ENVIRONMENTAL GEOCHEMICAL AND RADIOMETRIC SURVEY IN THE VICINITY OF ABU SKHAIR URANIUM MINE, NAJAF, IRAQ

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ABSTRACT

A field survey to investigate the environmental impact of Abu Skhair uranium mine, closed for more than two decades, has been carried out. The survey included total count radiometric measurements, soil, stream sediments, rocks, water and plant sampling. The area covered by this survey is about 1 Km^2. All samples were analyzed for uranium, in addition to major ions in the water.

The results revealed higher intensity of total count radiation around the mine opening accompanied by higher uranium concentration in soil samples. Both rapidly decrease to normal background values away from the mine. Stream sediments showed lower uranium concentrations relative to soil. Limestone fragments, left over from previous mining works at the site, showed normal background values, except for one sample, which may represent part of the excavated radioactive horizon. Surface water and groundwater samples showed variable concentrations of uranium, most of which are within the permissible limits for drinking water. All groundwater samples are with high salinity, contain dissolved H_2S and not suitable for drinking. Plant samples (shrubs and small trees around the mine opening) showed variable uranium concentrations, generally normal, with higher concentrations in the roots. The results of this survey indicate minor and negligible environmental impact of Abu Skhair uranium mine on the surrounding area. However, in view of the high salinity of the H_2S-rich groundwater in the area, it is suggested that the present wells should be perfectly sealed and the water of the springs diverted to specific drainage system and pools where they can be treated.

مسوحات بيئية جيوكيميائية واشعاعية في موقع منجم اليورانيوم في أبو صخير، النجف، العراق

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المستخلص

أجريت مسوحات إشعاعية ونمذجة حقلية في موقع منجم اليوارنيوم في أبو صخير في محافظة النجف الأشرف لدراسة الآثار البيئية لوجود المنجم المغلق منذ ما يقرب من عشرين سنة في المنطقة. تناولت الأعمال الحقلية إجراء

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قياسات إشعاعية لحوالي 40 نقطة وجمع 30 عينة من التربة السطحية و9 عينات من الصخور الموجودة عند فوهة المنجم و4 عينات من النباتات المحيطة بالمنجم فضلا عن 18 عينة من المياه الجوفية والسطحية وجرى تحليل كافة العينات لعنصر اليورانيوم فضلا عن الأيونات الرئيسية في المياه.

بينت النتائج عدم وجود متغيرات كبيرة على الوضع البيئي للمنطقة المحيطة بالمنجم وعلى امتداد مساحة العمل الحالي والبالغة حوالي 1 كم^2. بينت تحليلات التربة وجود ارتفاع نسبي في تركيز اليورانيوم عند فوهة المنجم وذلك بسبب وجود بقايا من الصخور والركام الفتاتي من المواد التي استخرجت من باطن المنجم عند فتحه وكانت نتائج كافة العينات ضمن المعدلات الاعتيادية للتربة في العالم وهذا ما أكدته القياسات الإشعاعية المرافقة والتي بينت ارتفاعا نسبيا عند موقع المنجم لنفس السبب، تناقص بسرعة إلى المعدلات الطبيعية عند الابتعاد عن موقع المنجم. بينت تحليلات الصخور المتبقية عند فتحة المنجم أن تركيز اليورانيوم فيها ضمن المعدلات ألمقبولة والاعتيادية باستثناء عينة واحدة احتوت على تركيز أعلى من المعدل وهي بقايا من المواد المستخرجة في ذلك الوقت وأظهرت تحليلات النباتات قرب المنجم وجود تراكيز طبيعية في الأغصان مع ارتفاع نسبي في تركيز اليورانيوم في السيقان والجذور.

بينت تحليلات المياه الجوفية وجود تراكيز اعتيادية ومقبولة من اليورانيوم في معظم العينات وهذه المياه مصدرها الخزان الجوفي لتكوين الفرات الذي يحتوي على الصخور المشعة المستهدفة عند فتح المنجم فضلا عن المياه الجوفية الموجودة في خزان تكوين الدمام، وهذه المياه لا تصلح للشرب لاحتوائها على نسبة ملوحة عالية وهي محملة بغاز H_2S. بالمقارنة مع تحليلات سابقة للمياه الجوفية في أبو صخير ومواقع أخرى مشابهة على طول فالق هيت – أبو جير – شثاثة – الناصرية يتضح أن التراكيز الحالية لليورانيوم مقاربة للوضع العام المعروف سابقا وهي أن هذه المياه الجوفية حاملة لليورانيوم وبدرجات مختلفة فضلا عن الأملاح وغاز H_2S ولا تصلح للاستعمال البشري. لذا، يكون من الضروري العمل على إغلاق الآبار المائية التي تتغذى من خزان تكوين الفرات في المنطقة وتحويل مياه العيون من هذا المصدر المائي الجوفي الى مبازل خاصة حيث يمكن معالجتها.

INTRODUCTION

This work was conducted in April, 2012 to assess the possible uranium pollution in the area surrounding Abu Skhair uranium mine which has been closed for more than two decades. The mine is located in Al-Najaf Governorate with the following coordinates (Fig.1):

N 31.87083 E 44.43699.

The area is characterized by active groundwater discharge, presence of marshes and wet land, dense vegetation and rice agriculture. Scattered villages with small population are present in the area.

The mine, which was opened in the late eighties of the past century, consists of a 2 m diameter and 75 m deep vertical shaft, connected to about 100 m horizontal tunnel. It was officially closed, without achieving any routine production, in the late nineties of the past century. The rocks excavated to open the tunnel were partly used for pilot plant uranium extraction tests and partly for dumping the mine tunnel and shaft when closed. Some remains of the excavated rocks are scattered near the mine (Fig.2). At present the mine opening is secure by welded iron plates (Fig.3).

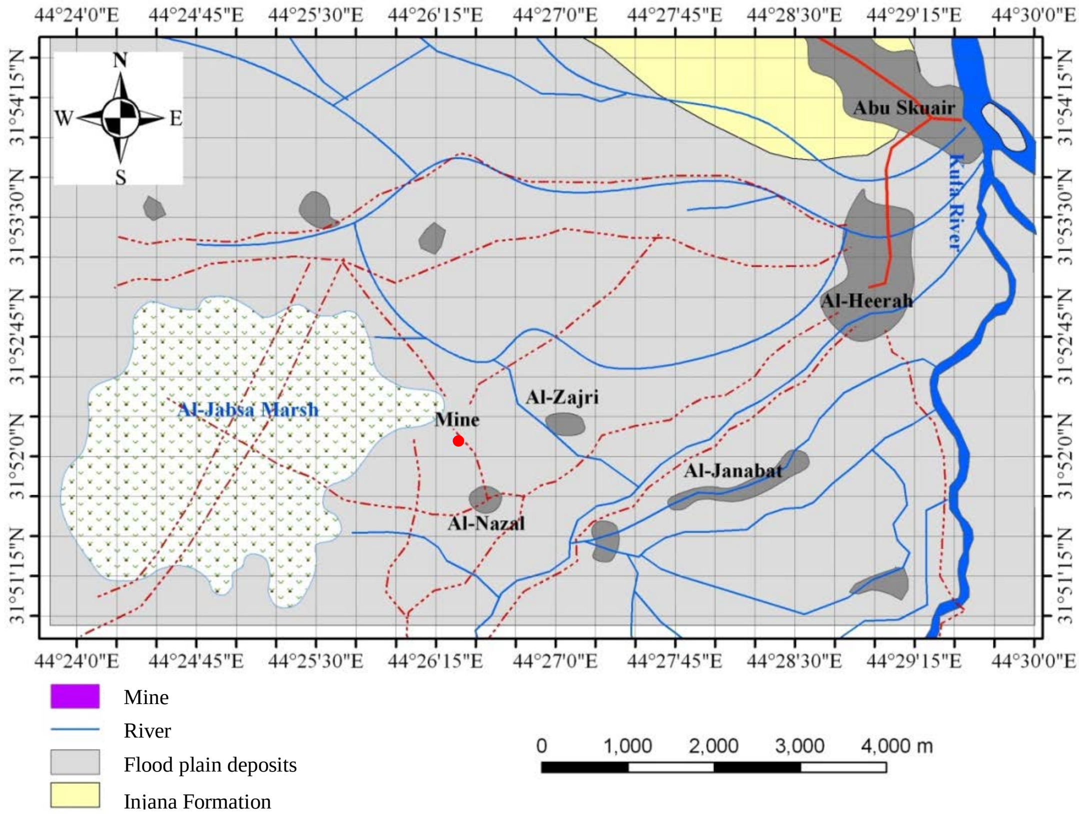

Fig.1: Location and geological map

Fig.2: Rock fragments at the mine site

Fig.3: Shaft opening

HISTORICAL REVIEW

Abu Skhair uranium deposit was discovered accidentally in (1977) when the gamma-log of a well, drilled in the Abu Skhair region for groundwater survey, showed anomalous radiation at 70 m depth within the carbonate rocks of the Euphrates Formation (Early Miocene) (Al-Atia and Mahdi, 2005). The anomaly was followed by subsurface exploration that lasted for about ten years where about 400 exploratory wells were drilled. The final stages witnessed mine design and development of uranium extraction process. The mine was opened in 1988 and closed after ten years without actually producing any uranium ore, except what was excavated while tunneling.

Abu Skhair uranium deposit is important for two main aspects; firstly, it is the only uranium deposit that undergone systematic exploration, assessment, extraction processing and underground mining. Secondly, it is a unique type of uranium deposits in the world standards (IAEA, 1974), being associated, syngenetically and epigenetically, with carbonate rocks, which is of scientific importance in uranium genesis. However, the deposit is far from being considered as an economic target, being a “lean ore” of no commercial value (Al-Atia and Mahdi, 2005).

SCOPE OF WORK

This is the first environmental impact assessment in the Abu Skhair uranium mine area that included various environmental elements of direct concern to human life. To cover the aims and targets of this survey, the work accomplished included the followings:

- **Field Work**

– Radiometric total count measurements in 41 stations along 500 m long radial profiles originating at the mine opening with 100 m intervals, using SPP2 scintillometer.

– Collecting 30 surface soil samples (0 – 30 cm depth), sieved in the field at 2 mm mesh and covered almost the same area as the radiometric survey with a sampling density of about 1 sample/200 m along 9 profiles.

– Collecting 9 rock samples scattered at the mine opening and believed to be remains of previous excavations.

– Collecting 18 water samples 7 are groundwater from wells drilled in the area, 3 from stagnant groundwater surface accumulations, 3 from irrigation discharge canals and 5 from freshwater irrigation canals. Water sampling was carried out in two periods; two weeks apart.

– Collecting 3 samples from stream and pool sediments.

– Collecting 4 plant samples from branches and roots of trees and shrubs surrounding the mine opening (Fig.4). All sampling and radiometric measurements stations were defined by GPS, and the pH of water was measured in the field using portable pH meter.

Fig.4: Trees and shrubs at the mine shaft

▪ **Laboratory Work**

All samples were analyzed for uranium, using fluorometric method, at Iraq Geological Survey laboratories using standard work procedures (Al-Janabi *et al*., 1992) and the accuracy of analyses was controlled by an international standard. Water samples of the first period were also analyzed for major ions and TDS.

▪ **Data Processing**

Isoradiation and isoconcentration maps were compiled using conventional software for the radiometric measurements and soil uranium concentration. The results of uranium content in soil were statistically treated to define background and anomaly threshold.

PREVIOUS WORK

- Al-Kazzaz and Hussain (1978); Hussain (1980) and Abdul Qadir (1982): Exploratory follow up of the radiometric anomaly detected in the water well at Abu Skhair area, included drilling, sampling and analysis of the radioactive horizons.
- Al-Atia *et al*. (1983): Drilling of 100 exploratory wells in an area of 55 Km^2 and (500 × 500) m grid, where four radioactive horizons were identified within the Euphrates Formation.
- Al-Atia *et al*. (1984): More detailed exploratory drilling of 118 wells in (250 × 250) m grid, where three potential areas were identified.
- Jassim (1984): Studied the geochemical distribution and association of some major and trace elements analysed in subsurface borehole sections of the Euphrates Formation at Abu Skhair area.
- Mahdi and Al-Hamad (1985 and 1986): The identified potential areas were further explored by 172 wells in (100 × 00) m grid.
- CETEM (1986): Design and development of underground mine at Abu Skhair deposit, in addition to constructing pilot plant for uranium extraction.
- Al-Atia and Mahdi (2005): Study of origin and environment of deposition of Abu Skhair uranium deposit, with emphasis on the role of weathering and oxidation processes in the uranium enrichment in the carbonate host rocks, as a unique scientific case.
- Mahdi *et al*. (2005): Study of geological and structural factors that contributed to the uranium enrichment in parts of the Euphrates Formation.
- Mahmud and Abd Allah (2006): Theoretical study to investigate the requirements to lower groundwater level at the Abu Skhair mine to facilitate extraction operations.
- Al-Bassam *et al*. (2006): Presented a new theory on the origin of the syngenetic uranium enrichment in the Euphrates Formation.
- Mahdi and Al-Timimi (2009): A review and evaluation of uranium contamination in groundwater aquifers of the Southern and Western Deserts, where several anomalous concentrations were outlined.

GEOLOGY OF THE DEPOSIT

Abu Skhair uranium mine is located in the western extremity of the Mesopotamia Plain. The surface is covered with several meters of flood plain Quaternary deposits. The area is within the activity of the Hit – Abu Jir – Shithatha – Nassiriya Fault Zone (Euphrates Fault Zone) which is a tectonic boundary separating the Stable Shelf (the Western Desert) from the Mesopotamia Plain (Fig.5). Many groundwater springs are aligned along this fault zone, some of which are bituminous with high salinity and H_2S concentrations.

The stratigraphic sequence consists of the following units (from older to younger):

- **Dammam Formation (Eocene)** Fossiliferous and recrystalized limestone (base not reached by drilling).
- **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.
- **Nfayil Formation (Middle Miocene)** Clayey limestone with minor gypsum showings, (20 – 27) m thick.
- **Injana Formation (Late Miocene)** Siltstone, claystone and minor limestone, 14 m thick.
- **Flood Plain Deposits (Quaternary)** Sand, silt and clay, friable deposits several meters thick.

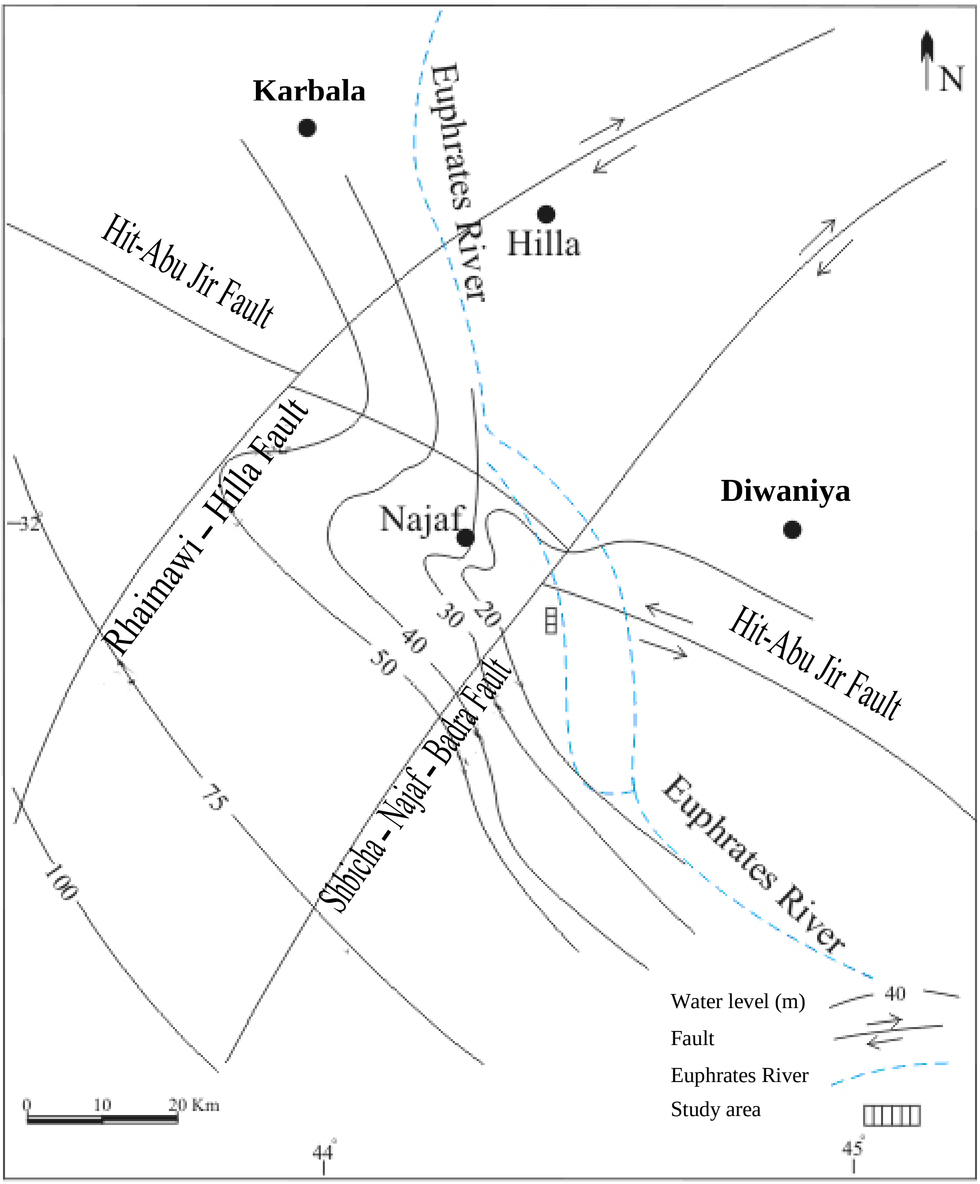

Fig.5: Structural and hydrogeological map of the Najaf area
(Al-Kadhimi *et al*., 1996 and Araim, 1990)

The area is characterized by active groundwater movements and the presence of several aquifers, which can be described as follows (top to bottom) (Araim, 1990):

- **Quaternary deposits aquifer** Unconfined aquifer, affected by recharge from irrigation water and groundwater springs. The water is located in sand lenses, in various horizons, but the main aquifer is about 7 m below surface. The water is sulfate-type with (2500 – 3000) mgm/l salinity.
- **Euphrates Formation aquifer** The aquifer is confined with chloride-type water and salinity of (3000 – 4500) mgm/l.
- **Dammam Formation aquifer** This is the main groundwater aquifer in the area. It is confined with high porosity. The water has a salinity of (2500 – 3500) mgm/l and rich in H_2S.

Four uranium-bearing horizons were identified in the upper parts of the Euphrates Formation within dolomitic limestone (Fig.6). The upper horizon is the highest in uranium concentration and range in thickness between (0.2 – 4.7) m (Al-Atia and Mahdi, 2005). This uranium-bearing horizon is stratigraphically controlled by the contact between the Euphrates and Ghar formations, which are interfingering in this area.

Uranium is present in two main phases (Mohamed, 1983, CETEM, 1989 and Al-Atia and Mahdi, 2005): uraninite (UO_2) as very fine grained disseminations in the carbonate rocks, and uranium associated with organic and clayey materials without specific mineral phase. The later is the dominant form of uranium in the deposit.

Uranium equilibrium is distorted in favor of (U_3O_8) on the expense of the radioactive series of radium (e U_3O_8) (Al-Atia and Mahdi, 2005). Two genetic types of mineralization were suggested by Al-Kazzaz and Mahdi (1991): **1)** syngenetic uranium enrichment in the Euphrates Formation carbonate rocks, which is a common phenomenon in this formation along the western side of the Euphrates River from Al-Qaim to Abu Skhair, and **2)** epigenetic uranium enrichment; only found in Abu Skhair deposit; with higher uranium concentrations.

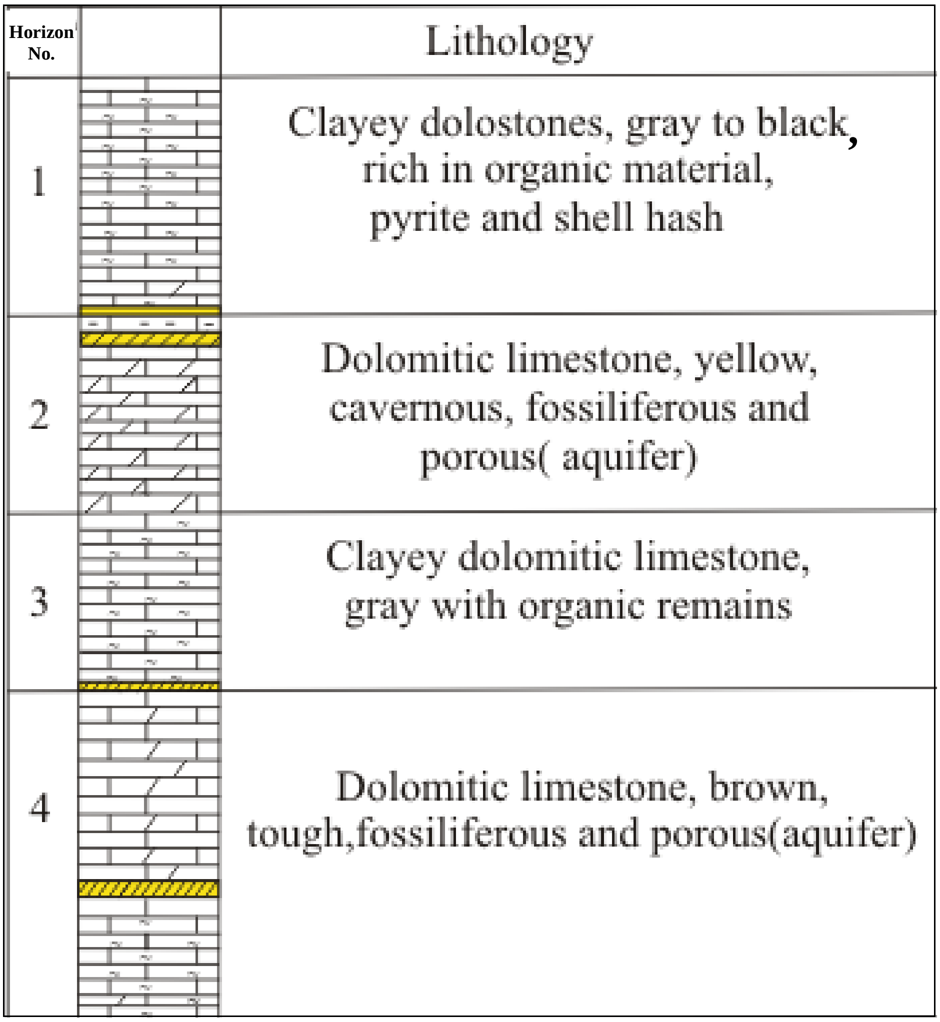

Fig.6: Lithostratigraphic column of the uraniferous part (yellow) of the Eupharates Formation (not to scale) (Al-Atia and Mahdi, 2005)

RESULTS

▪ Radiometric Survey

The area was covered, together with the rest of Iraq, by airborne radiometric survey (CGG, 1974). The total count isorad map of the area shown by that survey (Fig.7) shows that the mine is located in a relatively lower radiation zone of 900 cps located NW of a relatively higher radiation zone of 1150 cps. The present ground radiometric survey shows a single anomalous zone of 450 cps radiation located at the mine shaft (Fig.8) where remains of rock fragments are scattered. This anomaly rapidly diminishes away from the mine to 50 cps at 10 m distance and even lower to (25 – 30) cps in the rest of the 1 Km^2 area covered by this survey.

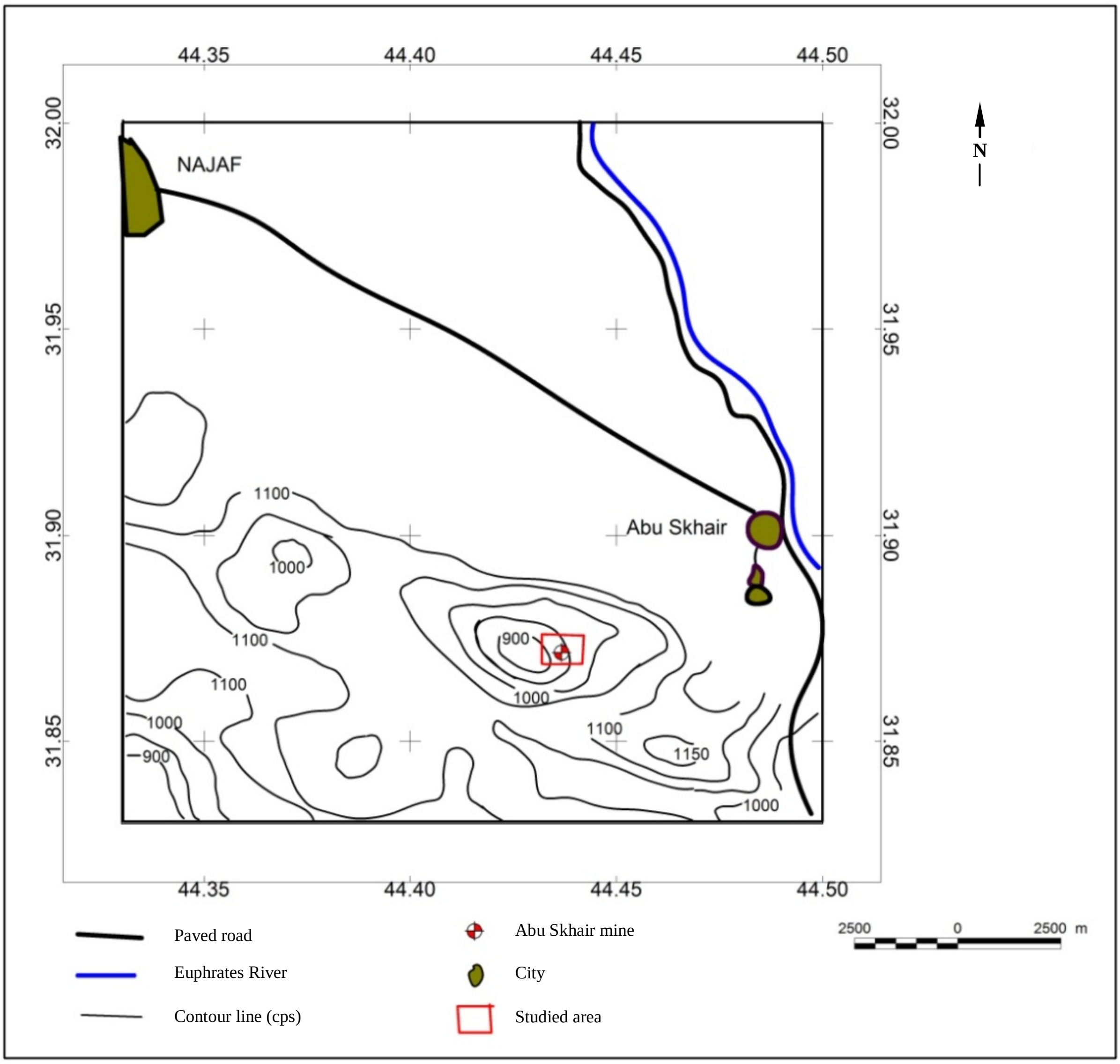

Fig.7: Total count isorad map of the airborne radiometric survey (CGG, 1974)

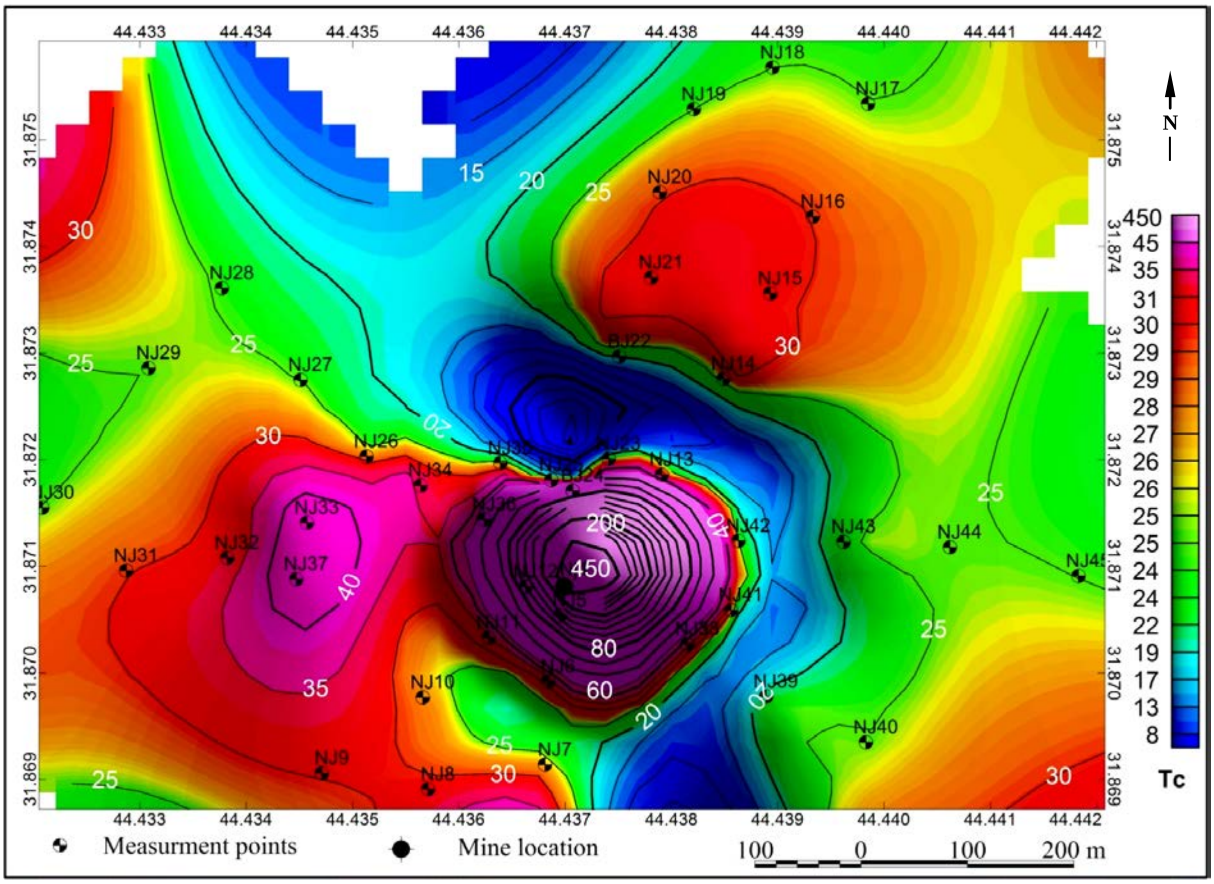

Fig.8: Total intensity isorad map (cps) (present survey)

▪ **Soil Geochemical Survey**

Uranium concentration in the analyzed soil samples ranged between (0.65 – 3.85) ppm, with a mean of 1.32 ppm (Table 1). The high values are concentrated near the mine shaft where the soil is contaminated with rock debris of the early excavations (Fig.9). The statistical processing of the data (Fig.10) shows normal geochemical distribution with single anomaly represented by sample Nj4 of 3.85 ppm U.

▪ **Rock Samples**

These are various carbonate rock fragments (limestones and dolostones) of various textures, which are remains of the excavated rocks when the mine was opened. Uranium concentration in these samples ranged between (1.9 – 4.2) ppm (Table 2) except for one sample Nj1 with 31 ppm U, which may be remains of the radioactive horizon. The majority of the samples are within world average for carbonate rocks of 2.5 ppm (Hawkes and Webb, 1962).

▪ **Stream and Pool Sediments**

The uranium concentrations in these samples are lower than that in soil samples, with a range of (0.6 – 0.8) ppm (Table 3).

▪ **Plant Samples**

Three samples from branches of small trees surrounding the mine shaft and one sample from the roots were analyzed for uranium. The results (Table 4) ranged between (0.035 – 0.10) ppm U in the branches and 0.853 ppm in the roots.

Table 1: Uranium concentration in soil samples

Ser. No.	Sample No.	Location		U (ppm)
		N	E	
1	NJ1	31.87076	44.45526	1.50
2	NJ2	31.87046	44.44381	1.05
3	NJ3	31.87124	44.43961	1.70
4	Nj4	31.87083	44.43699	3.85
5	NJ5	31.87054	44.43695	1.90
6	NJ6	31.86992	44.43684	1.35
7	NJ7	31.86914	44.43681	1.05
8	NJ8	31.86891	44.43571	1.10
9	NJ9	31.86906	44.43471	0.65
10	NJ11	31.87033	44.43628	0.70
11	NJ12	31.87081	44.43663	1.70
12	NJ13	31.87186	44.43791	1.40
13	NJ15	31.87356	44.43893	0.95
14	NJ17	31.87534	44.43985	0.85
15	NJ19	31.87529	44.43821	1.30
16	NJ21	31.87371	44.43781	0.80
17	NJ23	31.87201	44.43741	1.20
18	BJ24	31.87171	44.43707	1.60
19	NJ25	31.87181	44.43687	1.25
20	NJ27	31.87275	44.43451	0.65
21	NJ29	31.87286	44.43308	1.55
22	NJ31	31.87096	44.43287	1.10
23	NJ33	31.87141	44.43457	1.60
24	NJ35	31.87197	44.43639	0.90
25	NJ36	31.87144	44.43624	1.95
26	NJ37	31.87088	44.43447	1.20
27	NJ39	31.86978	44.43889	1.15
28	NJ41	31.87059	44.43856	0.85
29	NJ43	31.87123	44.43962	1.80
30	Nj45	31.87091	44.44183	0.80

Statistical processing

Sample No.	Min.	Max.	Mean	Median	Median abs. deviation	Standard deviation	25%-tile	75%-tile	Threshold (mean + 2 Std. Dev.)
30	0.65	3.85	1.32	1.2	0.35	0.6	0.9	1.6	2.5

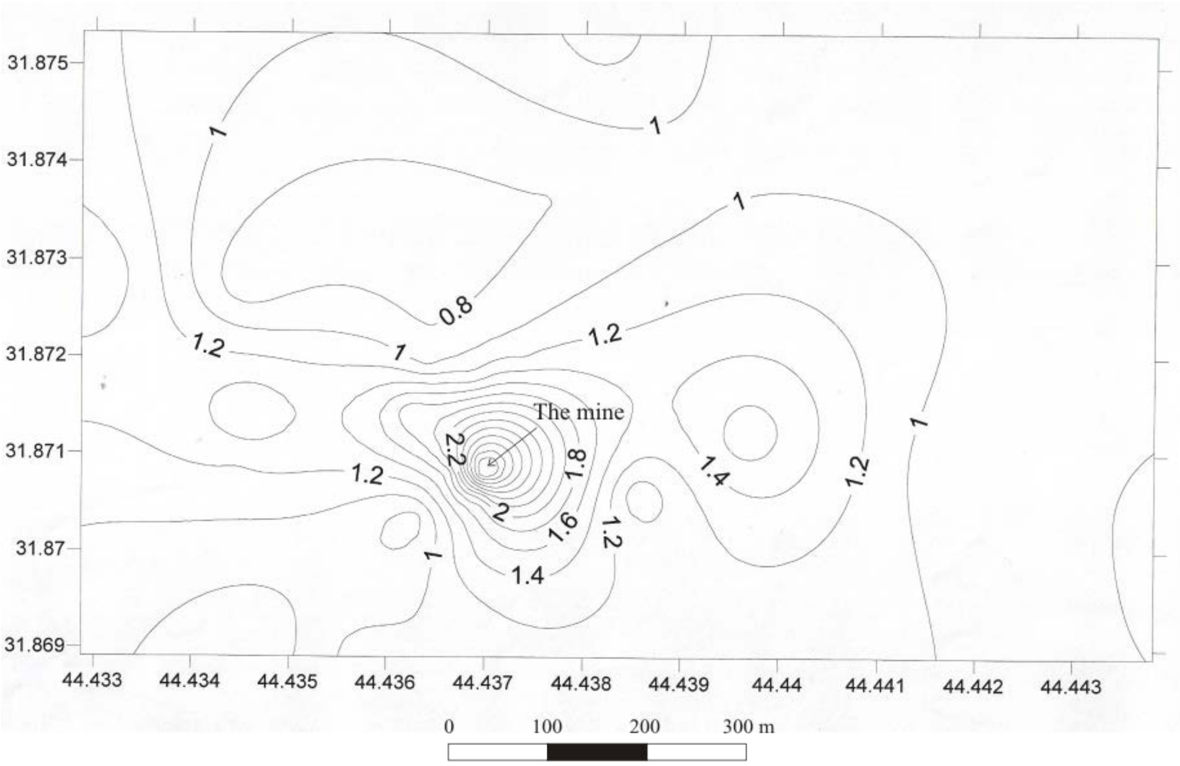

Fig.9: Soil uranium isoconcentration map (ppm) (present survey)

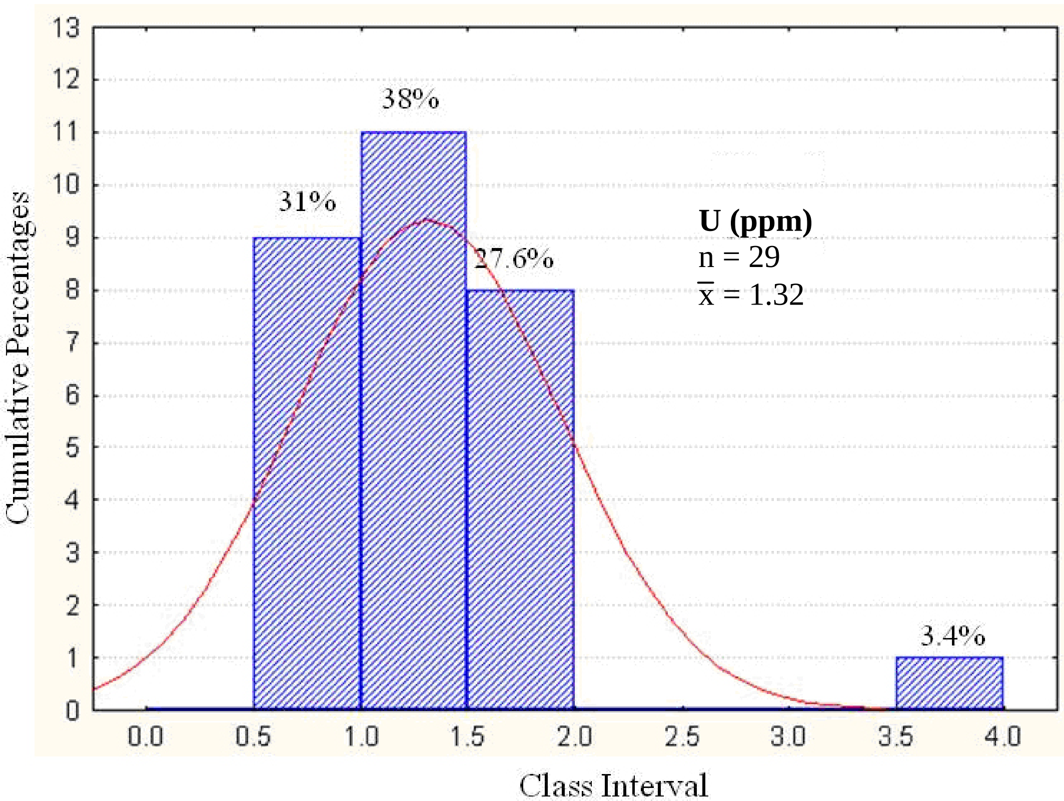

Fig.10: Soil uranium distribution histogram

Table 2: Uranium concentration in rock samples

Ser. No.	Sample No.	Location		U (ppm)
		N	E	
1	NjA	31.87083	44.43699	3.8
2	NjB	31.87083	44.43699	2.25
3	NjC	31.87083	44.43699	2.1
4	NjD	31.87083	44.43699	3.75
5	NjE	31.87083	44.43699	3.4
6	NjF	31.87083	44.43699	4.2
7	NjG	31.87083	44.43699	2.1
8	NjH	31.87083	44.43699	1.9
9	NjI	31.87083	44.43699	31.0

Table 3: Uranium concentration in stream and pool sediments

Ser. No.	Sample No.	Location		U (ppm)
		N	E	
1	NJS1	31.87226	44.43751	0.6
2	NJS2	31.87136	44.43231	0.75
3	NJS3	31.87096	44.43285	0.8

Table 4: Uranium concentration in plants

Sample No.	Type	Weight dry (gm)	Weight ash (gm)	U in plants (ppm)	U in ash (ppm)
1	branches	110	7	0.10	1.60
2	branches	118	4	0.035	1.05
3	branches	101	5	0.037	0.75
4	roots	135	18	0.853	6.40

- **Water samples**

All groundwater samples are with H_2S and high salinity (TDS 3352 – 5276) mg/l and slightly acidic (pH 6.4 – 6.5) as determined in the field, increased to (7.2 – 7.5) in the laboratory after escape of H_2S gas (Table 5). Samples (1G, 2G and 4G) are chloride – sulfate type with Na as a dominant cation, whereas sample 3G is sulfate – chloride type with Na as a dominant cation (Fig.11). The similarity in composition of samples 1G and 2G may indicate the same aquifer. Nitrate high concentrations in samples 1G and 4G suggest contamination with irrigation water rich in nitrogen fertilizers.

Uranium concentrations in the first batch of samples (Table 5 and Fig.12) are variable and ranged between (0.006 – 0.047) mg/l. Compared with the permissible limits of uranium in drinking water of 0.015 mg/l and 0.02 mg/l (WHO, 2011 and USEPA, 2003 respectively), samples (3G and 4G) are not suitable for drinking.

The results of the second batch of samples (Table 6) included groundwater, irrigation discharge water and fresh surface irrigation water. Uranium concentration was the highest in the groundwater (average 0.0055 mg/l), followed by irrigation discharge water (average 0.0025 mg/l) and the lowest concentrations were recorded in the fresh irrigation water (average 0.0012 mg/l).

Table 5: Hydrochemical composition of water samples (1st period samples) (in mg/l except EC in µs/cm)

Water Sample	Lat.	Long.	pH	Na	K	Mg	Ca	Cl	SO_4	HCO_3	CO_3	NO_3	U	TDS	EC
1S Surface	31.86817	44.45850	7.50	477.71	6.65	213.72	356.71	887.50	1220.64	317.20	19.20	3.72	0.016	3352	4788
1G Ground	31.86861	44.43984	7.15	693.68	41.45	217.61	368.74	1526.50	1036.80	122.00	24.00	8.06	0.006	3986	4850
2G Ground	31.86828	44.43979	7.50	693.68	41.45	217.61	368.74	1526.50	1031.04	158.60	19.20	0.00	0.0026	4048	4510
3G Ground	31.86844	44.43648	7.50	854.71	18.38	294.39	496.99	1278.00	2196.00	222.04	26.40	0.00	0.030	5276	7537
4G Ground	31.86836	44.44071	7.50	760.15	21.51	216.27	360.72	1420.00	1228.80	170.80	24.00	12.40	0.047	4164	5060
5G Ground	31.87065	44.43945	7.50	691.38	21.51	217.49	364.73	1491.00	1035.84	134.20	24.00	8.06	0.014	3984	4810

Note: samples 1G and 2G were collected directly from wells, whereas, samples 3G, 4G and 5G were collected from groundwater accumulations in stagnant ponds or pools.

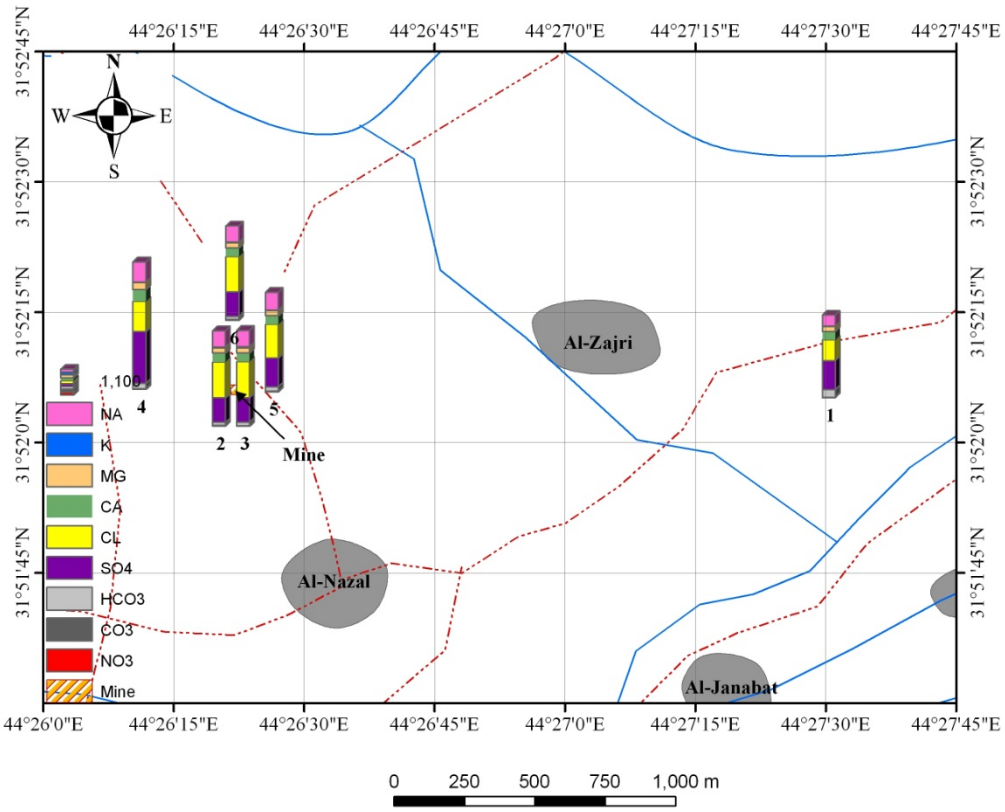

Fig.11: Groundwater hydrochemistry (1st sampling period, present survey)

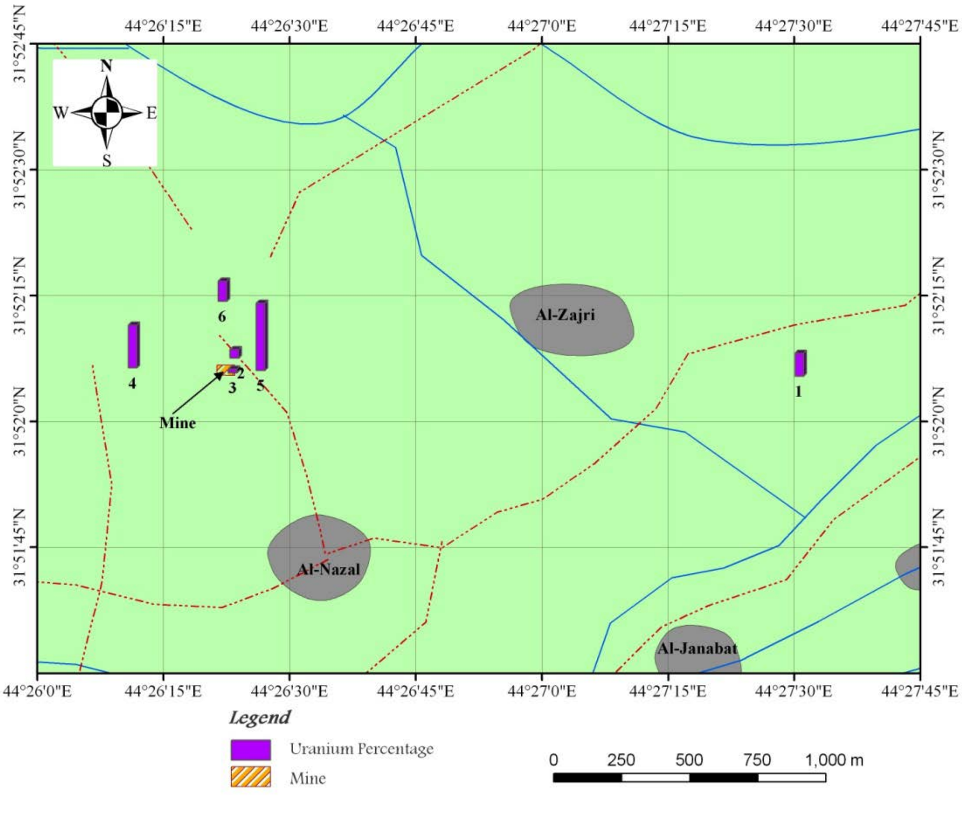

Fig.12: Uranium content in groundwater (1st sampling period, present survey)

Table 6: Uranium concentration in water samples (2^{nd} period samples) (in mg/l)

Groundwater			Discharge canals			Surface irrigation water		
Sample No.	**Coordinates WGS.84**	**U**	**Sample No.**	**Coordinates**	**U**	**Sample No.**	**Coordinates**	**U**
1	44.436477 31.868415	0.015	1	44.436477 31.86837	0.0014	1	44.440378 31.870164	0.0016
2	44.439477 31.870584	0.0004	2	44.442015 31.868764	0.0035	2	44.440456 31.866068	0.0001
3	44.439841 31.868168	0.0040				3	44.439839 31.866697	0.0038
4	44.440355 31.868711	0.0016				4	44.447773 31.867625	0.0001
5	44.440355 31.86872	0.0065				5	44.448350 31.858344	0.0004
Mean 0.0055			**Mean** 0.0025			**Mean** 0.0012		

DISCUSSION

Uranium is a radioactive element; its hypothetical half life is estimated by about 4.468 billion years (for U^{238}). Its biological half time (average time for the human body to get rid of half the uranium intake) is estimated by about 15 days (Georgia State University, 2012).

Uranium salts are biologically toxic and influence the kidney, brain, liver and heart (ATSDR, 1999). However, they are considered less toxic than many other heavy metals such as lead, arsenic and mercury. Most of the uranium intake to the human body through the digestive system is get ridden off in the urine, but a small amount may be retained in the kidney (Craft *et al*., 2004). The WHO have set, an upper limit for soluble uranium salts (tolerated intake) for the human body by 0.5 µg/kg of body weight (about 35 µg/70 kg weight of an adult) (IAEA, 2010).

In the past decades, uranium became one of the main environmental concerns due to its increasing use in power generation and as depleted uranium in weapons. Uranium mining areas represent highly potential pollution risk especially for soil and water. The use of uranium-bearing phosphate fertilizers is another pollution hazard.

Abu Skhair uranium mine is the first and only mine of its kind in Iraq. Being located in a populated and agricultural area, characterized by very active groundwater discharge, it represents a potential pollution hazard, despite the fact that the deposit is a “lean ore”.

Most of the springs along the Euphrates River are characterized by higher than “normal” uranium concentrations (Al-Atia and Mahdi, 2005 and Mahdi and Al-Timimi, 2009). Groundwater discharging from the Euphrates Formation aquifer in particular is relatively high in uranium. The Euphrates Formation is uraniferous in several horizons in its upper part and is one of the main groundwater aquifers in this region. Uranium is not so mobile as U^{4+}, but once it is oxidized to U^{6+}, it becomes highly mobile and can be transported in the aqueous system as uranyl ion (Livinson, 1980).

Analysis of groundwater in Abu Skhair area, before opening the mine, showed up to 0.25 mg/l U (Mahdi and Al-Timimi, 2009). In the present survey, the highest concentration was (0.047 and 0.030) mg/l (samples 4G and 3G respectively). Both samples are groundwater accumulations in surface ponds, subject to evaporation and subsequent increased U concentration. Eight of the ten groundwater samples collected contained less than 0.015 mg/l uranium which is within the acceptable limits for drinking water (WHO, 2011). Moreover, surface water samples contained generally lower concentrations of uranium relative to groundwater samples.

Compared with uranium concentrations in groundwater elsewhere in the world, an average of 0.445 mg/l has been reported in Sweden (Skeppstrom and Olofsson, 2007) and a range of (0.003 – 1.443) mg/l in India (Babu *et al*., 2008). In uranium mining areas uranium concentrations in groundwater may be much higher.

The above results suggest that the Abu Skhair uranium mine has negligible impact on the ground and surface water systems in the area; as far as uranium pollution is concerned. On the otherhand, the groundwater is heavily polluting the area with salts and H_2S gas, and these waters are not suitable for drinking.

The soil survey revealed that about 30% of the samples contained less than 1 ppm U and about 65% contained (1 – 2) ppm U. Only one sample collected from the soil at the mine shaft, probably contaminated with rock debris, contained 3.85 ppm U. All these values are considered normal background concentrations for average soil (Hawkes and Webb, 1962).

Considering sample Nj4 as an anomalous is strictly statistical, relative to the rest of the samples, since the obtained concentration is well within the normal values reported for uncontaminated soil of the world (Hawkes and Webb, 1962) and was reported to vary between (0.3 – 11.7) ppm with an average of about 2 ppm (UNSCEAR, 1993). The limited time of mining at Abu Skhair and the low grade of the deposit helped in keeping the soil of the area clean from pollution. The same can be said for stream and pool sediments in the area, which showed less than 1 ppm U.

Trees and shrubs around the mine shaft were sampled (branches and roots) to look for uranium enrichment caused by intake from groundwater discharge in the site from unsealed wells. The results show less than 1 ppm U in all samples; small branches contained 0.1 ppm U or lower concentrations, whereas the roots contained 0.853 ppm U; a natural phenomena noticed elsewhere (UNSCEAR, 1993).

The results of uranium concentration in Abu Skhair plants are comparable to many results reported elsewhere in the world and averaged about 0.06 ppm (UNSCEAR, 1993). Uranium content of plants depends on various factors, among which are the type of plant, part of plant analyzed and type of soil. Values up to 200 ppm U were reported in the roots of trees planted in uranium mining areas (Henson, 1974).

The Abu Skhair Mine (shaft and tunnel) was closed by dumping all the rocks excavated when the mine was opened inside the tunnel and shaft. The surface was cleaned from almost all rock fragments from the early excavations, but a few remained scattered around the mine. The analysis shows that most of this rock debris is non-radioactive. One sample only contained relatively higher value and can be part of the mined radioactive horizon.

The radiometric survey clearly indicates normal radioactive background in the area of (25 – 30) cps with a relatively higher total count intensity restricted to the mine shaft location, mostly caused by the rock debris remains.

CONCLUSIONS

- Abu Skhair closed uranium mine has no or negligible environmental effect on the surrounding area.
- Uranium concentrations in groundwater are mostly within WHO drinking water permissible limits of 0.015 mg/l with a few exceptions of higher values caused by uranium mobilization from the source rocks within the Euphrates Formation aquifer.
- Soil, stream and pool sediments contained uranium concentrations within the world average for uncontaminated soil.
- Plants at the mine location showed normal uranium concentrations, comparable to reported values elsewhere in the world with a tendency of having higher concentrations in the roots.
- Most of the rock debris around the mine shaft are non- uraniferous, with normal background concentrations for carbonate rocks. One sample contained relatively higher uranium concentration and believed to be remains of the excavated radioactive horizon.
- The total count radiometric survey complemented the geochemical results, where all measurements were within natural background for the Mesopotamia Plain, except the mine shaft location, where higher radioactivity were noticed and can be attributed to the remaining rock debris.
- The data and information obtained in the present survey are useful as a reference for comparison in future environmental studies in Abu Skhair.
- It is recommended that all wells in the area of Abu Skhair should be sealed and any natural groundwater discharge should be collected in special pools, insulated from the natural environment, where the water can be treated.

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