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An investigation of radon and heavy metal detection for cancer patients in Barji village, in the Iraqi Kurdistan region

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ABSTRACT

Background: Exposure to radiological agents such as natural radon gas and consumption of heavy metals in edible plants are two potential causes of unusual cancer in Berje village near Amedi town in Duhok city in the Iraqi Kurdistan Region. ***Material and Methods:*** Samples of soil, fruits, and vegetables were collected at various stages in the village, particularly at locations close to the homes of cancer patients. The collected samples underwent digestion and heavy metal absorption tests to detect ratio of heavy metal content as well as in their contents of radon. ***Results:*** showed that both heavy metals and radon gas in all samples were with different ratios. Moreover, results revealed that the evolution of radon ranged between 51.375 and 170.25 Bq.m^{-3}, which is within the normal range of radon emission for soil sample. Similarly, results demonstrated that the average content of radon ranged between 0 and 24.1 Bq/kg in most fruits and vegetables which are within the allowable range. However, cadmium was found to be in marginal limits as target hazard quotient (THQ) for lead was greater than 1. Furthermore, bioaccumulation factors of tested fruits and vegetables were less than 1. ***Conclusion:*** The translocation of radon from soil to plants is only hazardous for tomatoes and common purslane. Furthermore, health risk index (HRI) of lead and cadmium was between 1 and 5, which indicates a threat to human health. The hazardous index (HI) was also larger than 1, which implies that heavy metals had significant non-carcinogenic effects on human health. The study found that the target cancer risk (TCR) of lead was low as results demonstrated that heavy metal content was within allowable range.

INTRODUCTION

Radon gas is a well-known radioactive gas that escapes from soil, sediment, and water because it is easily dissolved in water and restricted in a close environment like a home's basement, so usually its concentration indoors is higher than outdoor. The presence of this gas actually depends on the presence of uranium in rocks and sediments in certain areas because it comes from the disintegration series of uranium, radium content in the soil, soil moisture content, soil permeability, season, weather, home construction, geological material under the home, and so geological studies on radioactive material are important for the regions where the level of cancer is not usual. Radon gas crosses the soil-air interface and reaches the atmosphere; the estimated rate of radon release from the soil is 0.42 pCi/m^2 per second in the U.S. (1, 2). It has been reported that the 8.5 million homes in the US receive 148 bq/m^3 of radon and over US action levels. Radon gas in a close room mostly enters the human body through inhalation, skin absorption, and direct digestion to cause lung, skin, and abdomen cancers, and the smoker will significantly get hurt. High soil permeability allows rapid radon migration from the soil in large areas to reach home basements by convection flow, and usually quartz-rich metamorphic rocks like schist have a high radon content (3). It has been reported that indoor radon concentrations are correlated with geological features, and nine counties out of 66 in South Dakota in the US have actual indoor radon pollution. Reddy *et al.* (2022) reported that indoor radon is the second cause of lung cancer just after smoking (4). As radon is soluble in water, it closely relates to stomach cancer. Also, the digestion of 600 liters of water annually containing 1000 Bq/L of radon will result in a dose of 1.5–50.4 mSv to the stomach and 0.01-1.26 mSv to the lungs (5). Sherafat *et al.* (2019) found that the radon levels emitted in Iran varied from 3.92 to 520.12 bq/m^3, with a mean of 56.19 ± 45.96 bq/m^3, and 9% of dwellings are vulnerable to radon exceeding 100 bq/m^3, the limit recommended by the World Health Organization (6).

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It is suspected that radon poses significant health problems in some states of the US by increasing lung cancer, and radon indoor concentrations exceeded 4 pCi/L in about 15% of US homes [4, 5]. It is reported that the average radon concentration in Weifang city, China, is 35.7±15.2 Bq/m^3. Indoor radon and its daughters have a very short half-life and disintegrate rapidly in the epithelial lining of the lungs, which does not give the mucociliary clearance system a chance to remove these radioactive particles out of the lungs. However, the human body has mechanisms to repair the damage, but if the exposure is predominant over allowable ranges for a long time, the damage will be accumulative and will lead to lung cancer. The concentration of radon in water, especially in ground water, is more than the soil concentration, and studies proved that water of 10,000 pCi/L will supply about 1 pCi/L to the indoor radon. They also found the mean radon concentration in water samples ranged between 1.4±0.3 and 13.3±4.1 Bq l^{-1} in India. So, home water supplies may contribute to the large extent of indoor radon in homes [6].

The second suspected reason for cancer separation in a certain area is the consumption of foods and diets containing high amounts of heavy metals, because almost all heavy metals are classified as carcinogenic agents, being As, Cd, Cr, and Ni, which are in category 1 in causing cancer, according to the International Agency for Research on Cancer [7]. Exposure to heavy metals is mainly caused by food consumption of cereal crops, fish, vegetables, and fruit grown in soil contaminated naturally or industrially by heavy metals. Long-term exposure to heavy metals will cause DNA lesions, alter the gene system, and eventually lead to cancer [8]. The exposure of humans to cadmium is mainly caused by soil pollution, where plants are grown and consumed by inhabitants. Lead is the first of the cancer-causing heavy metals and mainly enters the human food chain from the soil, where its food begins to disrupt the tumor regulation gene and replace zinc in some proteins, while pancreatic cancer is not associated with chromium and nickel exposure [9]. Cadmium is blamed for causing a wide range of human organ cancers and blood diseases. Nickel is found naturally in the earth core, and its concentration is different from area to area depending on the geological nature of the area. Nickel has a bad reputation as a cancer-causing agent as it causes cancer in a wide range of ways [10].

The incidence of cancer developing in Barji village within Amedi district in Duhok province in Iraqi Kurdistan Region is absolutely a source of concern and discomfort for the people and health authorities in the region because their rates exceed the normal rates by dozens of times. This calls on the scientific authorities to investigate its scientific causes. The most important of these natural causes may be exposure to nuclear radiation resulting from the release of radon gas from the soil and sediment or the containment of large quantities of heavy metals in the soil. This study comes to confirm these two things. The third reason may be that the village was attacked with chemical weapons in the late eighties of the last century by Saddam's army, and studying it is beyond our current capabilities. The international institutions are called upon to conduct studies on the impact of long-term chemical weapons on human health. The spread of cancer cases in this village and all Amedi districts, according to the Amedi health office, is lung, thyroid, gall bladder metastasis, and right axilla (skin) cancers. The current investigation aims to identify a possible correlation between excessive exposure to radon and heavy metals with cancer cases detected in this region. Subsequently, the main objectives of this study are to examine the radiological effects of natural radon gas released from soil, and the impact of heavy metals present in soil and edible plants on human health in Berji village, within Amedi town in Duhok province in Iraqi Kurdistan.

MATERIALS AND METHODS

Description of the study area and sampling

The study area is located in Berji village, around 10 km to the east of Amadi District and about 85km east of Duhok Governorate, in a mountain area between 37.0713889 N and 48.833888 E at 784 m altitude. According to local health authority statistics, the inhabitants of this village are highly susceptible to cancer. The population of the village was approximately 400 when bombarded with chemical weapons by the Iraqi army in 1988. As a result, tens of inhabitant were severely injured and suffered serious skin and eye irritation problems. Until now, more than 20 people have died from various cancer diseases for unidentified reasons. Thus, samples of soil, fruits, and vegetables were collected from various locations in the village, especially those close to the homes of cancer patients. The samples were directly transferred to the laboratories of the Environmental Directorate in Duhok City to analyze them and determine radon and heavy metal contents (figure 1).

Radon measurements

Alpha-track radon monitors manufactured by DURRIDGE in the United States are used for indoor radon measurement. This research served as an active tool in a solid-state determination to locate the radon activity concentration. The experiment's setup is shown in figure (1). It plainly has a PVC (Polyvinyl Chloride) plastic tube technique with about a liter of volume inside it as a radon accumulation chamber. Due to the desiccant ($CaSO_4$) it contains and the

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radon device monitor, the PVC tube is linked with vinyl tubing to help dry the gas from dampness.

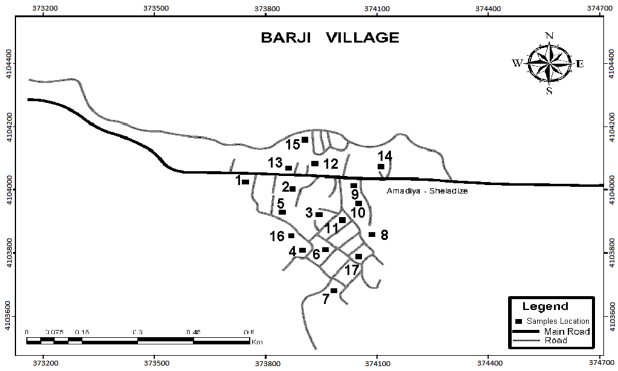

Figure 1. The figure showing the location of samples of study area. from 1 to 17.

The plastic-tube container was isolated using two valves adjusted in the different directions of the walls of the container after a soil sample was placed in the bottom as a source of radon exposure. Following the placement of the samples, the container's radon gas content was monitored and then left at room temperature for approximately one month. One month is enough time for the inner tube chamber to attain equilibrium between the creation of radon decay and radium with radon. Both valves opened when connected to the closed loop. Air from the container will be gathered by the device through this close loop, then the desiccant is next, followed by the inlet filter, the RAD7 device, and finally the measuring tube chamber. The air was escaping from the RAD7 device's output into the loop. Inside the chamber, the air degrades, generating detectable (alpha α) particles that emit offspring, including isotopes of polonium. On the chamber walls, there is a high voltage of roughly 2218 volts. The detector of RAD7 was able to differentiate the distinct electrical pulses produced from ^{214}Po and 218Po with energies of 7.0 MeV and 6.0 MeV, respectively, by converting (α) alpha radiation immediately to electrical sign by using the alpha technique. Testing was carried out in a dry environment. The humidity level inside the RAD7 device is between 4 and 8 percent, while the ambient temperature is between 20 and 31^{o}C. The calibration factor for the radon chambers operated by the US EPA and Durridge Co. was found to be equal to 0.4790 CPM/(pCi/L) in normal mode and 0.232 CPM/(pCi.L^{-1}) in sniff mode, with a 2% margin of error [11].

The second method was used for measuring radon in soil by mixing a weight of soil of about 10 grams by 50 ml with distal water (distal water is free of radon because boiling water, tested by RDA7 H_2O, resulted in zero radon in it), so the result of measuring radon by this mixture was that it came from only soil and the ratio was for the weight of 10 grams of soil. The air volume and water volume are fixed and independent of flow rate in the closed-loop aeration system used by the RAD H_2O technique. The water is circulated with the air and continues to remove radon until equilibrium is reached. Within five minutes, the RAD H_2O system reaches this equilibrium, at which point no more radon can be extracted from the water. For a 40-mL sample, the extraction efficiency, or the percentage of radon extracted from the water to the air loop, is typically 99%. The precise extraction efficiency value varies slightly depending on the surrounding temperature, although it is usually far above 90%. Since the overall measurement is usually accurate, we observe little to no temperature effect [12].

Heavy metal determination

The samples of soil and edible plants collected in the village were subjected to the determination of heavy metal's contents. 0.5 grams of each soil and edible plant samples were digested in the presence of aqua regia (a mixture of nitric acid HNO_3 and $HClO_4$ in a ratio of 3:1), both from Bayer, a glassware and reagents manufacturing company in Germany. The studied heavy metals were determined in the filtrate of samples by an atomic absorption spectrophotometer (AA-7000) and graphite furnace atomizer (GFA-7000), a Shimadzu brand of Japanese instrument, at the Environment Directorate in Duhok City, according to [13].

Transfer factor and bioaccumulation factor

The transfer factor of radon and the bioaccumulation factor of heavy metals were calculated by dividing the contents of plants by the dry weight of the soil in which they were grown.

Dietary exposure estimation

Dietary exposure estimation was evaluated by measuring the estimated daily intake (μg/kg body weight/day) using equation 1.

$$EDI = C \times CF \times ER / B \tag{1}$$

Where; C is the heavy metal concentration in consumed fruits and vegetables by ppm, CF is the conversion factor of 0.085 to convert fresh vegetable and fruit weights to dry weight, ER is the ingestion rate of consumed fruits and vegetables, which was considered to be 0.0385 kg/person/day, and B is the average person body weight by kg, which is 70 kg [14].

Health risk estimation

Health risk estimation was evaluated by measuring the following parameters:

Health Risk Index (HRI), which is the proportion of the estimated daily intake of heavy metals to the reference's doses of heavy metals was calculated by using equation 2:

$$HRI = EDI/RFD \tag{2}$$

Where; HRI > 1 for heavy metal in food means that

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the consumer inhabitants were in danger of a health risk as carcinogenic, and when HRI value is between 1 and 5, it indicates that the heavy metal is not suitable for long-term exposure.

Target Hazard Quotient (THQ) for non-carcinogenic health risk, which is the ratio between the concentration of pollutant in living tissues and the maximum harmful limits of pollutant values in the same organisms. THQ was determined using equation 3 (15).

$$THQ=(EFr\times ED\times FIR\times C/RFD\times B\times TA)\times 10^{-3} \quad (3)$$

Where; EFr = exposure frequency to pollutant, which is 365 days in a year; ED = exposure duration, during average lifetime, which is 65 years; and FIR = average daily consumption of food stuff in grams for one person, which is 70 g. C = concentration of heavy metal in food sample in µg per g. RFD is an oral reference dose of heavy metals in µg per g in a day, which are (Pb, Cd, Cu, Zn, Cr, Fe, Mn, and Ni values were 0.0035, 0.001, 0.040, 0.300, 1.50, 0.7, 0.14, and 0.020 mg/kg/day, respectively). TA is the average exposure time for non-carcinogens (ED × 365 days/year).

When the value of THQ is less than 1.0, it indicates that the level of exposure to heavy metals is safe, less than the standard reference dose, and does not cause any carcinogenic effects during a person's lifetime.

Hazardous index (HI)

The hazard index (HI) is an indicator of the health risk caused by many heavy metals and is calculated as the sum of the hazard quotients for all metals by using equation 4 (16).

$$HI = \Sigma HQ = THQPb + THQCd + THQFe + THQMn + THQCu + THQZn + THQNi + THQCr \quad (4)$$

If the HI is greater than 1, it means there is potential for great noncarcinogenic other health diseases.

Target cancer risk (TCR) for lead

The target cancer risk (TCR) was estimated using equation 5 (17):

$$TCR=MC\times IR\times EFr\times RFD\times Scpo/RFD\times W\times Tavcar \quad (5)$$

Where; IR is the ingestion rate, which is 0.125 kg/day for vegetables and fruits, and Scpo is the carcinogenic potency slope for Pb, which is 0.0085 mg/kg/day for body weight. Tavcar is the averaging time for carcinogens (365 days × 65 years). If TCR ≤ 10^{-6}, the risk of cancer is low; if TCR is 10^{-5} to 10^{-3}, it indicates moderate health risk; if TCR is 10^{-3} to ≥10-1, the risk is high (18).

Statistical Analysis

The collected data on heavy metals in soil and edible plants was subjected to SPSS software (12) using the one-way ANOVA method; subsequently, the difference between the means was tested using the Fisher test (13).

RESULTS

Radon (^{222}Rn) is a radioactive gas generated by radium (^{226}Ra) decaying, which is the decay product of ^{238}U in various depths of the lithosphere to be escaped from the soil and accumulated in close areas like buildings and homes. Its amount is proportional to the amount of uranium and radium in rocks, so the geology of the investigated area is a useful means to predict the accurate level of indoor radon concentration. Radon is denser than atmospheric air eight times. As indicated in table 1, soil samples were taken from different locations and depths inside Berje village, almost close to the homes of people who get cancer, whereas radioactive radon emission from the soil is high or in the normal range by calculating radon Bq/m^3 in a container with a fixed volume of 1153.95 cm3 with a RAD7 device. The results revealed that the evolution of radon from the soil is different from site to site and ranges between 51.375 and 170.25 Bq/m^3, within the normal range of radon emission from the soil; however, concentrations over 100 Bq/m^3 are not desirable according to the worldwide levels prescribed by the International Commission on Radiological Protection (ICRP), EU, and WHO.

Table 1. The calculated Radon Bq/m^3 in soil samples of 115.395 cm^3 volumes after 30 days incubation in container volume1153.95 cm^3 inside various locations of Berji village.

Sample number	Sample Weight, g	Calculated Radon [Bq/m^3]
1	127	151
2	104.3	51.375
3	136.1	170.25
4	137.19	85.875
5	110.43	160
6	127.7	155.75

As indicated in table 2, the average content of radon Bk/kg ranged between 0 and 24.1 Bq/kg in common fruit and vegetables cultivated in this village, which are within the recommended levels prescribed, and the maximum concentration of radon in soil sediment did not exceed 16.1 Bq/kg. As shown in table 2, the translocation of radon from soil to the plants cultivated in the village is only at-risk level for tomato and common purslane, as the translocation factor is higher than one unit and indicates the translocation of radon to the human body by consuming these vegetables, and this may be due to the spatial decrease in soil pH in these areas due to manuring the soil. And all the investigated heavy metals in this study were found within the normal safety range of the selected seven locations inside the village, as shown in table 3.

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Table 3 shows the statistical analysis (P<0.05) and values of some heavy metals by ppm in selected soil samples within the Berji village, and they are located in the normal range of worldwide standards. However, there are significant differences in the same heavy metal contents in different locations inside the village, with Pb value being above permissible levels in location 5 and Ni being above WHO standards in all locations.

The second potential reason for cancer-causing agents is the high level of toxic heavy metals, especially Pb, Cd, Cr, and Ni, in food. Hence, the common fruits and vegetables grown in this village were determined as shown in Table 4, the statistical analysis (P<0.05) of heavy metal content ppm in most cultivated edible plants inside the village.

As shown in table 4, the health risk index (HRI) of lead and cadmium is between 1 and 5, which indicates a threat to human health if consumed for a long time, while for the rest of the investigated heavy metals, the HRI is less than one and safe for human consumption. Target hazard quotient (THQ) is an index for non-carcinogenic effects of heavy metals, such as kidney failure and mental lapse. Also found HI for vegetables (4.0257) and cereals (12.6269), recorded hazard index (HI) between 3.99 and 4.43 in some vegetables in Qater. The target cancer risk (TCR) of lead or the susceptibility of people to get cancer from consuming these vegetables and fruits is low according to the New York State Department of Health, as shown in table 4, and the recorded carcinogenic risk (CR) of some heavy metals is between 5.24×10^{-3} and 8.85×10^{-4}.

Table 5 shows that the bioaccumulation factor of most edible fruits and vegetables grown within Berji village was less than 1, which means the threat of being at a risky level for people's consumption is very low, except for tomato and watercress, which bioaccumulate considerable amounts of cadmium in their tissues, and purslane with watercress, which absorbs high amounts of zinc and may be useful to be used as phytoremediators for Cd and Zn-polluted soils.

Table 2. Radon tests after decomposition of substances in water and measurement of radon in water.

Samples	5 g sample in 50 ml water Bq/L	Bq/m^3	Transfer Factor
1	Chard	810	0.50
2	Common purslane	1610	1
3	Fig 1	0	0
4	Grapes	803	0.49
5	Fig 2	0	0
6	Mulberry	0	0
7	Sumac leaves	803	0.49
8	Pomegranates	803	0.49
9	Tomato	2410	1.49
10	Watercress	803	0.49
11	Mint	1610	1
12	Soil 1	803	-
13	Soil 2	0	-
14	Sediment 1	1610	-
15	Sediment 2	799	-
16	Soil 3	0	-
17	Soil 4	1610	-

Table 3. Heavy metals content (ppm) in selected soil samples inside Berji village.

Locations	Fe ppm	Cu ppm	Mn ppm	Cd ppm	Zn ppm	Ni	Pb ppm	Cr ppm
location1	15818±0.57 c	16.410±0.57 d	392.42±0.57 d	0.050±0.0057 d	82.06±0.57 d	137.80±0.577 d	42.53±0.57 e	56.28±0.57 a
Location2	10050±0.57 f	16.010±0.57 d	394.21±0.57 c	0.040±0.0057 d	88.37±0.57 c	97.620±0.577 e	11.59±0.57 f	31.15±0.57 c
location3	13580±0.57 e	15.610±0.57 d	577.50±0.57 b	0.090±0.0057 c	48.95±0.57 f	95.420±0.577 f	73.90± 2.81 c	56.76±0.57 a
location4	14826±0.57 d	21.380±0.57 c	362.82±0.57 e	0.760±0.0057 a	62.48±0.577 e	158.20±0.577 c	67.00±0.57 d	34.90±0.57 b
Location5	28045±0.57 b	35.900±0.57 a	362.90±0.57 e	0.70±0.0057 b	125.71±0.57 a	271.30±0.577 b	102.07±0.57 a	24.91±0.57 d
Location6	28509±0.57 a	31.720±0.57 b	784.07±0.57 a	0.760±0.0057 a	121.54±0.57 b	312.70±0.577 a	82.06±0.57 b	29.98±0.57 c
Soil Standards WHO (1996)	50000	36	850	0.8	50	35	85	100
ANOVA Summary P-values								
P- values	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.035

Means with the same letter are not significantly different (Fisher's test, P<**0.05**).± denotes standard errors of the mean total of each variable at each site . Locations inside village and close to cancer patient homes.

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Table 4. Heavy metals contents (ppm), Estimated daily intake (EDI), Health risk index (HRI), Target hazard quotients (THQ), Hazardous index (HI), and Target cancer risk (TCR) in some common fruits and vegetables inside Berji village.

Locations	Variables							
	Fe ppm	Cu ppm	Mn ppm	Cd ppm	Zn ppm	Ni	Pb ppm	Cr ppm
Chard	606.73±0.57 c	4.77±0.577 cd	57.91±0.5 c	0.16±0.005 b	75.64±0.5 c	47.44±0.5 a	1.57±0.57 efg	27.33±0.5 b
Purslane	271.16±0.57 d	5.17±0.57 cd	46.710±0.5 d	0.15±0.005 b	144.9±0.5 a	1.1±0.5 ef	1.24±0.7 g	14.23±0.5 c
Fig 1	69.55±0.57 g	3.78±0.57 de	11.19±0.5 f	0.35±0.005 b	20.22±0.57 h	6.62±0.5 cd	4.6±0.5 d	10.5±0.5 d
Grapes	13.39±0.57 j	2.78±0.57 e	4.70±0.5 h	0.21±0.005 b	0.05±0.005 I	0.0±0.0 f	20.99±0.5 a	4.28±0.5 f
Fig 2	40.53±0.57 h	0.99±0.005 f	8.92±0.5 g	0.23±0.005 b	37.18±0.5 e	7.72±0.5 C	0.21±0.005 fg	6.54±0.5 e
Mulberry	165.89±0.57 e	7.55±0.57 b	25.22±0.5 e	0.35±0.005 b	34.61±0.5 f	0.55±0.005 f	1.124±0.57 fg	7.46±0.5 e
Sumac leaves	136.35±3.51 f	7.06±0.57 b	82.88±0.57 a	0.07±0.005 b	34.5±0.5 f	2.21±0.5 e	2.21±0.5 ef	10.26±0.5 d
Pomegranates	30.08±0.57 i	10.14±0.57 a	12.65±0.57 f	0.32±0.005 b	39.96±0.57 d	0.0±0.0 f	10.38±0.5 b	7.64±0.5 e
Tomato	28.90±0.57 i	7.36±0.57 b	9.41±0.57 g	0.5±0.005 b	35.73±0.5 ef	0.0±0.0 f	6.27±0.5 c	6.64±0.5 e
Watercress	694.14±0.57 b	5.96±0.57 bc	84.26±0.57 a	4.54±0.57 a	135.07±0.5 b	6.07±0.5 d	3.02±0.57 de	31.17±0.5 a
Mint	826.64±0.57 a	6.36±0.57 bc	73.56±0.57 b	0.27±0.005 b	26.85±0.5 g	9.93±0.5 a	2.97±0.5 e	31.03±0.5 a
Plant WHO standards	450	10	100	0.2	100	10	0.3	18
ANOVA Summary P-values								
P- values	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
EDI µg/kg/day	0.051	0.39	0.204	0.215	1.007	0.145	0.054	0.044
HRI	1.9	4.2	0.02	0.20	0.05	0.59	0.001	0.08
THQ	0.65	1.41	0.17	0.14	0.037	0.1	0.01	0.37
CTR for lead	4.6×10^{-6}							
HI	2.88							

Means with the same letter are not significantly different (Fisher's test, P<**0.05**).± denotes standard errors of the mean total of each variable at each site. EDI=Estimated daily intake, HRI=Health risk index, THQ=Target hazard quotients, HI=Hazardous index, TCR=Target cancer risk

Table 5. Heavy metals bioaccumulation factor in some common fruits and vegetables inside the village.

Plant type	Cd	Pb	Zn	Cu	Fe	Mn	Cr	Ni
Chard	0.4	0.02	0.85	0.2	0.03	0.1	0.7	0.3
Purslane	0.3	0.01	1.64	0.2	0.01	0.09	0.3	0.01
Fig 1	0.8	0.07	0.2	0.1	0.003	0.02	0.2	0.06
Grapes	0.5	0.3	0.0003	0.1	0.0003	0.09	0.1	Nil
Fig 2	0.5	0.003	0.4	0.04	0.01	0.01	0.1	0.06
Mulberry	0.8	0.01	0.3	0.3	0.008	0.05	0.1	0.01
Sumac leaves	0.1	0.03	0.3	0.3	0.007	0.1	0.2	0.01
Pomegranates	0.7	0.1	0.4	0.4	0.001	0.02	0.1	Nil
Tomato	1.4	0.09	0.4	0.3	0.001	0.01	0.1	Nil
Watercress	11.3	0.04	1.5	0.2	0.03	0.1	0.8	0.06
Mint	0.6	0.04	0.3	0.2	0.04	0.1	0.8	0.07

DISCUSSION

The variation in radon emission in investigated region may be due to the geochemical process in the soil or the geological condition of the locations [19-21]. In a local study conducted in various locations in Duhok Governorate, they recorded the minimum radon emission from the soil samples of Amedi district near Berji village, which contained 163±72 to 221±58 Bq.m^{-3}. with a mean of 196 ±17 Bq.m^{-3}. The study found that the radon emission increased with increasing soil depth. It is worth mentioning that that accepted indoor range of radon prescribed by WHO is 100 bq/m^3, meanwhile the upper limit of radon should not exceed 300 bq/m^3, and in bedrock, it is 400 bq/m^3 [22]. In another study carried out at a number of kindergartens in numerous cities in Kurdistan, it was concluded that the average radon gas level was approximately 96.815±26.939 Bq.m^{-3} [23]. In addition, the study used RAD7 technique for measuring the radon concentration in the same region in Zakho district, and they found the smallest values in soil at 14.12±8.59 and 16±4.24 Bq.m^{-3}. In study carried by Thabayneh *et al.* [24] the indoor radon concentrations in various buildings in Palestine was found in a range from 27.8 to 962 Bq.m^{-3}. However, Alhamdi and Abdullah [25] concluded that outdoor radon radiation in Duhok city may have biological effects from potential long-term exposure. Radon gas may travel through the food chain from soil and water to reach the human body, especially if the cultivated soil or irrigation water were polluted by radon gas. Various radioactive isotopes can be found in human tissues, such as ^{226}Ra, ^{222}Rn, ^{238}U, and others. Radon is also transported to human lungs through the air breathing, as radon is present as a gas in the air. Moreover, it is also found that the translocation factor of radon and other nucleotides is greater than 1 in most food items in Egypt, which indicates pollution by radioactive materials [26]. Radon is very reactive with other nutrients in the soil such as phosphorous, sulfur, bromine, and chlorine. Radon can be absorbed by plants and transported through the food chain to humans by digesting vegetables grown in polluted areas, drinking radon-polluted water, inhaling radon directly from the air, or consumption meat contaminated by various radioactive isotopes (Rn-222, Ra-226, U-238, etc.) [27, 28]. It is well known that the most common diseases caused by radon alpha radiation are lung cancer, kidney infections, and skin cancer [29], therefore, the presence of various chemicals in the environment would adversely affect human health.

It is evident that there is a significant difference in

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heavy metal contents among the different edible plants grown inside the village. The two hazardous toxic heavy metals Pb and Cd were found at high levels in all investigated plants, which means that the consumption of these plants by the villagers is fraught with many dangers to getting cancer as these two toxic nonessential heavy metals are well-known to cause various cancer types in human organs. Moreover, Cr was found at a highly risky level in chard, watercress, and mint. Ni was the prevalent heavy metal in this village to be more dangerous and was found above the normal range in most fruits and vegetables, such as chard, figs, watercress, and mint. The other four heavy metals that act as essential micronutrients that serve a beneficial physiological function for living cells and plant growth, Zn, Cu, Fe, and Mn, were found in the normal safe range in the food stuff of consumers in this village [(30)]. After carrying out a survey of heavy metal contents in the Badinan region of Iraqi Kurdistan Region, they found that the values of almost all heavy metals in the soil were within normal ranges.

The estimated daily intake of most investigated heavy metals, as shown in table 4, is within the allowable range; however, cadmium is in marginal limits as Cd, which must not exceed 0.05, and the chronic consumption of this marginal dose will expose a threat to human health as carcinogenic. Similar result was reported by Thabayneh *et al.* [(24)], who also recorded the daily intake of metals in vegetables for Zn (0.51–1.46 mg/kg) and Ni (0.05–0.22 mg/kg). The health risk index is another indicator of the threat of heavy metals to human health due to the consumption of polluted food [(31)]. Pb has adverse effects on almost all human organs particularly brain and nervous system as they are the most targeted parts, causing anemia, kidney failure, and damage to the reproductive and immune systems. However, Cd is slightly absorbed by the body, but when it reaches the bloodstream, it largely causes kidney failure, lung damage, and interferes with bone. The toxic heavy metals of Pb, Cd, Cr, and Ni need to be monitored and investigated periodically in the food consumed by the villagers to establish a valid and accurate correlation between contamination and the rise of cancer cases among the inhabitants [(32)]. Additionally, the target hazard quotient (THQ) for cadmium in wheat was >1 when irrigated with primary treated wastewater. As revealed from table 4, the THQ for lead is greater than 1, which indicates that the lead in vegetables and fruits in this village will adversely affect human health, especially for long-term consumption. Hazard index (HI), which is the total of THQ for all eight heavy metals investigated in this study, is 2.88 and greater than 1, as shown in table 4, which indicates that the heavy metals have great non-carcinogenic effects on human health [(33)].

CONCLUSION

The non-carcinogenic target hazard quotient (THQ) for lead is greater than 1, which indicates that the lead in vegetables and fruits in this village will adversely affect human health. The hazardous index (HI) in this study is also greater than 1, but the confirmation of carcinogens is low to moderate for long-term consumption of vegetables and fruits. The suspected factor is the effects of direct chemical weapons that were used in 1988 against this village and not investigated in this study due to the lack of instrumentation and technique availability in the Kurdistan Region. So, it is recommended that the international scientific centers that have the ability to study the effects of chemical weapons such as mustard, VX, Sarine, and tabun on human health, especially the appearance of cancer, do this study in this region.

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