

Article

Evaluation of Uranium Concentration in Soil Samples of Central Jordan

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Abstract: Naturally occurring radionuclides such as uranium, thorium and their decay products (^{226}Ra , ^{222}Rn) are present in a number of geological settings in Jordan. Motivated by the existence of uranium anomalies coupled with its lack of conventional energy resources, Jordan decided that the development of this indigenes resource (uranium) is the first step in introducing nuclear power as part of its energy mix. Uranium deposits in Central Jordan were perceived not only as a secured resource that will fulfill Jordan's energy needs, but also as an economic asset that will finance Jordan's nuclear program. The average uranium concentration of 236 soil samples using ICP-Mass (inductively coupled plasma mass spectrometry) was found to be 109 parts per million (ppm). Results analysis revealed a wide range of 1066 ppm for uranium concentration, and a median of 41 ppm uranium. The measurements frequency distribution indicates that 72% of samples measured had a uranium content of less than 100 ppm, a concentration that characterizes overburden and tailings quality, rather than minable reserves. This paper presents and evaluates the concentration of uranium in central Jordan, being the most promising area with the highest radioactive anomalies in Jordan.

Keywords: uranium; exploration; Jordan; nuclear energy; ICP-Mass

1. Introduction

Worldwide most countries rely on imports to fulfill their energy needs. Jordan is no exception, with the lack of conventional energy resources and motivated by the existence of uranium occurrences coupled with official studies claiming proven reserves of high-grade uranium. The

government of Jordan declared in 2007 its intention to introduce nuclear power as part of its energy mix [1].

The development of this indigenous fuel (uranium) resource was presented by Officials not only as a secured resource that will help fulfill Jordan's energy needs, but also an economic asset that will finance Jordan's nuclear program [2,3].

In 2008, Jordan Atomic Energy Commission (JAEC) was established, and its Chairman stated that, "The first step in Jordan's nuclear program is the mining and extraction of uranium, which constitute a strategic wealth being available in commercial quantities in Jordan" [4]. He added, "Uranium reserves in central Jordan are estimated at about 70,000 metric tons, with an average concentration of 500 ppm" [5].

In 1980, a countrywide Gamma airborne survey was carried out revealing 11 areas with high background radiation intensity of up to 2000 counts per second (cps) as shown in Figure 1 [6]. Although most areas are related to known phosphorite formations (outlined in black), where Phosphate is being mined and exported, five of the areas were identified as potential uranium deposits (outlined in red); the most promising of the five is an area located the central part of the Jordan.

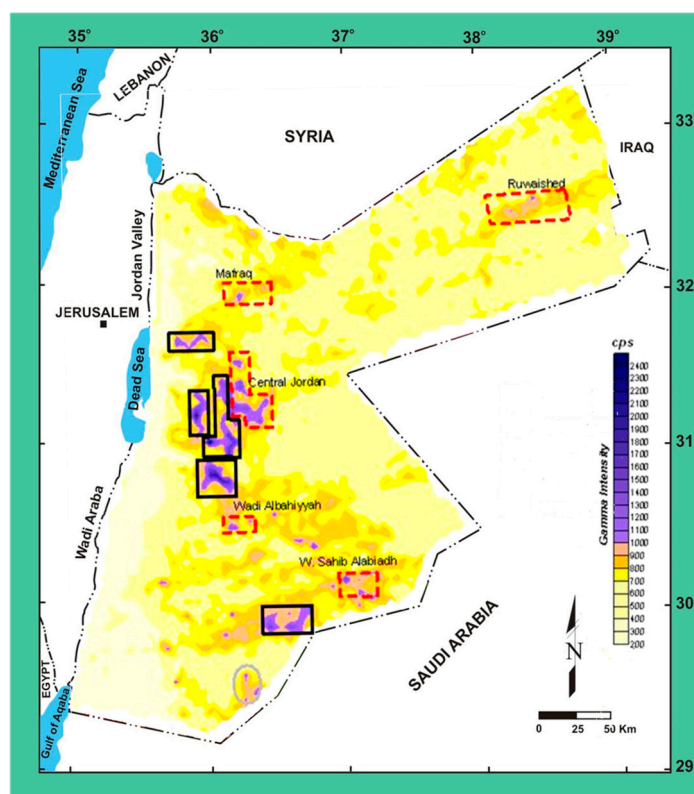


Figure 1. Jordan countrywide Gamma intensity airborne survey, showing areas of high radiation. Known phosphate mining areas are outlined in black, areas with uranium anomalies are outlined in red, and one area with thorium anomalies is outlined in gray (modified after [6]).

Naturally occurring radionuclides such as uranium, thorium and their decay products (^{226}Ra , ^{222}Rn) are present in a number of geological settings in Jordan. Uranium occurrences in phosphorite, oil shale, limestone, marble, sandstone have been studied over the last 40 years primarily during geological

mapping and exploration projects [7–14]. Jordan does not have any assured uranium resources, or uranium mining.

The aim of this work is to present and evaluate the concentration of uranium in central Jordan, and to analyze the results in the framework of international standards for uranium ore, resources and reserves classification.

2. Geological Setting

Jordan is a small country situated to the north west of the Arabian Peninsula, south of Syria and east of the Great Rift Valley home of the Dead Sea and Jordan River, between latitudes 29° and 33° north and longitudes 34° and 39° east. The study area is located in central Jordan, approximately 65 km southeast of the capital Amman, and 40 km East of the Dead sea, and consists of two zones, the Fertile Zone (FZ) and Khan Az-Zabib (KZ) (Figure 2).

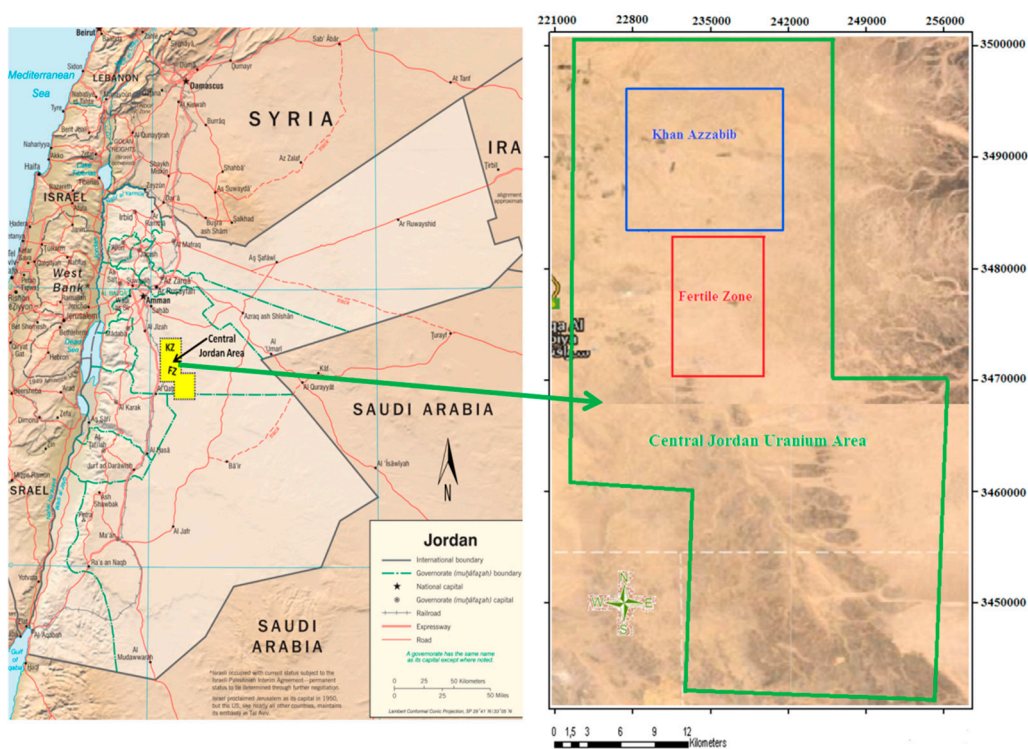


Figure 2. Map of Jordan showing the location of central Jordan area (modified after [15,16]).

During the Late Cretaceous to early Eocene period, Jordan was situated in a shallow marine environment of the Tethys Sea. In the Cenomanian times, transgression took place in relation to a global warming event, which resulted in the deposition of mostly calcareous marine sediments.

During the Late Eocene, a regression led to a period of uplifting, folding and faulting in the region, which are mostly related to the continued tectonic movement along the Great Rift. This period is also characterized by left lateral trans-tensional events, which were responsible for the Dead Sea rifting, extensive basalt flows, that extend to Syria and Saudi Arabia [17–19].

The central Jordan area is located near the opening area of the Dead Sea, a sector that is strongly structured by fault system; the main faults are the Zerqa Main, Daba and Siwaqa fault systems [20,21].

Central Jordan area was mapped by the Natural Resources Authority (NRA) [20,21] and its geology was described in detail as illustrated in Figure 3 [13,18,19,22].

In 2008, Jordan Atomic Energy commission (JAEC) delineated an area of 1469 km² in central Jordan for uranium exploration and mining, the area was licensed to Areva and was closed to all mining activities except uranium. The central Jordan uranium area map is shown in Figure 1, and its coordinates are tabulated in Table 1.

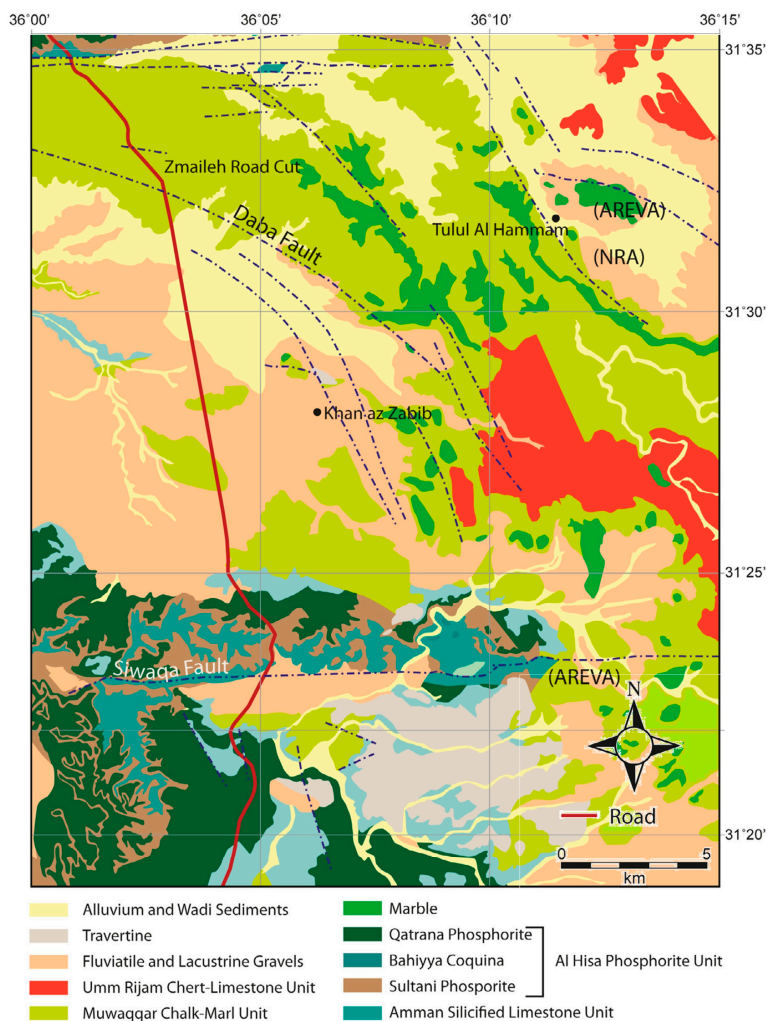


Figure 3. Geological map of central Jordan (modified after [13]).

Table 1. Coordinates of the Central Jordan uranium area, in UTM (Universal Transverse Mercator) 37° north, and in GPS.

North (UTM)	East (UTM)	Latitude	Longitude
3,500,685	246,010	31°36'	36°19'
3,470,281	245,863	31°20'	36°19'
3,470,281	256,291	31°20'	36°26'
3,441,306	255,339	31°04'	36°26'
3,442,076	232,782	31°04'	36°11'
3,460,200	233,403	31°14'	36°12'
3,460,734	222,363	31°14'	36°05'
3,500,685	222,510	31°36'	36°04'

Two zones in central Jordan (Figure 1) were identified as having the highest concentration of uranium anomalies in the country [15]; the Fertile Zone with an area of 100 km², and Khan Azzabib with an area of 178 km². JAEC claim that the average uranium concentration in the two zones is 500 ppm [5].

3. Results and Discussion

The uranium concentration of 236 soil samples from central Jordan was measured using inductively coupled plasma mass spectrometry (ICP-MS) [23], a precise method that is capable of detecting uranium concentration as low as 0.001 ppm. Collected soil samples were oven dried for 24 h and sieved to remove stones and pebbles. The samples were then crushed in a ball mill to pass through a fine mesh sieve (0.5 mm), each sample was mixed after sieving to assure homogeneity.

Measurement results of uranium concentration in parts per million (ppm) vs. sample number are tabulated in Table 2, and depicted graphically in Figure 4. Statistical analysis revealed that the results exhibit a very wide range of 1066 ppm for uranium concentration, with a mean value of 109 ppm, and a median of 41 ppm. Which indicate that uranium mineralization is dispersed over wide areas in small-localized areas rather than uniform concentration in a large enough layers adequate for exploitation.

The mean average value of 109 ppm uranium in the soil samples, is analogous to the concentration of secondary uranium found in phosphorite beds adjacent to the study area. The average uranium concentration in Jordanian phosphate ore of central Jordan is 105 ppm [24].

The measurements frequency distribution (Table 3) indicates that 72% of samples measured had a uranium content of less than 100 ppm, an extremely low concentration that is characteristic of natural radioactivity rather than uranium resources, and certainly falls below the cut-off grade of any commercially operated uranium mines worldwide.

In fact, the frequency distribution reveals that 86% of samples measured have a concentration below the cut-off grade of 250 ppm, which was set-up by the government of Jordan for uranium resource estimation in Central Jordan [15].

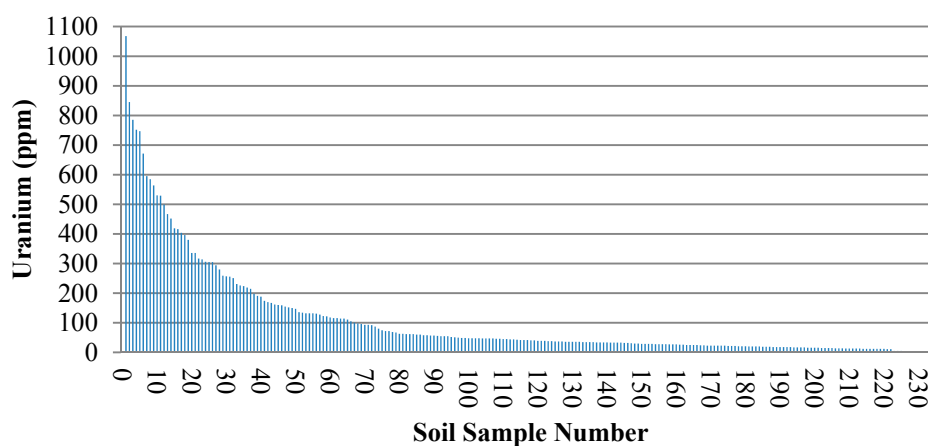


Figure 4. Uranium concentration in parts per million (ppm) in soil samples from Central Jordan using inductively coupled plasma mass spectrometry (ICP-MS).

Table 2. Uranium concentration in soil samples using ICP-MS, in parts per million (ppm).

Sample Number	Uranium (ppm)	Sample Number	Uranium (ppm)	Sample Number	Uranium (ppm)
1	1068	36	219	71	93
2	845	37	215	72	93
3	785	38	198	73	92
4	752	39	191	74	87
5	747	40	188	75	80
6	671	41	174	76	75
7	595	42	170	77	72
8	585	43	167	78	72
9	564	44	162	79	69
10	530	45	160	80	67
11	529	46	159	81	63
12	499	47	155	82	63
13	467	48	152	83	62
14	452	49	150	84	62
15	419	50	147	85	62
16	416	51	136	86	60
17	404	52	134	87	60
18	396	53	132	88	58
19	380	54	132	89	58
20	336	55	132	90	57
21	336	56	131	91	57
22	317	57	128	92	56
23	314	58	123	93	55
24	306	59	122	94	55
25	305	60	118	95	55
26	305	61	116	96	52
27	294	62	116	97	51
28	280	63	114	98	50
29	259	64	114	99	49
30	257	65	111	100	49
31	256	66	105	101	48
32	251	67	101	102	48
33	231	68	98	103	48
34	226	69	96	104	48
35	224	70	93	105-236	<48

Results were grouped into eight categories depending on the uranium content of the sample as illustrated in Figure 5, the lowest category is for uranium of less than 50 ppm of which 139 samples fallen into this category. The highest category is for uranium of more than 500 ppm of which only 11 samples fallen into this category. The rest of our measurements, 86 samples fell in the six categories in between with the majority of result closer to the lower concentration categories.

The US Nuclear Regulatory commission (NRC) has established a threshold of 500 ppm (0.05%) uranium concentration for ore grade to be deemed as source material under its regulations 10 CFR (Code of Federal Regulation) 40.4; NRC has carefully taken into account current technology and

economics in selecting this threshold [25]. Applying the NRC threshold, we found that only 5% of the samples have an adequate amount of uranium concentration to pass the threshold and maybe considered with potential for exploration.

Table 3. Measurements frequency distribution.

Uranium Concentration (ppm)	Number of Samples	Frequency (%)	Cumulative Frequency (%)
Less than 50	139	59%	59%
50–99	30	13%	72%
100–149	18	8%	79%
150–199	12	5%	84%
200–249	5	2%	86%
250–299	6	3%	89%
300–499	15	6%	95%
More than 500	11	5%	100%

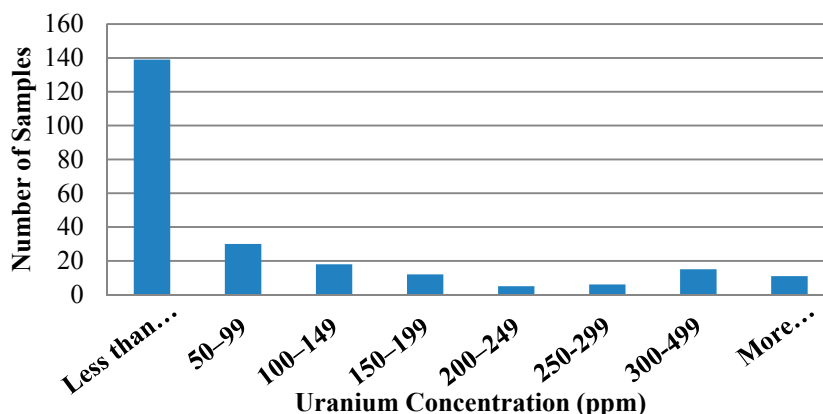


Figure 5. Uranium concentration in parts per million (ppm) vs. number of samples.

4. Conclusions

Countrywide Gamma airborne survey of Jordan revealed the presence of high radiation intensity areas, some associated with the presence of uranium mineralization. Two zones in central Jordan (Fertile zone and Khan Az-Zabib) were identified as having the highest concentration of uranium anomalies in the country.

The average uranium concentration of 236 soil samples from central Jordan was found to be 109 ppm. Farther analysis showed that more than 72% of the samples measured had a uranium content of less 100 ppm, an extremely low concentration that is characteristic of natural radioactivity rather than uranium resources.

Statistical analysis revealed that the results exhibit a very wide range of 1066 ppm for uranium concentration, with a median of 41 ppm. Results that are normally indicative of scattered mineralization rather than uniform concentration in large enough layers adequate for exploitation.

We can finally conclude, based on our findings, that the central Jordan area offers little or no uranium prospectively. Furthermore, that apart from perhaps by-product uranium arising from phosphate mining, Jordan does not seem to have any prospect for radioactive minerals.

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Conflicts of Interest

The authors declare no conflict of interest.

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