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Natural radioactivity concentrations in air samples in Baghdad

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ABSTRACT

Increase through the population of Baghdad province causes more air pollution. Such population growth leads to the need for transportation vehicles and diesel generators in addition to power plants installed in cities, oil refineries and similar sources of pollution. This study focuses on analyzing radioactivity in air samples of different locations in Baghdad using a new method for air sampling. The air conditioner (AC) filters are considered as air sampler filters. The results showed that Dora-Altuama has the highest levels of NORM concentration (564.8 μBq.m^{-3}) near Al-Dora petroleum refinery/thermal power plant in the south of Baghdad while the lowest was in Karradah (204.9 μBq.m^{-3}). The annual effective dose due to inhalation of normal indoor air inside residences has been calculated. The study has revealed that a human could be exposed to about 104 μSv.yr^{-1} in the Dora- Altuama region. The mean annual dose for the thirteen location is about 6.1% of the annual dose limit for the public (1 mSv.yr^{-1}).

1. Introduction

Air pollution is a major environmental issue that affects public health and the life quality in urban areas. Baghdad, capital city of Iraq, has faced significant air quality issues and pollution in recent years. The air quality in Baghdad is a major concern for public health since the pollutants in air exceeds the recommended levels [1]. The primary pollutants causing air pollution in Baghdad include particulate matter, nitrogen dioxide, sulfur dioxide, and ozone. The main common pollution sources in Iraq generally and in Baghdad especially are categorized into fixed sources (brick manufacturing factories, steam and gas power plants, diesel generators, industries, different sites burning, and construction sites) or mobile sources (cars and natural dust storms).

Old fossil fuel-powered electrical power stations are considered the biggest air pollution sources, and Al-Dora power station is one of them. Al-Dora power station (Fig 1) was built in the mid-sixties of the last century and it is a steam power plant located on the shore of the Tigris River, south of Baghdad (33.258ºN, 44.376ºE). Currently, Al-Dora power station is surrounded by very populated regions in all directions especially the biggest university in Iraq, Baghdad University in Al-Jaderyia in the east direction.

Many studies focus on the chemical analysis of air to find the concentration of toxic heavy elements such as the stable isotopes of lead (Pb). Pb is one of the most common toxic elements, causing hazards for human

Figure 1: The Dora power station, on the right: an aerial photograph from Wikimapia and on the left a screenshot from GoogleEarth.

beings and environment. It is possible to observe accumulations of Pb in the human body, which resulted in health problems and its effects include lung cancer, anemia, blood enzyme changes, neurological disorder, and hyperactivity [2-7].

From the radiological aspects, radon (Rn) radioisotopes and their daughter nuclides are major contributors to

*Corresponding author: engakram89@gmali.com natural radioactivity in the air layer near the ground. When radon gas is breathed in heavy ionizing alpha particles from the decay daughters of radon, these alpha particles can damage organic tissue in the lungs prompting DNA harm [8,9]. ^{220}Rn is an inert noble gas and it is a part of the decay series of the natural radionuclide ^{232}Th within the Earth crust where it eventually decays into its radioactive daughter ^{212}Pb (with a half-life of 10.64 h). The major radioactive exposure of public health concern is inhalation of short-lived decay products (^{218}Po and ^{214}Po) of ^{222}Rn [10].

There have been several studies in the Baghdad governorate on measuring the concentration of radon isotopes in buildings and residential [11-15] Concentration of radon is mostly calculated by measuring the alpha particles either passively using a track tracer (CR39 measuring tool) or using a silicon semiconductor detector (RAD7 device).

Several researches have on the concentration of airborne radioactivity and the most of them have focused on the artificial (man-made) radionuclide after nuclear accidents such as ^{131}I, ^{137}Cs, and ^{90}Sr [16,17]. Other studies [18-20] have focused on the naturally occurring radioactive nuclides (e.g., ^{7}Be, ^{22}Na, ^{35}S, ^{218}Po, ^{214}Pb, ^{212}Pb, ^{210}Pb and ^{210}Po), where ^{7}Be comes from cosmic nuclear reaction and the heavy elements such as Pb and Po isotopes that come from the decay series of ^{238}U and ^{232}Th.

The aim of this study is to calculate the natural radioactivity concentrations of the radionuclides detected in air samples collected from Baghdad and assess the radiation health hazard to residents. The studied samples were collected from thirteen locations using a new method of air sampling and an innovative idea, prepared and analyzed using a high-purity germanium detector.

2. Methodology

Airborne particles contain a variety of compounds, organic, natural biogenic, and heavy metal. Particles with aerodynamic diameters less than 10 μm are one of the most dangerous air pollutants for humans because their small size range makes it easy for respiration, leading to major health effects [21,22].

In air conditioning systems, the common air filters are washable with fresh water for regular repeated use. These filters are relatively cheap and are designed for low-intensity use. This type of filter usually has a MERV rating of 1-4, the number is dependent on the amount of matter of a particular particle size. This type of filters can capture between 20-34% of 3.0 to 10.0-micron particles [23].

At the sampling stage, thirteen locations were selected to cover as many regions as possible of Baghdad. Location names and coordinates are listed in Table 1. The air conditioner filters were considered as air samplers' filters since it is easier to collect from citizens and they are already installed. Dust particles that are collected on the filter may be inhaled by humans and accumulated in the lungs. The best method to collect all the dust and dirt from the filters is by washing them with tap water. Therefore, the filters were washed with tap water, then the water was collected in plastic containers for several days letting all the dust in order to precipitate at the bottom of the bottles and the relatively clean water at the top was discarded by keeping a volume of dirty water enough for filling a standard plastic cylinder container. The dirty water samples were then transferred to the gamma spectroscopy laboratory at the Iraqi radioactive sources regulatory authority to be analyzed using a high-purity germanium (HPGE) gamma spectrometer.

Measurements were performed using a high-purity germanium (HPGe) detector FALCON5000 (Canberra) in the Measurements and Calibration Department, Iraqi Radioactive Sources Regulatory Authority (IRSRA). The detector used in this study has a relative efficiency of 40% and full width at half maximum of 2 keV for a ^{60}Co gamma energy line at 1332 keV. The Energy calibration for the detector was performed using two point sources: ^{137}Cs and ^{60}Co. The detector was shielded by 10 cm thick lead bricks adequate to reduce the background radiation. The Efficiency calibration was done using the LABSOCS software developed by MIRION technologies which is based on the Monte-Carlo technique and evaluate the efficiency for each energy peak. For spectrum nalysis, the Genie2000 software tool was used for both the spectrum acquisition and the analysis using the analysis sequence recommended by the manufacturer.

Table 1: The coordinates of the sample locations in Baghdad governorate (33°18′55″N 44°21′58″E).

Sample code	Location	Longitude (E)	Latitude (N)
S1	Kafaat alsaydia	44.35056	33.2315
S2	Al-ialam- alsaydiya	44.34343	33.24216
S3	Dora-Arab jubor	44.43129	33.22617
S4	Madinat Alsadare	44.47179	33.40343
S5	Assa'dun -Alkarradah	44.42348	33.31667
S6	Palestine st	44.40726	33.3654
S7	Al-shua'la	44.28797	33.37922
S8	Dora-Asia	44.41239	33.24179
S9	Al-hurya	44.32301	33.35776
S10	Hay Ajamiaa	44.32414	33.31964
S11	Dora-Altuama	44.41179	33.26515
S12	New-Baghdad	44.49204	33.30433
S13	Jisr Diyala	44.5441	33.22665

To collect the background spectrum, clean tap water samples from the same locations at the same period of washing the air filter and then filled in the same plastic container, same configuration, and environment (Fig 2).

Then, the gamma spectrum is obtained with the same acquisition time and then analyzed to be considered as the background spectrum which is subtracted from the gamma spectrum of each sample.

Figure 2: A photograph of the water sample containers.

3. Results and Discussion

The activity concentration of the radionuclides detected in the samples is calculated implicitly by the Genie2000 based on Equ (1). All the radionuclides detected and quantified came from the naturally occurring ^{226}Ra and ^{232}Th decay series, as well as non-series ^{40}K.

$$A_s\left(\frac{Bq}{sample}\right) = \frac{C_{net}}{I_\gamma\, Eff\, t} \quad (1)$$

Where C_{net} the net area under peak (counts) of each identified peak for each sample after subtracting the background count, t is the spectrum acquisition time (10,800 sec), I_γ is the gamma yield intensity (all the gamma energy intensities are listed in Table 2), Eff is detector efficiency for the corresponding gamma peak.

Table 2: The key gamma peak energies and the radioisotopes.

Radioisotope	Energy peak in keV	Gamma yield intensity %
K-40	1460.81	10.67
Bi-212	727.17	11.80
Pb-212	238.63	44.60
Bi-214	609.31 768.36 934.06 1120.29	46.30 5.04 3.21 15.10
Pb-214	241.98 295.21	7.49 19.20

The results of the net radioactivity concentration (Bq/sample) of gamma emitter radioisotopes in the thirteen samples are shown in Table 3. These values are obtained after subtracting the values found in the background water samples.

The values in Table 3 do not provide any meaningful indication. The required activity should be from the dust collected on the filter but the results in Table 3 is from the tested sample which is dirty water. Therefore, the units should be activity of a specified nuclide per unit volume of air ($Bq.m^{-3}$). it is needed an assumption about the amount of air passing through the filter when the air conditioner is operating. In general, the amount of dust accumulated on the filters depends on the filter specifications (mesh size), windows and door sealing which is different from one house to another, volumetric flow rate (given by the manufacturer), humidity (its effect is neglected), and the operation time of the air conditioner which is quite difficult to estimate or predict. Normally, people in Iraq normally use air conditioners in cooling mode from March to October, 9 to 12 hours per day considering the absence of national electrical power in the summer season. Additionally, an electronic survey using Google Forms service was published online using social media regarding the period that people use air conditioners per year. The results of the survey were very close to the above prediction of 9 to 12 hours for 6 to 8 months.

Table 3: Radioactivity concentration of gamma emitter radioisotopes found in the thirteen samples in the units of Bq/sample.

Sample code	K-40	Pb-212	Bi-214	Pb-214	Bi-212
S1	654.8	11.42	42.79	13.69	16.99
S2	733.7	11.73	31.31	17.18	BDL
S3	691.3	17.28	49.68	11.84	BDL
S4	684.4	19.79	30.69	18.00	BDL
S5	496.7	11.84	22.41	14.34	BDL
S6	703.4	21.50	44.99	21.50	BDL
S7	696.5	16.38	32.38	23.28	BDL
S8	705.2	10.51	36.92	22.54	41.88
S9	751.0	19.59	41.74	5.88	BDL
S10	675.0	17.04	30.35	28.91	BDL
S11	1357.6	24.84	92.75	46.38	BDL
S12	996.8	22.33	50.56	17.79	10.35
S13	1235.4	16.11	64.09	48.86	12.92
Mean	798.6	17.0	43.9	22.3	-

Standards of the air conditioner manufacturers for airflow rates for residential split systems are typically 350-450 cubic feet per minute per ton (590-760 $m^3.h^{-1}$ per ton) of cooling capacity [24]. Therefore, the mean volumetric flow rate is 680 $m^3.h^{-1}$. This range is relatively in line with the airflow rate that [18] in their proposed design for a new high-volume standard air filter for the efficiency calibration process of the HPGe detector where the author mentioned that the air flow rate works from 300 to 900 $m^3.h^{-1}$. For consistency, when collecting the samples, we made sure that the AC was all of two tons capacity. So the volumetric flow rate is 680 multiplied by 2 which equals 1360 $m^3.h^{-1}$. To calculate the total volume of air that passed through the AC filter throughout the assumed running time:

$$V_t = 1360\frac{m^3}{hr}\ x\ 9\frac{hr}{day}\ x\ 30\frac{day}{month}\ x\ 7\ month = 2{,}570{,}400\ m^3 \quad (2)$$

All the values in Table 3 were divided by the total volume ($\mu Bq.m^{-3}$) calculated in Equ (2).

$$A_{net} = \frac{A_s}{V_t} \quad (3)$$

Hence, we get the activity per unit volume of air (Table 4) throughout the running time of the AC appliance.

Table 4: The activity concentration of airborne gamma emitters in μBq.m^{-3}.

Sample code	K-40	Th-232	U-238	Total
S1	254.7	5.53	10.99	**271.2**
S2	285.5	4.56	9.43	**299.4**
S3	268.9	6.72	11.97	**287.6**
S4	266.3	7.70	9.47	**283.4**
S5	193.2	4.61	7.15	**204.9**
S6	273.7	8.37	12.93	**294.9**
S7	270.9	6.37	10.83	**288.1**
S8	274.3	10.19	11.57	**296.1**
S9	292.1	7.62	9.26	**309.1**
S10	262.6	6.63	11.53	**280.7**
S11	528.1	9.66	27.06	**564.8**
S12	387.7	6.36	13.30	**407.4**
S13	480.6	5.65	21.97	**508.2**
Mean	310.6	6.92	12.88	**330.4**

If we consider eight months of operation then it will be equal to 2,937,600 m^3 passed through the air filter, for checking, divide A_s for ^{40}K in the sample (S1) and we get A_{net} to be 223 μBq.m^{-3} which is only 12% less than the value of An_{et} in case of seven months of operating time.

Sample 11 from Al-Dora region was the highest total radioactivity concentration with 564.8 μBq.m^{-3}, and the minimum value was in Al-Karradah (S5) with a total concentration of 204.9 μBq.m^{-3}. The highest concentration of ^{40}K was 528.1 μBq.m^{-3} in (S11) which belongs to the Al-Dora region, while the lowest value was 193.2 μBq.m^{-3} in (S5) in Al-Karradah. The concentration of ^{238}U series daughters was 27.06 μBq.m^{-3} in Al-Dora and 21.97 μBq.m^{-3} in Jisr Dyiala. The concentration of ^{232}Th series daughters was 10.19 μBq.m^{-3} in Dora-Asia district.

It is analyzed Airborne particulate samples collected in Barcelona during the period from January 2001 to December 2005 from a flat roof of a building using a sampler pump fitted with a polypropylene filter of 93% collection efficiency and a filtration rate of 1 m.s^{-1} [25]. The Results for naturally occurring ^{7}Be, ^{210}Pb, ^{40}K, ^{214}Bi, ^{214}Pb, ^{212}Pb, ^{228}Ac and are presented in Table 5.

According to [26], The capacity of the adult lung is about 4 Liter, and generally a person inhales about 23 m^3 per day this is about 8,395 m^3.yr^{-1}, while In [27], it is mentioned that the inhalation rate is 8,234 m^3.yr^{-1}. Consider the activity concentration per unit

Table 5: Mean activity concentration in air (μBq.m^{-3}) for different locations.

Sample code	K-40	Pb-212	Bi-214	Pb-214	Bi-212
Baghdad, Iraq (present study)	310.7	6.6	17.1	8.7	102.0
Barcelona, Spain (Vallés 2009)	26	2.1	1.9	2.3	2.1

volume of air is constant throughout the year, so we can calculate the activity that a person inhales per year. The Annual Effective Dose (*AED*) from inhalation of incense smoke can be estimated using the formula [28]:

$$AED = A * E * I \quad (4)$$

Where *AED* is the annual effective dose (Sv.yr^{-1}), *A* is the activity concentration for the radionuclide (Bq.m^{-3}), *E* is the dose conversion factor for the radionuclide (Sv.Bq^{-1}) which is listed in Table 6, and *I* is the annual intake of incense (m^3.yr^{-1}).

Table 6: Effective dose conversion factors for inhalation for adults [29].

Radionuclide	Sv.Bq^{-1}
^{212}**Pb**	1.8x10^{-8}
^{212}**Bi**	9.1x10^{-9}
^{214}**Pb**	2.8x10^{-9}
^{214}**Bi**	7.1x10^{-9}
^{40}**K**	2.1x10^{-9}

Figure 4 shows the annual effective dose for a person whether he/she spent the year indoors for the studied locations. It can be seen clearly that the values ranges from 38 μSv.yr^{-1} in Al-Karradah (S5) to 104 μSv.yr^{-1} in the Jisr Diyala region, with a mean of 61 μSv.yr^{-1} which is about 6.1% of the annual dose limit for public (1 mSv.yr^{-1}).

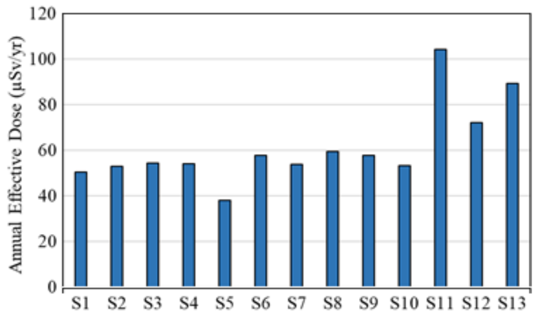

Figure 4: Annual effective dose for the thirteen locations in the Jisr Baghdad (μSv.yr^{-1}).

In Figure 5, the total annual effective dose mainly came from the gamma-emitting radionuclides with a share of 75-80% from ^{40}K and 8-15% from daughters of the ^{232}Th series and 10-12% from the ^{238}U daughters.

Another important factor that may cause further dose (not considered in this study) is the radon concentration accumulated indoors which depends on the type of building materials, ventilations, and other parameters.

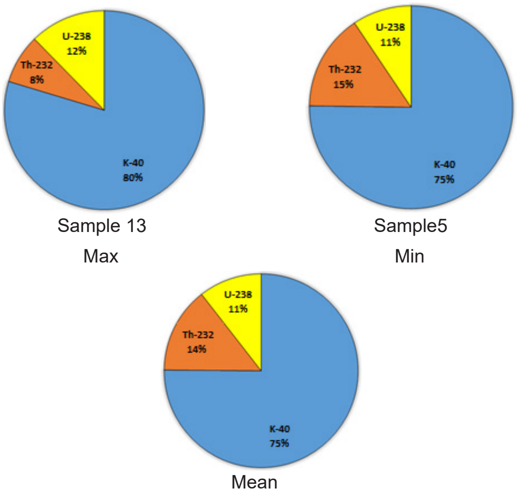

Figure 5: Contribution of each radionuclide to the total annual effective dose from inhalation of air for two samples as an example and the mean of the samples.

4. Conclusions

Thirteen air samples were collected from different locations in Baghdad and then analyzed to evaluate the concentration of NORM in those samples. The results of this study indicate the highest concentration of NORM was in Al-Dora region (Altuama) with 564.8 $\mu Bq.m^{-3}$ near Al-Dora power plant and the minimum value was in Al-Karradah with a total concentration of 204.9 $\mu Bq.m^{-3}$. the annual effective dose due to inhalation of normal indoor air inside residences was calculated. The study reveals that a human could be exposed to about 104 $\mu Sv.yr^{-1}$ in Al-Dora region (Altuama). The mean anuual dose was 6.1% of the annual dose limit for the public (1 $mSv.yr^{-1}$).

5. Recommendations

We would like to emphasize that there is an urgent need for further research on the radioactivity concentration of natural radionuclides. Some of the suggested and recommended possible study topics are given below:

1. Studying more regions in Baghdad and also other provinces, especially the locations with heavy traffic, locations near factories and industrial facilities, and locations were a high number of recorded cancer cases.

2. Analyzing the dust accumulated on the filters using the Alpha spectroscopy method.

3. Studying the effect of doors and windows sealing on the indoor air quality near the highly polluted areas.

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