is around 1850 Km, and its length in Iraq is around 1418 Km. some urban regions have been founded on the banks of the Tigris River since the start of evolution. Between these is city of Baghdad, the capital of Iraq with population of about 8765000 which making it as the biggest city in Iraq. Tigris River meets Diyala River at the southeast of Baghdad and borders its eastern rural areas .

The City of Baghdad is partitioned into two considerable regions (Al-Karch and Al-Rusafa) by the River Tigris. Al-Karch and Al-Rusafa are linked by twelve bridges which across the progression of the waters [12]. Tigris River is the fundamental source of the domestic water supplies for Baghdad occupants .

In 1985, Rustamai wastewater treatment plant (RWWTP) (arrange 3) was based on the Diyala River (44°52'69.98"E, 33°27'38.82"N) and worked to serve an aggregate of 1,500,000 occupants [9,13]. After treatment, the waste is released in the Diyala River which thusly ends in the Tigris River .

The study region was started from Al-Muthana Bridge at the north of Baghdad through Al-Sarrafia Bridge and Al-Shuhadaa Bridge then Al-Dora Bridge in the south of Baghdad demonstrated Figure 1. Site1 is close Baghdad Tourism Island (for example overwhelming human exercises), site2 is close Baghdad Medical Hospital (a complex of many teaching hospitals in Bab Al-Moatham, Baghdad, Iraq), site3 is close Al Mutanabi Street (one of the most seasoned and best known lanes in Baghdad for example Substantial Human Activities) and site4 is close Vegetable Oil Factory and Al-Rasheed Gas Power Plant. Moreover, Tigris River encounters outgrowth and aggregation of plants, for example, water hyacinth (Eichhornia crassipes), vascular plants of reeds and papyrus, and hornwort (ceratophyllum demersum). Figure 1 demonstrates the map of the selected sampling sites along Tigris River and also shows the location of RWWTP.

2.2. Sample collection and preparation

Water samples were gathered month to month from the investigation sites along Tigris River and from Rustumai wastewater treatment plant during the period began from September-2017 to January-2018. The coordinates of the selected sites are given in Table 1. The samples were put away in clean polyethylene bottle. Thereafter, water samples were left to vaporize to its half volume so as to assess radioactive isotopes levels. Thenceforth, water samples put away, topped and kept in fixed Merinelli beakers and left for 28 days before measuring so to accomplish secular equilibrium of uranium and Thorium with their progenies.

2.3. Sample analysis

Gamma activity were measured utilizing NaI (Tl) gamma-ray spectroscopy. The detector crystal size is (3"× 3") (ORTEC), its relative efficiency was 20% and 1.8 keV energy resolutions at the energy peak of 1333 keV of ^{60}Co isotope. The background distribution in the environment around the detector was determined using an empty sealed beaker in the same geometry as for the samples. The background spectra were used to correct the net peak area of the gamma rays of the measured isotopes. A dedicated software program was used (ScintiVision). Counting time was 18,000 s. Table (2) illustrates the gamma transition used to determine the concentration for each radionuclide.

Formula (1) is utilized to determine the radioactivity level (C) in the water samples [15]:

$$C(\mathrm{Bq.kg^{-1}}) = \frac{A_P}{\varepsilon . I . V . t} \quad (1)$$

Where A_p is the net peak area of the radionuclide of interest, ε is the detector efficiency for the radionuclide energy, I is the intensity/decay for the radionuclide energy, V is the Volume of the water sample and t is the total counting time in second.

2.4. Radiological hazards

2.4.1. Absorbed dose rate (DRA)

Assessment of DR_A is the main leading step to speculate the health hazard. Concerning to biological impacts, DR_A is directly proportional to the radiological and clinical impacts [16]. The total dose rate (D) (nGy. h^{-1}) is calculated using the following equation:

$$DR_A(\mathrm{nGy.h^{-1}}) = 0.426C_{Ra} + 0.604C_{Th} + 0.0417C_K \quad (2)$$

Where C_{Ra}, C_{Th}, and C_K are the activity concentrations (Bq.kg^{-1}) of ^{226} Ra, ^{232} Th, and ^{40}K in the river sediments, respectively. 0.462, 0.604, and 0.0417 are the conversion factors for uranium, thorium, and potassium, respectively [17].

2.4.2. The annual effective dose equivalent (AED)

In order to transform DR_A to AED, a transformation factor of 0.7 Sv.Gy^{-1} with 20% and 80% for an outdoor and indoor occupancy, respectively must be taken into considerations [18]. Outdoor and indoor AED is calculated utilizing equations (3 & 4) respectively:

$$\mathrm{AED}\ (\mu\mathrm{Sv.y^{-1}}) = \mathrm{D}\ (\mathrm{nGy.h^{-1}}) \times 8760\mathrm{h} \times 0.7\ \mathrm{Sv.Gy^{-1}} \times 0.2 \times 10^{-3} \quad (3)$$

$$\mathrm{AED}(\mu\mathrm{Sv.y^{-1}}) = \mathrm{D}\ (\mathrm{nGy.h^{-1}}) \times 8760\mathrm{h} \times 0.7\ \mathrm{Sv.Gy^{-1}} \times 0.8 \times 10^{-3} \quad (4)$$

2.4.3. Radium equivalent activities (Raeq)

Beretka and Mathew [19] suggested that 370 Bq.kg^{-1} of ^{226} Ra, 259 Bq.kg^{-1} of ^{232} Th, and 4810 Bq.kg^{-1} of ^{40}K can cause similar γ-ray dose rate. Hence, Ra_{eq} can be determined using equation (5):

$$Ra_{eq}(Bq.kg^{-1}) = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (5)$$

2.4.4. Hazard indices (Hex, Hin)

Two indices external (H_{ex}) and internal (H_{in}) radiation hazards were specified by Beretka and Mathew [19]. The main goal of H_{ex} and H_{in} is to restrict the dose of radiation to an equivalent dose limit of 1 mSv.y^{-1}. H_{ex} and H_{in} are calculated using equations (6 &7) respectively [19], [20]:

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (6)$$

$$H_{in} = (\frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (7)$$

H_{in} and H_{ex} give the internal and external exposures to carcinogenic radionuclides and their short-lived progeny [16]. In order to neglect the radiation hazards, both the H_{ex} and H_{in} must not exceed unity [17].

2.4.5. Gamma index (Iγ)

The next radiation risk, which represents the gamma activity index (I_γ), has been characterized by the European Commission [21], [22]. I_γ is calculated by the equation (8):

$$I_\gamma = \left(\frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000}\right) \quad (8)$$

The I_γ is associated with the annual dose rate due to the excess external gamma radiation caused by superficial material. Values of $I_\gamma \leq 2$ related to a dose rate value 0.3 mSv.y^{-1}, whereas $I_\gamma \leq 6$ relates to a value of 1 mSv.y^{-1} [21], [23]. Thus, materials with $I_\gamma \geq 6$ should be avoided since they related to dose rate greater than 1 mSv.y^{-1} [21], which is the highest value of the dose rates recommended for humans [17].

2.4.6. Annual gonadal dose equivalent

The gonads, the active bone marrow and the bone surface cells are important organs as considered by UNSCEAR [24]. Equation (9) was used to calculate the annual gonadal dose equivalent (AGDE) due to the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K [25]:

$$AGDE(\mu Sv.y^{-1}) = 3.09C_{Ra} + 4.18C_{Th} + 0.314C_K \quad (9)$$

3. Results and discussion

3.1. Activity concentrations in Tigris water samples

The distributions of the measured radioisotopes (^{226}Ra, ^{232}Th, and ^{40}K) in the Tigris River water samples during the survey period of five months started from November-2018 to January-2019 are shown in the Figures (2, 3 & 4). The results appear that there are no significant differences in the levels of radioactive material concentrations through the five months of the study. The little differences might be due to fluctuation in water temperature and rainy season, as well as, due to different human activities.

The average activity concentrations of ^{226}Ra and ^{232}Th in the four selected sites are shown in Figure 5, while the average activity concentration of ^{40}K radionuclide is shown in Figure 6. Activity concentrations varied from location to location, because the river bottom can exhibit large variations in chemical and mineralogical properties and rare-earth elements [16]. As well as, the variation in the radionuclide concentrations may be due to the human activities which vary from site to site that affect ecosystem of the Tigris River and increase the pollutants discharged to the Tigris River [26].

The activity concentration of ^{40}K dominated over that of the ^{226}Ra and ^{232}Th radionuclide activities, as naturally expected in environmental samples. The highest average concentrations of ^{226}Ra and ^{232}Th were found in Sarafia site with values of 49.9 Bq.kg^{-1} and 44.9 Bq.kg^{-1}, respectively and that of ^{40}K was found in Muthana site with a value of 864.0 Bq.kg^{-1}, whereas the lowest average concentration of ^{226}Ra was found in Dora site, of ^{232}Th was found in Muthana site and that of ^{40}Kwas found in Sarafia site with values of 32.0 Bq.kg^{-1}, 18.7 Bq.kg^{-1} and 750.7 Bq.kg^{-1}, respectively. The total mean value of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations were 44.3 Bq.kg^{-1}, 30.2 Bq.kg^{-1} and 789.6 Bq.kg^{-1}, respectively.

The worldwide average concentrations of the radionuclides ^{226}Ra, ^{232}Th, and ^{40}K, reported by UNSCEAR [17], are 35, 30, and 400 Bq.kg^{-1} respectively. Our results show that the average activity concentrations of ^{40}K in all water samples are higher than the worldwide concentrations reported by UNSCEAR [17]. The activity concentrations of ^{226}Ra and ^{232}Th in most water samples are also higher than the recommended value.

3.2. Activity concentrations in RWWTP samples

The concentration of the measured radionuclides, ^{226}Ra, ^{232}Th, and ^{40}K, in the RWWTP samples before and after treatment are shown in the Figures (7, 8 & 9). The average activity concentrations are given in Table 4. Normally the ^{40}K activity concentration dominated over that of the ^{226}Ra and ^{232}Th elemental activities. The average concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the after-treatment samples were found lower than that for the samples before treatment.

Our results show that the average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in RWWTP samples are higher than the recommended concentrations reported by UNSCEAR [17].

3.3. Radiological hazards

The determined values of DR_A (nGy.h^{-1}), AED (outdoor and indoor) (µSv.y^{-1}), Ra_{eq} (Bq.kg^{-1}), H_{ex}, H_{in}, Iγ and AGDE for Tigris River water and RWWTP samples are given in Tables (5 & 6).
The average AD_R for the surveyed samples in both Tigris River water samples and RWWTP samples was greater than the world recommended value (57 nGy.h^{-1}) [17].
The mean indoor and outdoor AED values for the Tigris River water samples and RWWTP samples were lower than the world average values at 450 µSv.y^{-1}and 70 µSv.y^{-1}, respectively [20].
The estimated average values of Ra_{eq} for Tigris River water study samples were lower than the recommended maximum value (370) Bq kg^{-1} [17]. The Ra_{eq} for the RWWTP samples were also lower than the recommended value, hence, the wastewater can be considered safe to reuse for irrigation.
The calculated average values of hazard indices and the average I_γ for all samples were less than unity. Hence, the annual effective dose delivered by the water samples was smaller than the annual effective dose limitation of 1 mSv.y^{-1}. Therefore, the study Tigris River water samples and RWWTP samples can be considered as safe as from the radiological point of view.
The average AGDE values for Tigris River water samples were ranged from 0.269 µSv.y^{-1}to 0.658 µSv.y^{-1}, while the average AGDE values for the investigated RWWTP samples ranged from 0.458 µSv.y^{-1} to 0.712 µSv.y^{-1}. The reason may be due to the continuous flow of water.

4. Conclusions

4.1. Tigris river water samples

The carried-out study shows that radioactive element's average activity concentrations ^{226}Ra and ^{232}Th in the Tigris River water samples were below the worldwide value given by UNSCEAR, while the average activity concentration of ^{40}K is higher than the world recommended value (400) Bq.kg^{-1}. No significant differences in the levels of the radioactive element concentrations through the study time period. The little differences might be due to fluctuations in water temperature and rainy season, as well as, due to different human activities that vary from site to site and the increase of the pollutants discharged to the Tigris River.
The indices of radiological hazards are below the world recommended values; thus, the study show that the Tigris River water samples do not show any significant source of radiation risk and are unharmed as far as radioactive element concentrations is concerned.

4.2. RWWTP samples

The average activity concentrations of radioactive elements in the RWWTP treated water samples are slightly lower than that of the untreated water samples. The results also show that all radiological hazard indices are lower than the world recommended values; hence we can conclude that the treated wastewater samples do not perform any important source of radiation risk and can be considered safe to reuse in irrigation as far as radioactive element concentrations is concerned.

Table 1: The Geographical Positions (GPS) of the Study Sites

Sites	Longitude (eastwards)	Latitudes (northward)
Muthana	44°34'55.50"E	33°42'83.22"N
Sarafia	44°37'36.01"E	33°35'37.53"N
Shuhadaa	44°38'79.03"E	33°33'79.59"N
Dora	44°45'02.84"E	33°28'96.82"N
RWRRF1	44°52'98.54"E	33°27'92.12"N
RWRRF2	44°52'69.98"E	33°27'38.82"N

Table 2: Gamma Transition Lines for Determination of the Radionuclide Concentration [14]

Ra-226		Th-232		K-40
Nuclide	Energy (KeV)	Nuclide	Energy (KeV)	Energy (KeV)
^{214}Pb	295.22	^{228}Ac	338.32	1460
^{214}Pb	351.93	^{208}Tl	538.19	
^{214}Bi	609.31			

Table 3: Average Activity Concentrations in Tigris River Water Samples

Isotope	Average activity concentration Bq.kg^{-1}				Total Mean	World permissible value
	Muthana	Sarrafia	Shuhadaa	Dora		
Ra-226	45.9	49.9	44.2	37.1	44.3	35
Th-232	18.7	44.9	32.9	24.1	30.2	30
K-40	864.0	750.7	756.4	787.2	789.6	400

Table 4: Average Activity Concentrations in RWRRF Samples

Isotope	Site	Average activity concentration Bq.kg^{-1}	
		BT	AT
Ra-226		46.1	44.7
Th-232		41.0	40.4
K-40		921.3	779.1

Table 5: Radiological Hazards of the Tigris River Water Samples

Site	Month	DR_A nGy/h	AED_{out} µSv.y^{-1}	AED_{in} µSv.y^{-1}	Ra_{eq} Bq/kg	H_{ex}	H_{in}	I_γ	AGDE ×10^{-3}
AlShuhadaa	Sep-18	65.2	80.0	320.1	137.4	0.4	0.5	0.5	0.477
	Oct-18	74.4	91.3	365.0	156.7	0.4	0.5	0.6	0.543
	Nov-18	88.5	108.5	434.2	187.5	0.5	0.6	0.7	0.645
	Dec-18	67.9	83.3	333.3	148.1	0.4	0.5	0.5	0.491
	Jan-19	55.3	67.8	271.1	118.1	0.3	0.4	0.4	0.403

AlSarrafia	Sep-18	85.9	105.4	421.5	185.7	0.5	0.6	0.7	0.622
	Oct-18	66.6	81.6	326.6	144.2	0.4	0.5	0.5	0.483
	Nov-18	79.0	96.9	387.5	173.7	0.5	0.6	0.6	0.568
	Dec-18	76.9	94.3	377.1	165.5	0.4	0.6	0.6	0.558
	Jan-19	90.2	110.6	442.3	190.7	0.5	0.7	0.7	0.658
AlMuthana	Sep-18	61.9	75.9	303.6	127.6	0.3	0.5	0.5	0.456
	Oct-18	72.2	88.6	354.4	151.5	0.4	0.5	0.6	0.529
	Nov-18	61.0	74.9	299.5	128.7	0.3	0.5	0.5	0.447
	Dec-18	63.8	78.2	313.0	134.0	0.4	0.5	0.5	0.467
	Jan-19	78.8	96.6	386.5	162.0	0.4	0.6	0.6	0.580
AlDora	Sep-18	36.1	44.3	177.0	69.7	0.2	0.2	0.3	0.269
	Oct-18	56.6	69.4	277.6	120.8	0.3	0.4	0.5	0.411
	Nov-18	65.9	80.8	323.4	137.8	0.4	0.5	0.5	0.484
	Dec-18	74.8	91.8	367.1	157.1	0.4	0.5	0.6	0.547
	Jan-19	71.5	87.7	351.0	149.9	0.4	0.5	0.6	0.523
WRV*		57	70	450	370	≤1	≤1	≤6	

*WRV = World Recommended Value.

Table 6: Radiological Hazards of the RWRRF Samples

Site		Month	DR_A nGy/h	AED_{out} $\mu Sv.y^{-1}$	AED_{in} $\mu Sv.y^{-1}$	Ra_{eq} Bq/kg	H_{ex}	H_{in}	I_γ	AGDE $\times 10^{-3}$
RWRRF	BT	Sep-18	98.4	120.6	482.5	211.5	0.6	0.7	0.8	0.712
		Oct-18	75.7	92.8	371.3	161.5	0.4	0.6	0.6	0.551
		Nov-18	85.3	104.7	418.6	178.8	0.5	0.6	0.7	0.624
		Dec-18	92.1	113.0	451.9	194.2	0.5	0.6	0.7	0.671
		Jan-19	62.6	76.8	307.2	132.4	0.4	0.5	0.5	0.458
	AT	Sep-18	77.5	95.1	380.2	165.8	0.4	0.6	0.6	0.564
		Oct-18	71.6	87.8	351.0	152.9	0.4	0.5	0.6	0.521
		Nov-18	78.2	95.9	383.6	166.9	0.5	0.6	0.6	0.568
		Dec-18	74.0	90.7	362.8	156.9	0.4	0.5	0.6	0.538
		Jan-19	78.6	96.4	385.6	170.3	0.5	0.6	0.6	0.569
WRV			57	70	450	370	≤1	≤1	≤6	

Fig. 1: Positions of the Selected Sites on Tigris River.

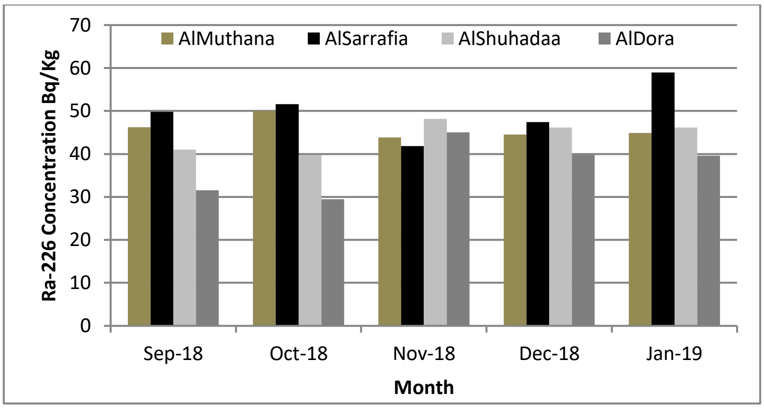

Fig. 2: Ra-226 Activity Concentrations in Tigris River Water Samples.

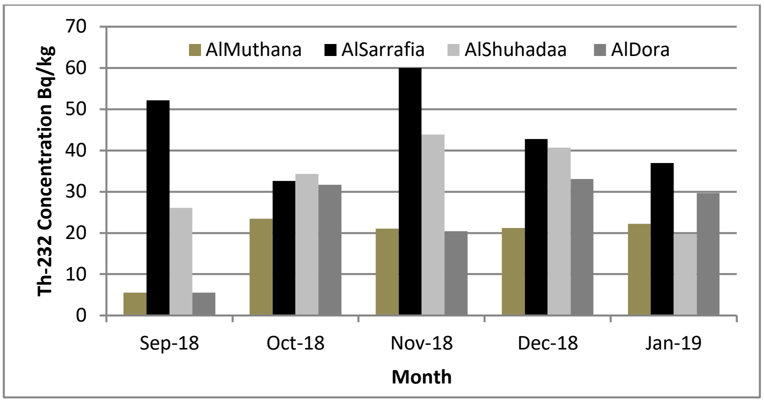

Fig. 3: Th-232 Activity Concentrations in Tigris River Water Samples.

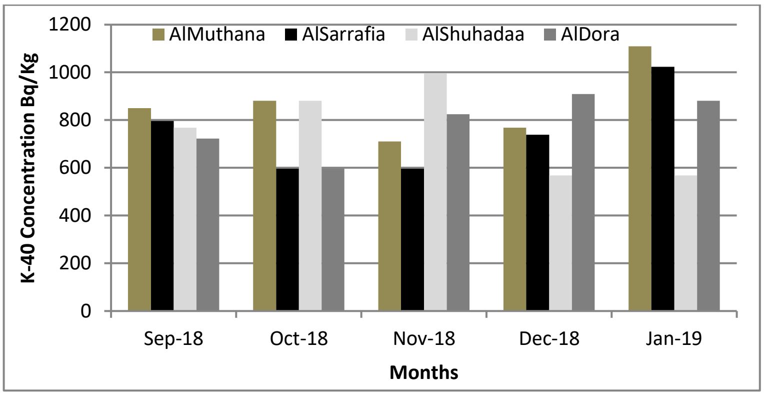

Fig. 4: K-40 Activity Concentrations in Tigris River Water Samples.

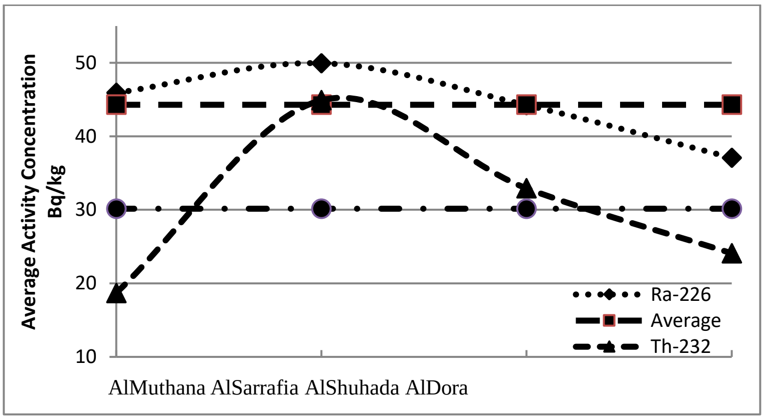

Fig. 5: R.A-226 and Th-232 Average Activity Concentrations in the Investigated Sites of Tigris River during the Period of Survey.

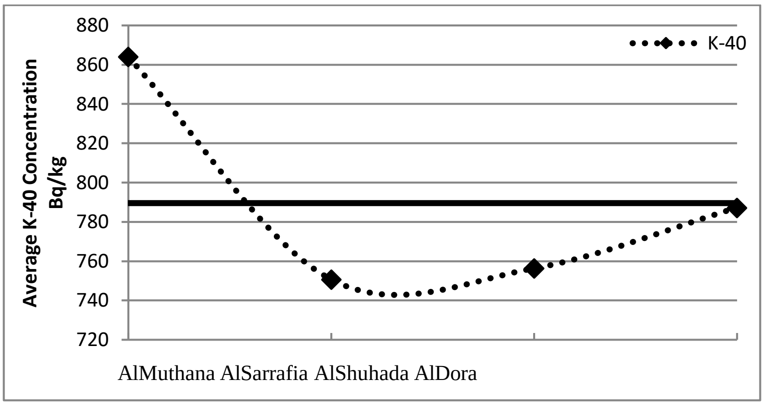

Fig. 6: K-40 Average Activity Concentrations in the Investigated Sites of Tigris River during the Period of Survey.

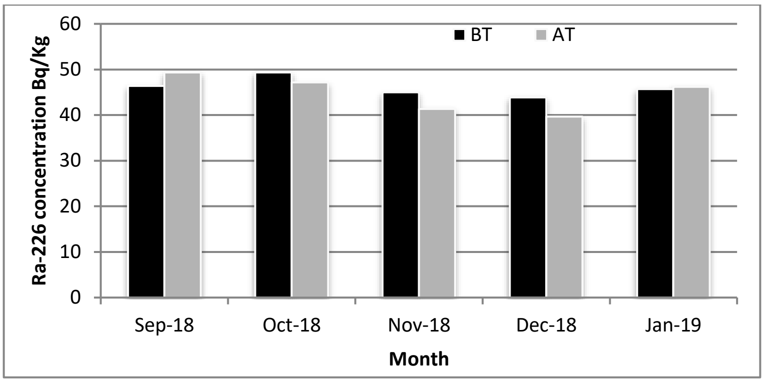

Fig. 7: Ra-226 Activity Concentrations in RWWTP Samples.

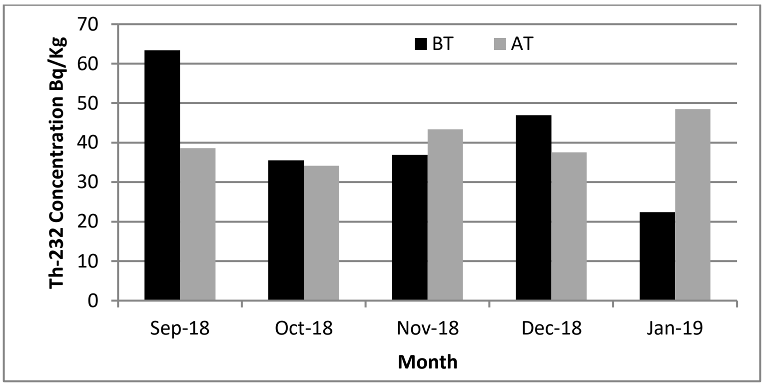

Fig. 8: Th-232 Activity Concentrations in RWWTP Samples.

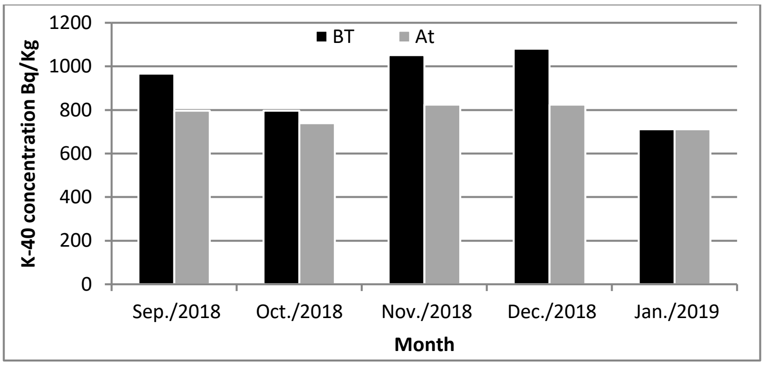

Fig. 9: K-40 Activity Concentrations in RWWTP Samples.

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