GEOCHEMICAL AND MINERALOGICAL ANALYSIS OF RECENT FLOOD PLAIN AND RIVER DEPOSITS IN BAGHDAD, IRAQ

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ABSTRACT

Baghdad City, the capital of Iraq, is characterized by high population density and great variation in land use. The Tigris River divides the city into two sides: Rasafa (east) and Karkh (west). The army canal is an artificial water course in the Rasafa side. Baghdad is covered by Quaternary flood plain deposits of variable nature in which silt is the predominant fraction.

Mineralogical analysis of the samples collected from the recent surface, subsurface and river deposits show wide range of heavy and clay minerals, which indicate the complexity of the depositional processes and the numerous genetic factors affecting their properties in addition to significant human influence on these sediments. The geochemical distribution of trace elements in the surface sediments of the study area show positive anomalous concentration of Pb, Zn, Co, Cu, and Sr, and negative anomalous concentration of Mn, Cr, and Ni which were observed in both sides of the city. Rasafa side is more complex due to the greater population density and dispersion of various human activities (agricultural, municipal and industrial). Comparing the activity concentrations of uranium of the studied samples, with those of the world average soils, it is clear that the Baghdad City is free from the radioactive pollution and uranium concentrations were within the normal limits.

Statistical factor analysis of the sediments properties reflect the main factors controlling the mineralogy, texture and geochemistry of the studied sediments. These are mainly the parent rocks of the source area, (including sedimentary, basic igneous and metamorphic rocks in the north and northeastern parts of the country), dynamic energy of the river system as well as human activities. The mineralogy, texture and trace elements concentrations of the Tigris River sediments are comparable to those of the surrounding flood plain deposits in Baghdad which reflects the genetic relation of the two sampling media.

تحليل جيوكيميائي ومعدني للرواسب الحديثة للسهل الفيضي ورواسب الأنـهار في بغداد، العراق

سوسن مجيد علي و خلدون صبحي البصام و بلسم سالم الطواش

المستخلص

تتميز مدينة بغداد، عاصمة العراق بالكثافة السكانية العالية والتغير الكبير في استخدامات الأرض. يقسم نهر دجلة المدينة الى قسمين، الرصافة (في الشرق) والكرخ (في الغرب) في حين تشكل قناة الجيش ممرا مائيا اصطناعيا في جانب الرصافة. تغطي بغداد رواسب السهل الفيضي للعصر الرباعي مختلفة الأنواع والتي يسود فيها الغرين.

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تبين التحليلات المعدنية للعينات التي تم جمعها من رواسب السطح وتحت السطح والأنهار مدى واسع من أنواع المعادن الثقيلة والمعادن الطينية، التي تشير الى تعقيد وتعدد العمليات الترسيبية المؤثرة على هذه الرواسب فضلا عن تأثير العوامل البشرية عليها.

يشير التوزيع الجيوكيميائي للعناصر النزرة في الرواسب السطحية لمنطقة الدراسة الى وجود شواذ موجبة للعناصر Pb، Zn، Co، Cu و Sr وشواذ سالبة للعناصر Mn، Cr و Ni لوحظت في جانبي المدينة مع توزيع أكثر تعقيدا في جانب الرصافة كونه الأكثر كثافة في السكان والأكثر تنوعا في أنماط النشاط البشري (الزراعي والبلدي والصناعي). بمقارنة شدة التركيز الإشعاعي لليورانيوم في عينات الدراسة مع تلك المقدرة للتربة في العالم يتضح أن مدينة بغداد خالية من التلوث الإشعاعي وإن تراكيز اليورانيوم تقع ضمن المحددات الطبيعية.

يعكس التحليل الإحصائي العاملي العوامل الحاكمة الرئيسية في معدنية ونسجة وجيوكيميائية الرواسب التي تمت دراستها وهي الصخور المصدرية (الرسوبية والنارية القاعدية والمتحولة) وطاقة ترسيب الرواسب النهرية والأنشطة البشرية. ويلاحظ بمقارنة الخصائص المعدنية والجيوكيميائية بين رواسب نهر دجلة ورواسب السهل الفيضي المحيطة به والتي تعكس العلاقة المنشأية بينهما.

INTRODUCTION

Baghdad is the largest and most heavily populated city in Iraq with an area of about 900 Km^2, whereas the total area of Baghdad Governorate reaches 5159 Km^2, the population was estimated by about 7 millions in 2007 (Nussaif and Qamar, 2007). Different land uses can be noticed from Baghdad maps, specifically those prepared by Baghdad Environment Directorate (2010) and Baghdad Myority statistics (2011). According to these statistics, the percentages of the urbanized, agricultural and industrial areas from the total area are 72.69%, 25% and 2.31% respectively.

The study area is restricted to latitudes (33° 10' – 33° 29') N and longitudes (44° 09' – 44° 33') E with an area of about 1350 Km^2 approximately (Fig.1). The Tigris River passes and divides Baghdad into two parts, Karkh and Rasafa, with length of 53 Km approximately. Army Canal, which is an artificial water course, starts from the left bank of the Tigris River with a total length of about 24 Km (Al-Hiti, 1985).

Baghdad city lies within the Arabian Platform of the Arabian Plate, within the Mesopotamia Foredeep (Fouad and Sissakian, 2011). The study area represents, as a whole, a flood plain which consists of Quaternary deposits. Pleistocene and Holocene deposits may exceed 250 m in thickness in many places (Jassim and Goff, 2006). The Mesopotamian Plain is covered mainly by Holocene deposits, which represent complex and alternating sequence of clay, silt sand and gravel. The deposits were derived mainly from Zagros – Taurus mountains, transported by the Tigris and Euphrates rivers and then deposited in a river flood plain sequence due to the river flow pattern (Buday, 1980). The flood plain deposits in Baghdad have been transported from the upper reaches of the Tigris and Euphrates river basins. They are non homogenous, characterized by great lateral and vertical variations in grain size and other soil properties. The upper part of these sediments represents the surface “soil” in Baghdad.

The main goal of the present work is to study the texture, mineral constituents and the geochemical distribution patterns of trace element in surface, subsurface and river sediments. Radioactivity of some selected samples were also measured to shed light on the nature of radioactivite pollution in the area. Interrelationships among the selected geochemical variables were statistically processed and analysed.

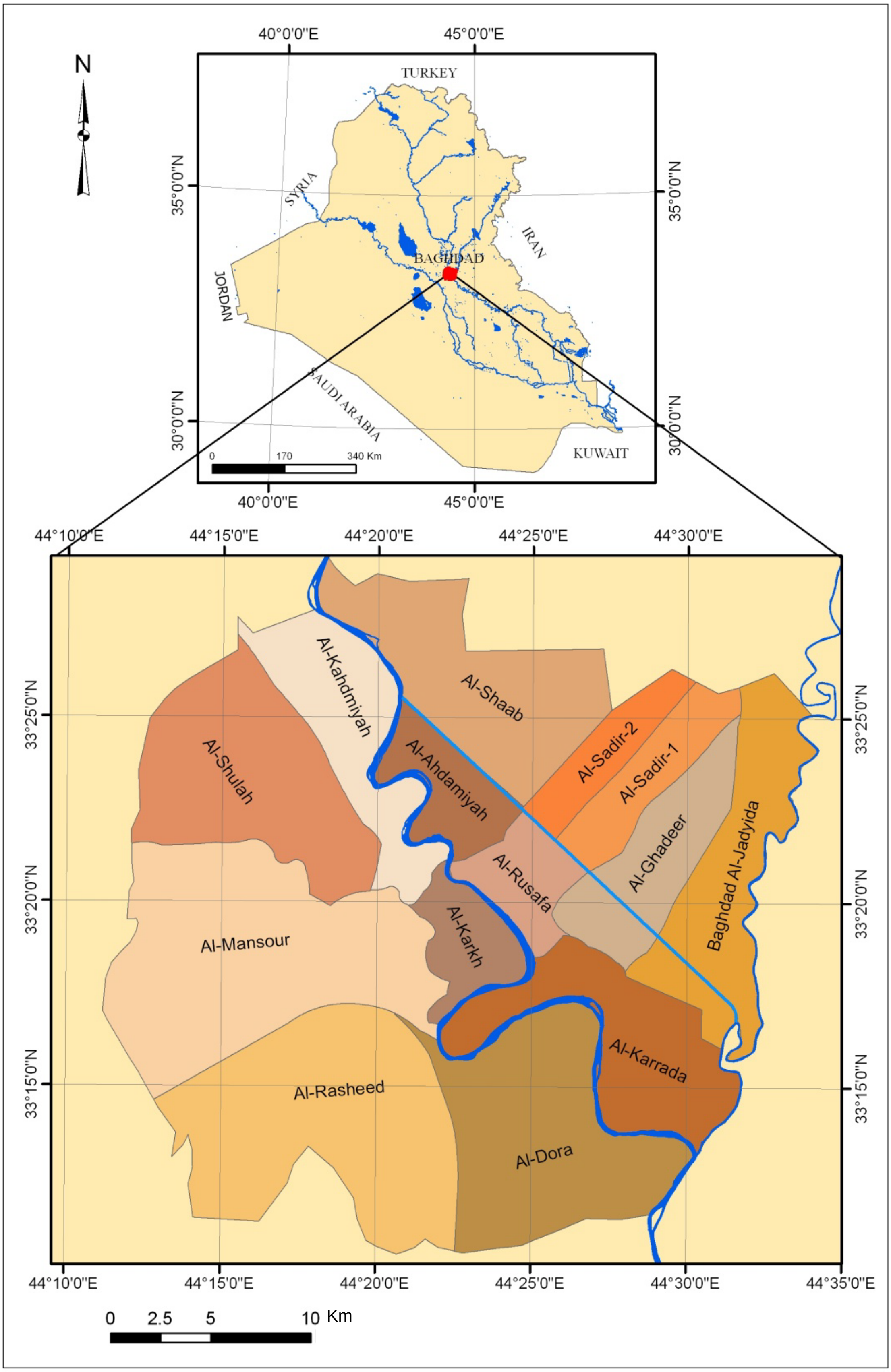

Fig.1: Location of the study area

SAMPLING AND ANALYSES

Field work and sampling were carried out in 2010. Sixteen surface sediments samples were collected from the study area, and six subsurface sediments samples were collected during the drilling of Al-Ammary well (12 m depth), at two meters interval with one surface sample at depth 0.5 m (S4). Four river sediment samples were collected from the Tigris River and one sample from Army Canal, samples are taken three to four meters away from the bank of the river at depth of (20 – 30) cm, while only one sample was taken from the middle part of the Tigris River (RS2) (Fig.2).Two kilograms of surface sediments were sampled at depth of 20 to 30 cm and then placed in a storage bag, one kilogram for measuring the radioactivity of thirteen of these samples and the other kilogram for the determination of mineralogy, chemical characteristics and grain size of twenty eight samples. Various analytical techniques were employed to treat the geochemistry of all samples. These methods can be described in the following paragraphs:

- pH, Organic Matter (OM), Cation Exchange Capacity (CEC) and trace elements were determined at the laboratories of Iraq Geological Survey following Al-Janabi *et al*. (1992) procedures.
- pH of sediments solution was measured by pH-meter, organic materials were detected by titration method, cation exchange capacity was determined by methylene blue method and trace elements were measured using Atomic Absorption Spectrophotometer (AAS 240 FS Varian).
- Heavy minerals were determined under the microscope after Bromoform separation according to Carver (1971). Heavy minerals were identified using point counting method of (Fleet, 1926, in Carver, 1971).
- Grain size was determined using pipette method of Folk (1974) and Carver (1971).
- Clay minerals were identified at the laboratories of the Ministry of Science and Technology. Shimadzu X-ray 6000 was used for this purpose under the following specification: Target Cu, wave length: 1.5406Å, voltage 40.0 (KV) and speed 5deg/min. Three slides, normal, heated to 550 °C and ethylene glycolated for each sample were prepared following the method of Grim (1968) and Carver (1971).
- Radioactivity of some samples for U^{238}, Th^{232}, K^{40} and Cs^{137} were carried out at the Ministry of Science and Technology laboratory in which one kilogram of soil sample was dried at a temperature of 100 °C for 24 hours and then sieved through one millimeter mesh size sieve. Gamma spectrometric analysis was implemented for the measurement of the radioactivity of the radionuclides of the samples. Gamma spectroscopic analysis system composed of high purity germanium detector (HpGe) with an efficiency of 40% and resolution of 2.0 Kev attached to channel computer analyzer and computer with software Genie, 2000.

RESULTS

▪ Grain Size Analysis

Mean values of the size fraction of the surface sediments samples categories (agricultural, industrial and urbanized) were calculated and then mean of the total sixteen surface samples was calculated (Table 1). Results show that mean values of silt and clay fraction of subsurface samples are higher than those of surface samples and river sediment, Concerning subsurface samples, clay fraction show the lowest value at the depth of 4 m and the highest value at the depth of 12 m, (Fig.3). River sediments have the highest sand fraction values at the middle of the river (RS2) as compared with its banks. All results are plotted on the ternary diagram of Folk (1974) (Fig.4). As appear from this figure, sandy silt sediments type is dominant in surface sediments samples, whereas the subsurface sediments are characterized by silty type.

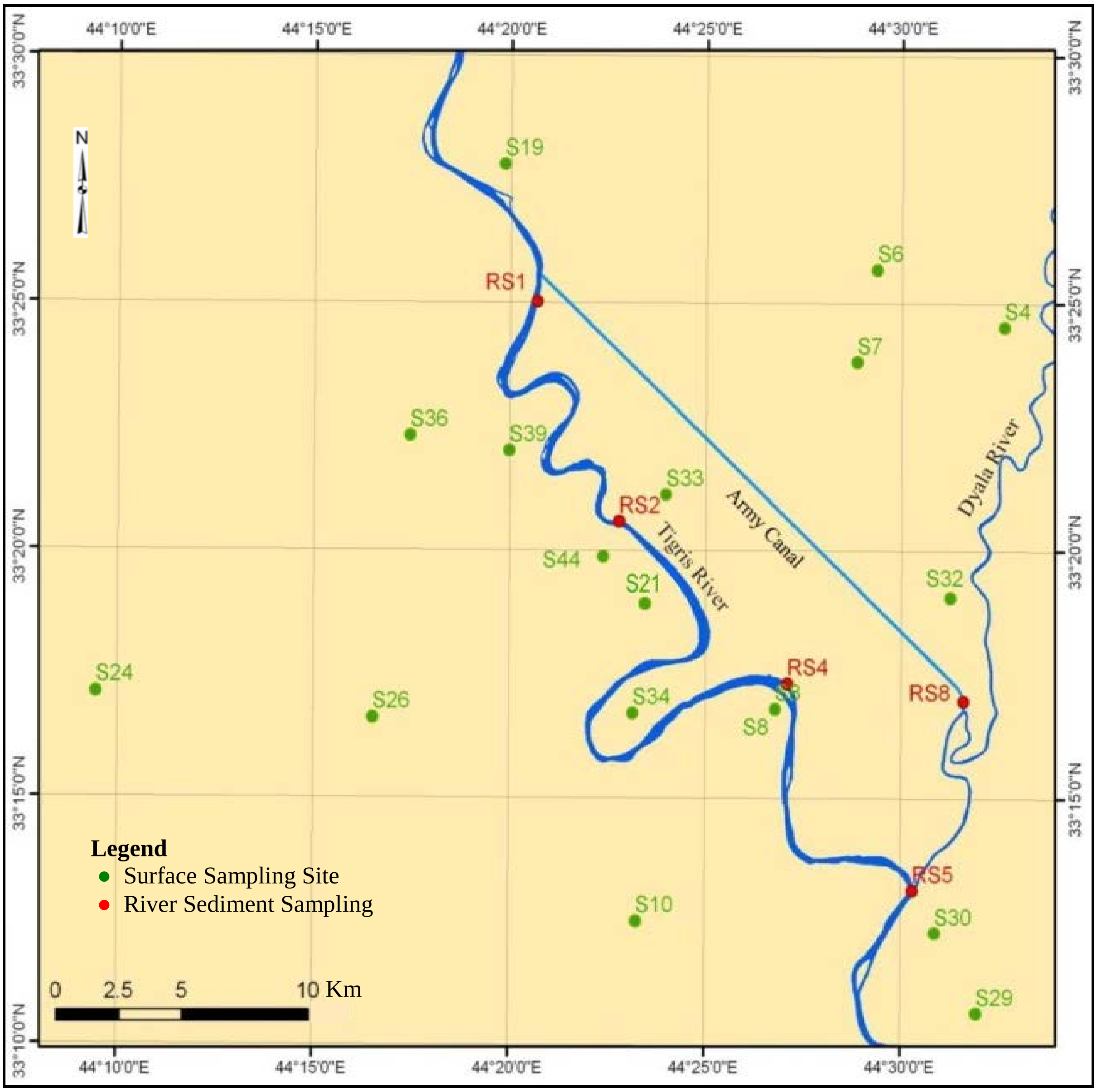

Fig.2: Sampling location map

Table 1: Grain size analysis of the studied samples

Sample No.	Location	Type of land use	Grain size analysis (%)			Textural type (Folk, 1974)
	Surface sediments		**sand**	**silt**	**clay**	
S19	Fahhama	Agricultural	6.73	67.2	26.07	silt
S24	Abu Graib	Agricultural	8.07	53.13	38.8	mud
S29	Wardiyah	Agricultural	13.73	48.60	37.67	sandy silt
Mean			9.5	56.3	34.2	
S6	Hameediya	Industrial	4.73	63.67	31.60	Silt
S8	Dora refinery	Industrial	2.60	54.20	43.20	mud
S30	Tuwaitha	Industrial	2.53	54.27	43.20	mud
S32	Al-Ameen	Industrial	26.13	60.74	12.13	sand silt
S33	Sheikh Omer	Industrial	61.34	27.53	11.13	silty sand
S39	Bagh. factory Kadhimiyah	Industrial	29.73	48.53	21.74	sandy silt
Mean			21.2	51.5	27.2	
S7	Sadar city	urbanized	81.74	12.73	5.53	silty sand
S10	Abu Dshair	urbanized	25.67	47.8	26.53	sandy mud
S26	Al-Furat	urbanized	12.47	69.40	18.13	sandy silt
S21	Al-Rasheed hotel	urbanized	60.0	31.27	8.73	silty sand
S34	Ministry of Science & Technology	urbanized	70.0	25.67	4.33	
S36	Shuala	urbanized	23.60	62.0	15.40	sandy silt
S44	Sheikh Marouf	urbanized	27.60	57.0	15.40	sandy silt
Mean			43.0	43.7	13.3	
Total Mean			28.54	48.98	22.41	
0.5 m	**Subsurface sediments** Al-Ammary site (S4)		9.60	61.0	29.4	silt
2 m			11.53	62.8	25.67	sandy silt
4 m			16.60	68.67	14.73	sandy silt
6 m			15.73	50.87	33.40	sandy mud
8 m			6.13	63.20	30.67	silt
10 m			6.60	64.67	28.73	silt
12 m			6.27	58.33	35.40	mud
Mean			10.4	61.4	28.3	
River sediments						
RS1	East Tigris Water Project		3.93	60.87	35.20	mud
RS2	Medicine City		92.87	5.13	2.0	sand
RS4	South Baghdad Electrical Power Plant		5.20	75.0	19.8	silt
RS5	Zaafarania area		19.73	56.14	24.13	sandy silt
RS8	Army Canal		11.13	55.54	33.33	sandy mud
Mean			26.6	50.5	22.9	

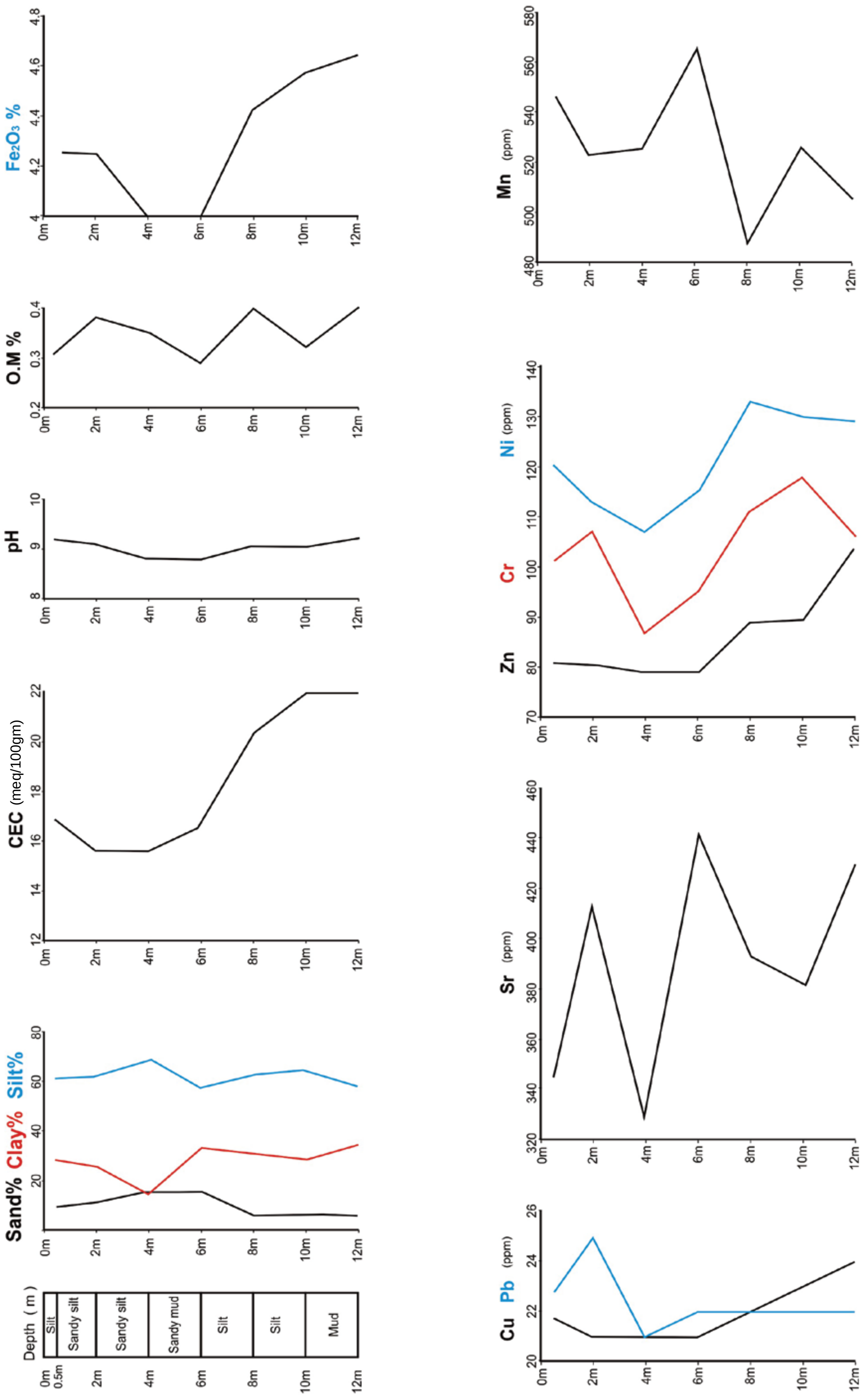

Fig.3: Vertical distribution of grain size, mineralogy and geochemical parameters of subsurface soil samples (Al-Ammary site S4)

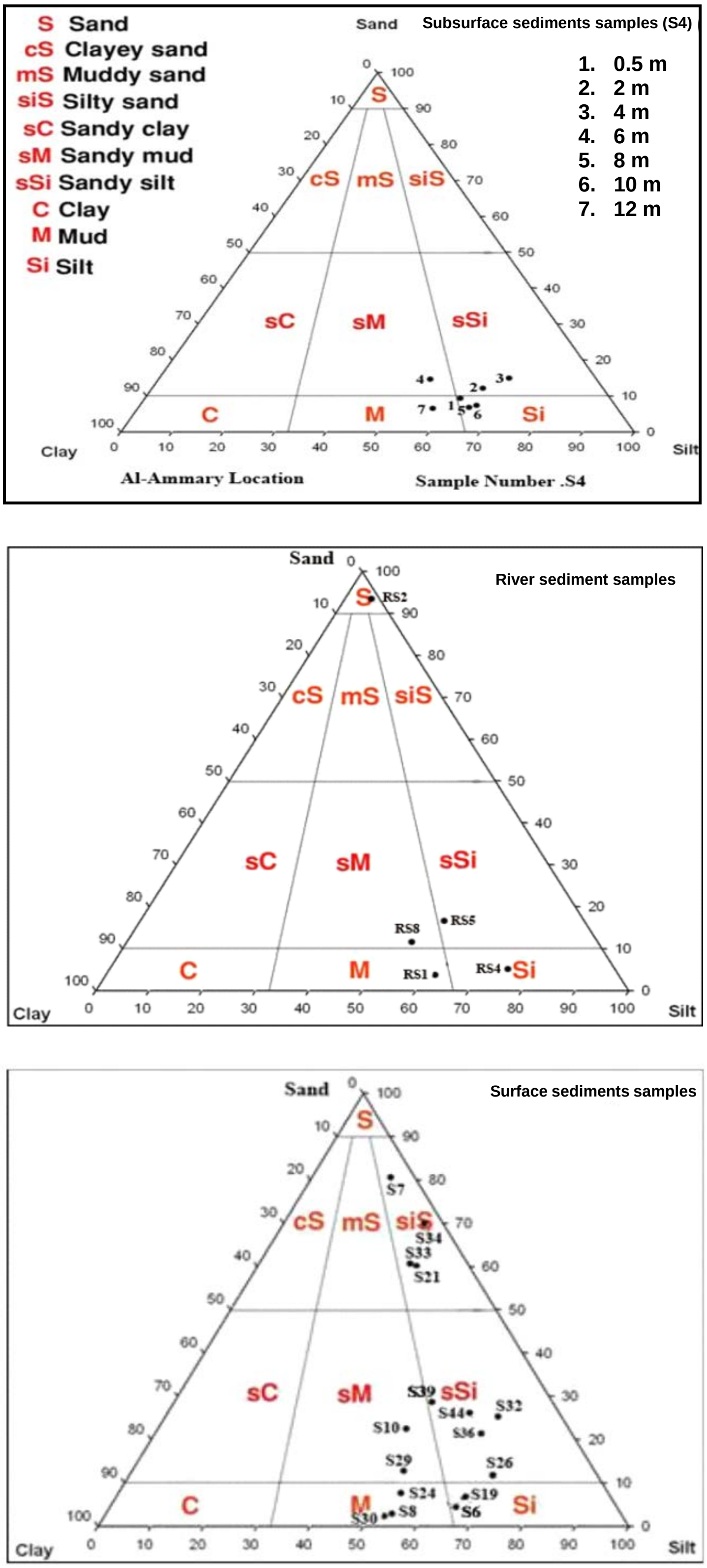

Fig.4: Ternary classification of grain size (Folk, 1974)

- **Heavy Minerals**

The results of the heavy minerals identification are shown in Figs. (5, 6 and 7). Distribution of the heavy minerals in the surface sediments samples and the Tigris River sediments are presented in Fig. (8) and Fig. (9) respectively, whereas Fig. (10) shows the vertical distribution of these minerals to a depth of 12 meters (sample S4, Al-Ammary site).

Mean and range of the heavy minerals content of the studied samples are presented in Table (2). The results show that the heavy minerals in the surface sediments samples constitute less than 5% of the total mineral content. The agricultural areas have the lowest values in comparison with the other land use categories, whereas, in the river sediment samples the heavy minerals constitute 9.7% and 1.5% in subsurface samples. Decreasing pattern of heavy minerals content with depth was noticed in subsurface samples. Opaque minerals show the highest concentrations as compared with other heavy minerals of the studied samples, whereas the sediments of urbanized areas show higher content than the other surface samples.

According to Fig. (8), high concentrations of opaque minerals are present in the northern part of Rasafa side and it decrease southward. This pattern matches with the distribution of these minerals in the river sediment samples, where opaque minerals decrease with river flow direction (Fig.9). Chlorite is also shown to be of high content, whereas the other translucent minerals show clear variations in their concentrations. Concerning ultrastable heavy minerals, zircon has the highest values as compared with the other ultrastable heavies and staurolite disappear in all river sediment samples. No clear systematic distribution of the above minerals with the depth could be distinguished (Fig.10).

- **X-Ray Diffraction (XRD)**

Mineralogical analysis of twenty four surface sediments samples was carried out by X-ray diffraction analysis. Results are shown in Figs. (11, 12 and 13). According to these results, illite, kaolinite, palygorskite, chlorite and montmorillonite were distinguished in the studied surface and river sediments samples in different quantities. Agricultural areas are characterized by relatively higher presence of chlorite and montmorillonite, whereas the other minerals prevailed in the urbanized areas of Baghdad.

The non-clay minerals: quartz, calcite and feldspar were distinguished in the river sediments, whereas the same minerals as well as gypsum and dolomite, appeared in the surface and subsurface sediments. Quartz and calcite contents are the highest; gypsum was detected in all subsurface sediments and in surface sediments of some urbanized areas but disappeared in the river sediments.

- **Cation Exchange Capacity (CEC)**

The measured CEC values of the surface and subsurface sediments were compared with river sediment samples of the study area (Table 3). The results show generally low CEC values, being relatively higher in subsurface samples.

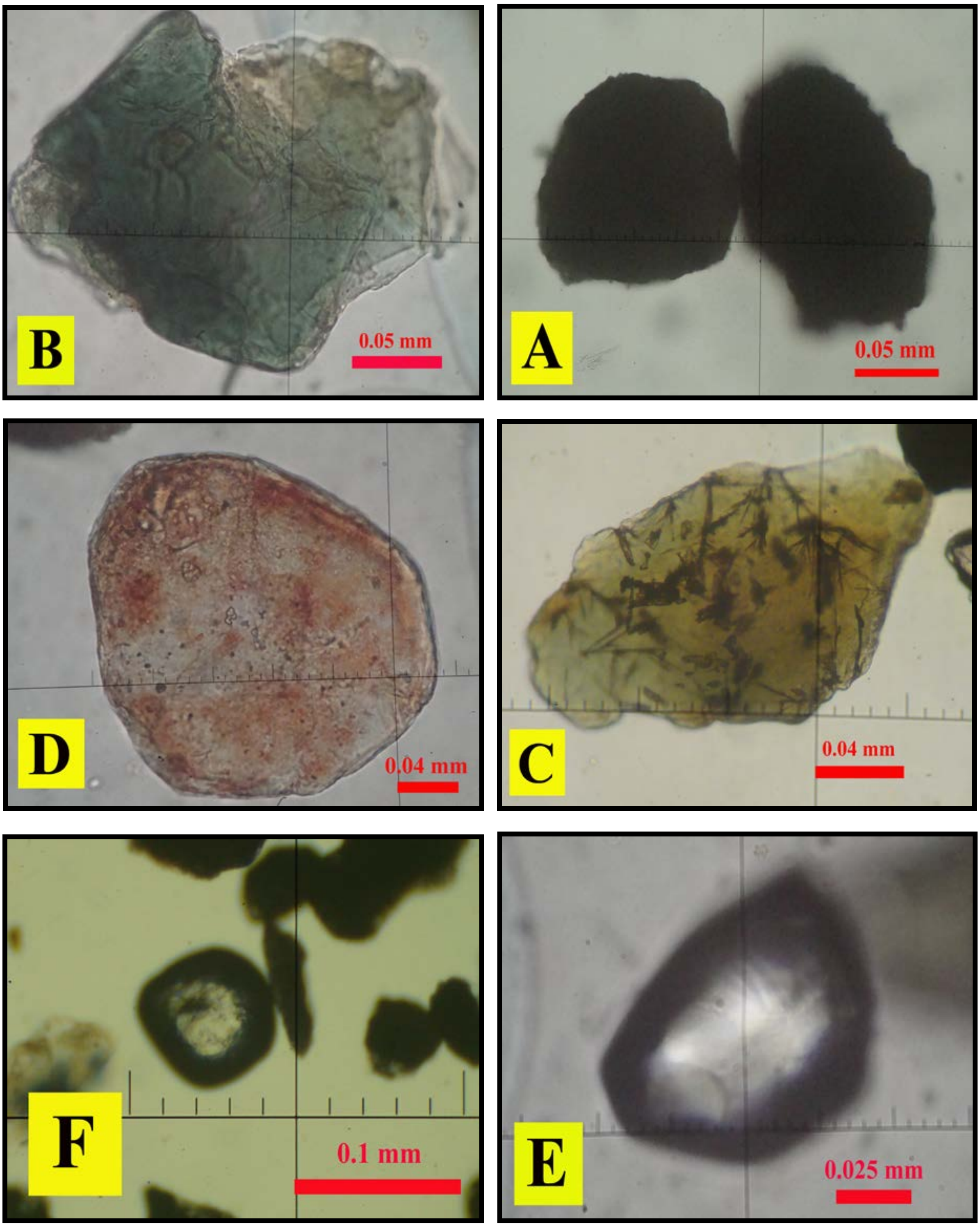

Fig.5: Heavy minerals in the surface sediments

A: Opaque grains, sample number S6, PPL
B: Green chlorite, angular, sample number RS4, PPL
C: Green chlorite with spot of iron oxides, sample number S26, PPL
D: Alterd, subrounded chlorite, sample number S44, PPL
E: Colorless, subangular zircon, sample number RS8, PPL
F: Colorless, subrounded zircon, sample number S4 PPL

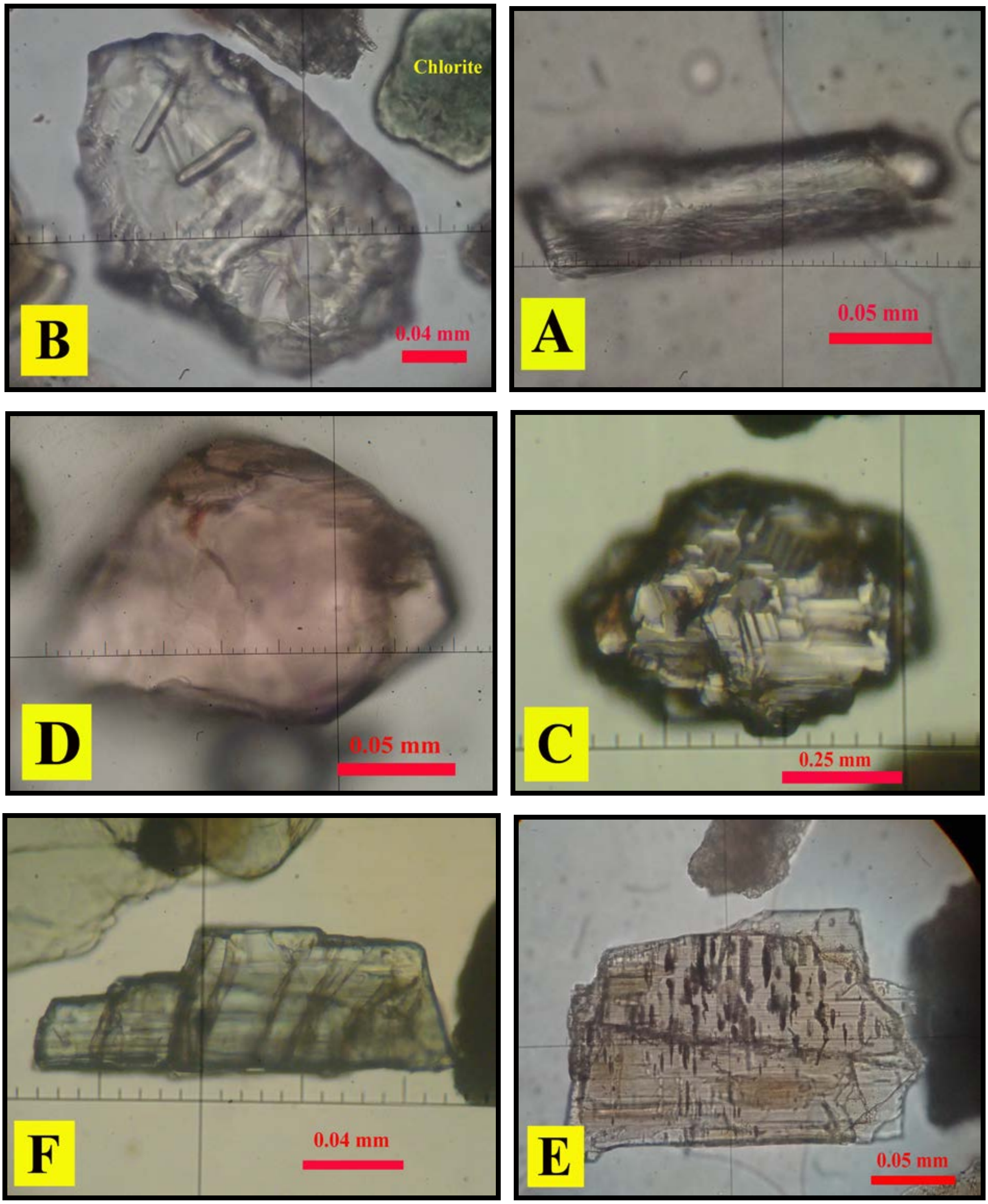

Fig.6: Heavy minerals in the river sediments

A: Prismatic, subhedral, colorless zircon, sample number S36, PPL
B: Angular, colorless zircon, with some inclusion, sample number S32, PPL
C: Colorless, angular, garnet, sample number RS5, PPL
D: Rose, angular, garnet, sample number S24, PPL
E: Light brown, angular, pyroxene, sample number RS2, PPL
F: Light green amphibole (hornblend), sample number S34, PPL

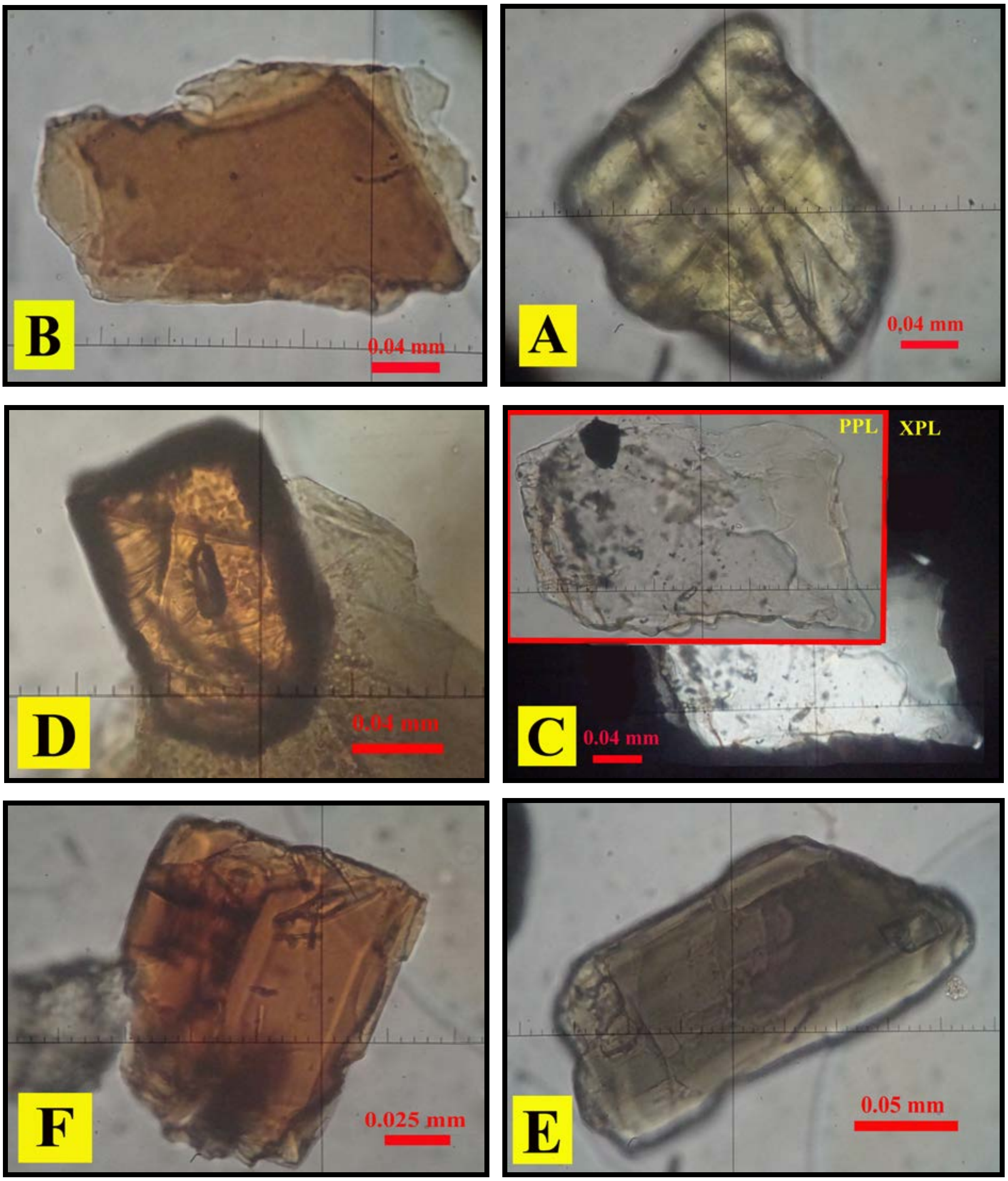

Fig.7: Heavy minerals in the subsurface sediments

A: Light green, epidote, sample number S10, PPL
B: Light brown biotite, sample number S30, PPL
C: Colorless muscovite, |sample number S8
D: Prismatic rutile, sample number S39
E: Honey color tourmaline, sample number S33, PPL
F: Yellowish staurolite, sample number S4, PPL

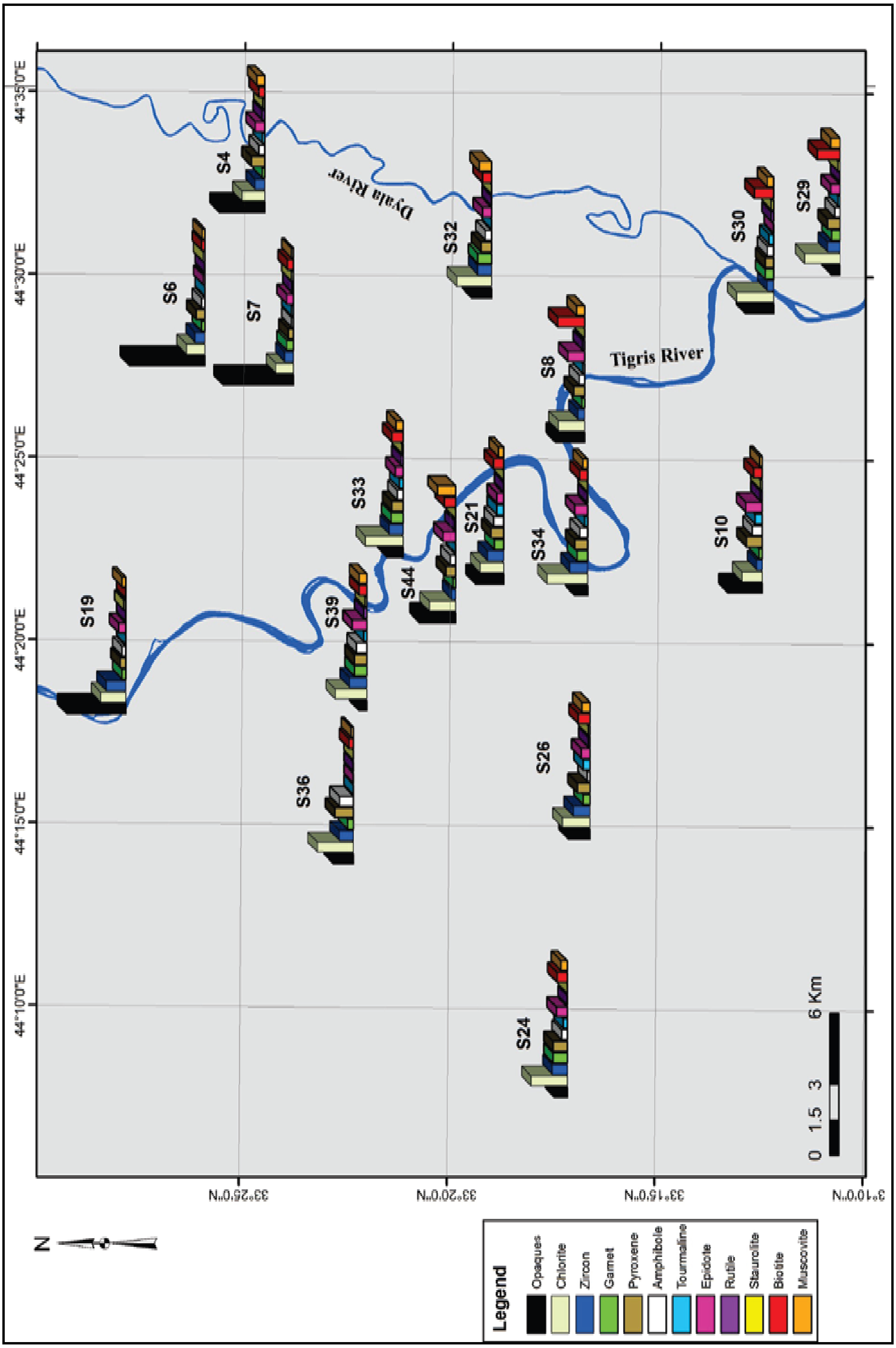

Fig.8: Distribution of heavy minerals in surface sediments samples

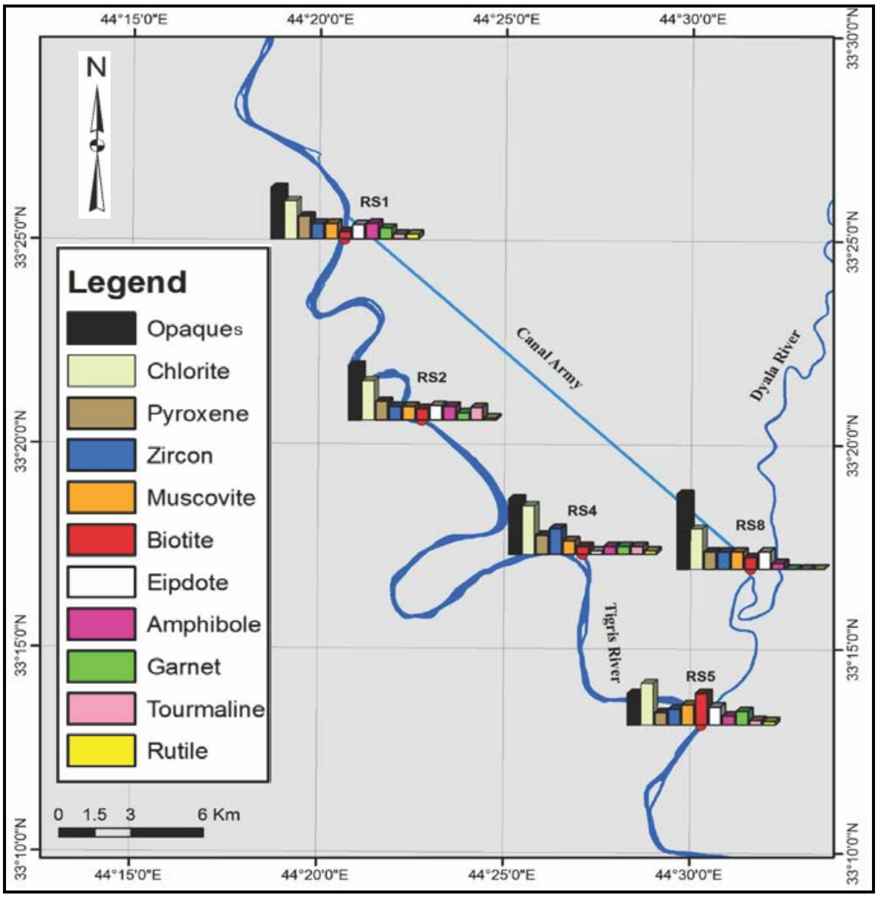

Fig.9: Distribution of heavy minerals in river sediment samples

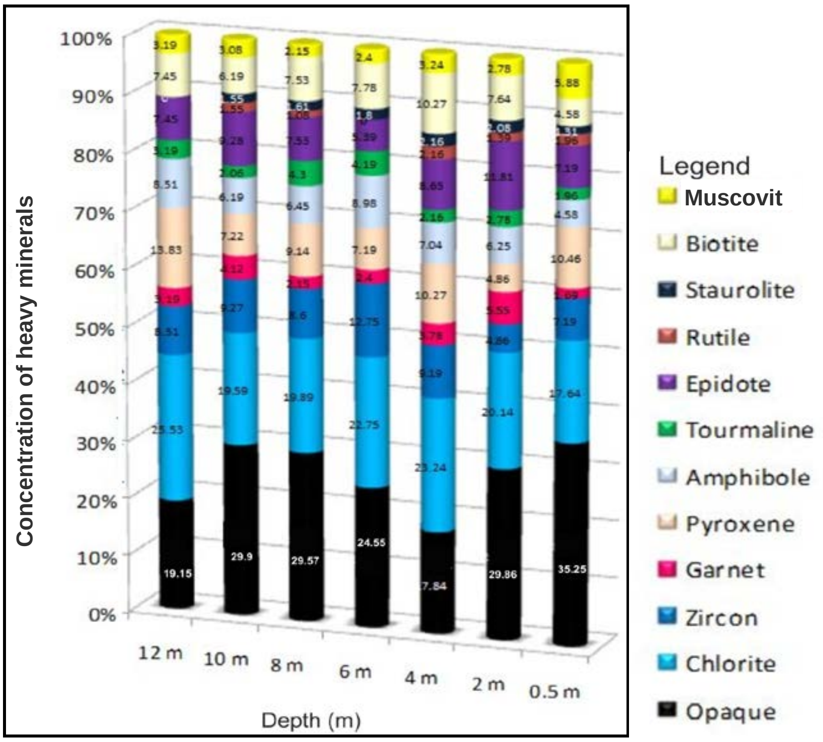

Fig.10: Vertical distribution of heavy minerals of subsurface sediments samples at Al-Ammary site (S4)

Table 2: Mean and range of the heavy minerals in the study area

Mineral	Surface sediments					River sediments		Subsurface sediments	
	Range	Mean	Agricultural	Industrial	Urbanized	Range	Mean	Range	Mean
	(%)		Mean (%)			(%)			
Light fraction	88.4 – 97.9	95.3	97.0	95.9	94.2	72.1 – 99.5	90.3	94.9 – 99.5	98.5
Heavy fraction	2.0 – 11.6	4.6	2.9	4.2	5.8	0.5 – 27.9	9.67	0.5 – 5.2	1.5
Opaques	5.9 – 58.5	23.2	20.7	22.7	24.7	15.6 – 37.2	26.7	17.8 – 35.3	26.6
Chlorite	13.4 – 31.3	23.0	24.9	23.9	21.3	19.1 – 24.2	20.7	17.6 – 25.5	21.3
Zircon	3.3 – 15.3	9.6	12.3	8.7	9.1	6.7 – 12.9	8.8	4.9 – 12.8	8.6
Garnet	1.9 – 11.O	6.0	6.8	6.8	5.1	3.6 – 6.7	4.9	2.0 – 5.6	3.3
Pyroxene	3.73 – 14.4	8.8	8.4	8.0	9.6	6.2 – 11.3	9.0	4.9 – 13.8	9.0
Amphibole	1.5 – 10.8	5.1	3.8	4.9	5.8	2.9 – 7.7	5.1	4.6 – 9.0	6.9
Biotite	2.7 – 20.7	8.8	12.8	10.0	6.7	3.6 – 15.6	6.9	4.6 – 10.3	7.4
Muscovite	1.5 – 14.1	5.1	4.9	5.6	4.8	6.7 – 10.1	8.0	2.2 – 5.9	3.3
Epidote	1.4 – 12.7	7.8	7.1	7.7	8.3	1.7 – 8.9	6.7	5.4 – 11.8	8.2
Tourmaline	1.4 – 5.8	3.2	2.4	2.5	4.0	2.2 – 6.2	3.7	2.0 – 4.3	3.0
Rutile	0.8 – 2.2	1.5	n.d.	1.7	1.2	1.0 – 2.4	1.7	1.1 – 2.2	1.6
Staurolite	0.8 – 1.7	1.4	1.5	1.3	1.5	n.d.		1.3 – 2.2	1.8

n.d.: not detected

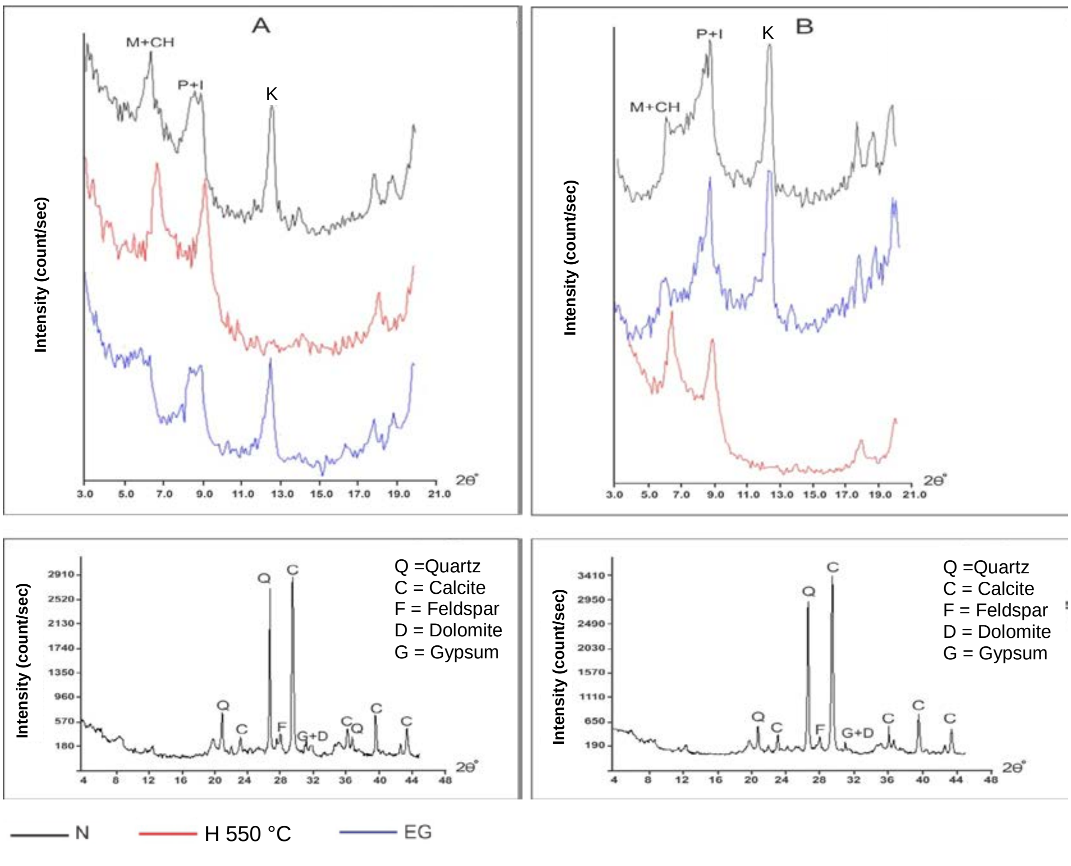

Fig.11: X-ray diffractograms for **A)** surface sediments sample (S6), **B)** surface sediments sample (S30)

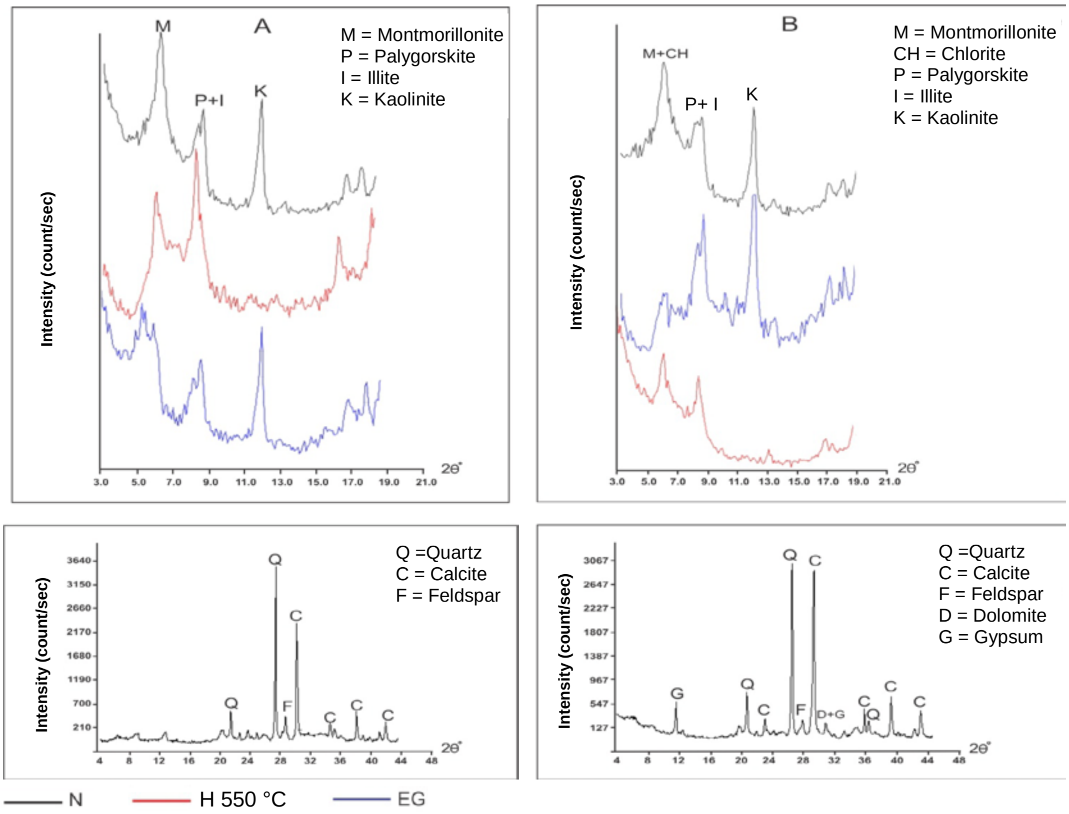

Fig.12: X-ray diffractograms for **A)** river sediment sample (RS1), **B)** subsurface sediments sample (S4 – 6 m)

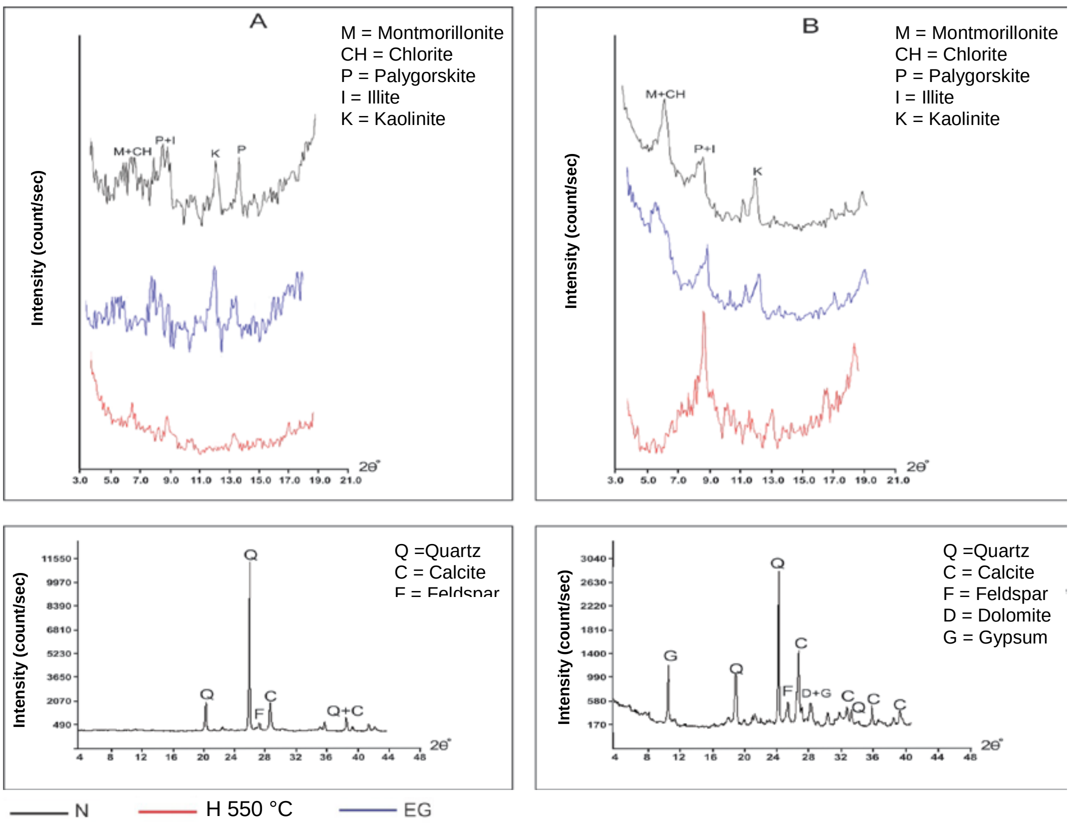

Fig.13: X-ray diffractograms for **A)** surface sediments sample (S7), **B)** surface sediments sample (S44)

Table 3: Results of cation exchange capacity of the surface and river sediments samples

Area category	Sample No.	CEC (meq/100gm)	River sediment samples No.	CEC (meq/100gm)	Subsurface sediments sample (S4)	CEC (meq/100gm)
			RS1	18.8	0.5 m	17.2
Agricultural	S19	14.1	RS2	1.2	2 m	15.6
	S24	18.8	RS4	20.3	4 m	15.7
	S29	14.1	RS5	12.5	6 m	16.5
Mean		15.7	RS8	18.8	8 m	20.3
Industrial	S6	15.6			10 m	21.9
	S8	15.6			12 m	21.9
	S30	17.2				
	S32	17.2				
	S33	7.4	**Mean**	14.3	**Mean**	18.4
	S39	12.5				
Mean		14.3				
Urbanized	S7	2.0				
	S10	17.2				
	S21	7.4				
	S26	18.7				
	S34	15.6				
	S36	15.6				
	S44	10.9				
Mean		12.5				
Total Mean		13.7				

- **Geochemical Parameters**

The values of pH, organic matter and iron oxide (Fe_2O_3) in the study area are shown in Table (4). pH values of the surface samples ranged between 8.8 and 9.5, whereas it ranged from 9 to 9.6 in river sediment samples. At Al-Ammary site the vertical distribution of these values showed range from 8.8 to 9.2. The pH values show that the surface sediments are alkaline and similar to that of the river sediments, which reflects the high carbonate and alkalis in these sediments.

Mean values of the organic matter of the studied surface samples, river sediment samples and subsurface samples were 1.19, 1.08 and 0.35% respectively. Subsurface samples are characterized by the lowest mean value of organic matter as compared with the surface and river sediment samples, possibly due to the disintegration of organic matter in the older sediments by decay. Higher contribution from human sources may be the main reason for increasing organic matter values in the younger sediments.

Mean values of iron oxide (Fe_2O_3) of the studied surface samples, river sediments samples and subsurface sediments samples were close to each other. The highest values found in agricultural areas of Baghdad as compared with other surface land use categories. Values of iron oxides of the study area are within the normal range as compared with the average value of 4% obtained by Al-Bassam (2004) and Shanshal (2004) for previously investigated surface Quaternary sediments of the Mesopotamian Plain. The possible sources of the iron oxyhydroxide may be the free Fe oxides (stains on detrital grains), opaque heavy minerals, clay minerals structure and human industrial waste.

The concentrations of trace elements in the surface, subsurface sediments and river sediments samples are shown in Table (5). Concentrations of the trace elements in subsurface sediments at Al-Ammary site are exhibited in Fig. (3). It appears that there is, some similarity in the behaviour pattern of Fe_2O_3 with Cr, Zn and Ni, whereas Sr has slightly different behaviour. The distribution of trace elements in the surface sediments and river sediments samples are shown in Figs. (14 and 15) respectively.

Table 4: pH values and concentration of organic matter and Fe_2O_3 in the studied samples

Sample No. and area category		**Surface sediments samples**			**River sediments samples**				**Subsurface sediments samples (S4)**			
		pH	**O.M (%)**	**Fe_2O_3* (%)**	**Sample No.**	**pH**	**O.M (%)**	**Fe_2O_3* (%)**	**Sample No.**	**pH**	**O.M (%)**	**Fe_2O_3* (%)**
Agricultural	S19	8.90	1.63	4.86	RS1	9.2	1.19	5.10	O.5 m	9.24	0.28	4.26
	S24	9.18	1.44	5.60	RS2	9.6	0.32	4.0	2 m	9.10	0.38	4.25
	S29	9.15	1.21	4.48	RS4	9.0	1.32	5.40	4 m	8.80	0.35	4.0
Mean		9.1	1.4	5.0								
Industrial	S6	8.90	1.10	4.18	RS5	9.13	1.31	4.90	6 m	8.81	0.29	4.0
	S8	9.40	0.96	5.38	RS8	9.11	1.26	4.83	8 m	9.05	0.40	4.43
	S30	9.15	1.27	4.80	**Mean**	9.21	1.08	4.85	10 m	9.04	0.32	4.58
	S32	9.10	1.29	3.68					12 m	9.20	0.40	4.65
	S33	9.25	1.45	4.10								
	S39	8.86	1.42	4.0					**Mean**	9.03	0.35	4.31
Mean		9.1	1.2	4.4								
Urbanized	S7	8.9	1.33	2.25								
	S10	9.34	0.52	4.73								
	S21	9.31	0.89	3.90								
	S26	8.95	1.04	5.05								
	S34	9.45	1.26	3.60								
	S36	9.13	0.95	4.52								
	S44	8.80	1.35	4.54								
Mean		9.1	1.0	4.10								
Total Mean		9.11	1.19	4.35								

* Total Fe as Fe_2O_3

Table 5: Trace elements concentrations of the studied samples

Surface sediments samples		Co	Zn	Mn	Cu	Ni	Pb	Cr	Cd	Sr	Fe_2O_3 (%)
		(ppm)									
Agricultural area	S19	32	163	616	35	172	29	136	< 1	235	4.86
	S24	26	76	507	26	164	26	92	< 1	270	5.60
	S29	33	80	563	26	153	27	135	< 1	270	4.48
Mean		30.3	106.3	562.0	29	163.0	27.3	121.0	< 1	258.3	5.0
Industrial area	S6	29	83	510	24	130	365	106	< 1	417	4.18
	S8	31	92	663	34	191	28	156	< 1	203	5.38
	S30	24	78	511	25	116	20	104	< 1	367	4.80
	S32	25	94	468	19	106	28	89	< 1	371	3.60
	S33	20	247	457	35	104	35	108	< 1	228	4.10
	S39	29	156	501	61	129	48	122	< 1	318	4.0
Mean		26.3	125.0	518.3	33.0	129.3	87.3	114.2	< 1	317.3	4.4
Urbanized area	S10	35	75	540	24	182	26	144	< 1	230	4.73
	S26	31	82	539	27	167	28	119	< 1	358	5.05
	S34	29	64	480	19	109	20	97	< 1	160	3.60
	S7	77	273	203	101	44	123	50	< 1	260	2.25
	S21	20	139	489	24	101	16	98	< 1	191	3.90
	S36	31	82	507	24	169	28	133	< 1	212	4.52
	S44	25	113	516	187	148	267	130	< 1	590	4.54
Mean		35.4	118.3	467.7	58.0	131.4	72.6	110.1	< 1	285.9	4.1
Total Mean		30.7	116.4	507.9	41.9	135.0	66.8	112.8	< 1	291.2	4.4
River sediments samples	RS1	28	107	721	29	168	31	141	< 1	182	5.1
	RS2	30	52	498	13	87	20	94	< 1	144	4.0
	RS4	29	142	620	40	164	39	144	< 1	177	5.4
	RS5	26	113	550	30	146	32	130	< 1	170	4.9
	RS8	25	111	545	31	129	37	100	< 1	290	4.8
Mean		27.0	105.0	586.8	28.6	138.8	31.80	121.8	< 1	192.6	4.8
Subsurface sediments samples (S4)	0.5 m	25	82	559	22	123	22	99	< 1	321	4.26
	2 m	25	81	523	21	113	25	107	< 1	414	4.25
	4 m	25	78	526	21	107	21	87	< 1	328	4.0
	6 m	25	78	565	21	115	22	95	< 1	441	4.0
	8 m	25	88	488	22	133	22	111	< 1	394	4.43
	10 m	25	89	526	23	130	22	118	< 1	382	4.58
	12 m	25	104	505	24	129	22	105	< 1	430	4.65
Mean		25	85.7	527.4	22.0	121.4	22.3	103.1	< 1	387.1	4.3

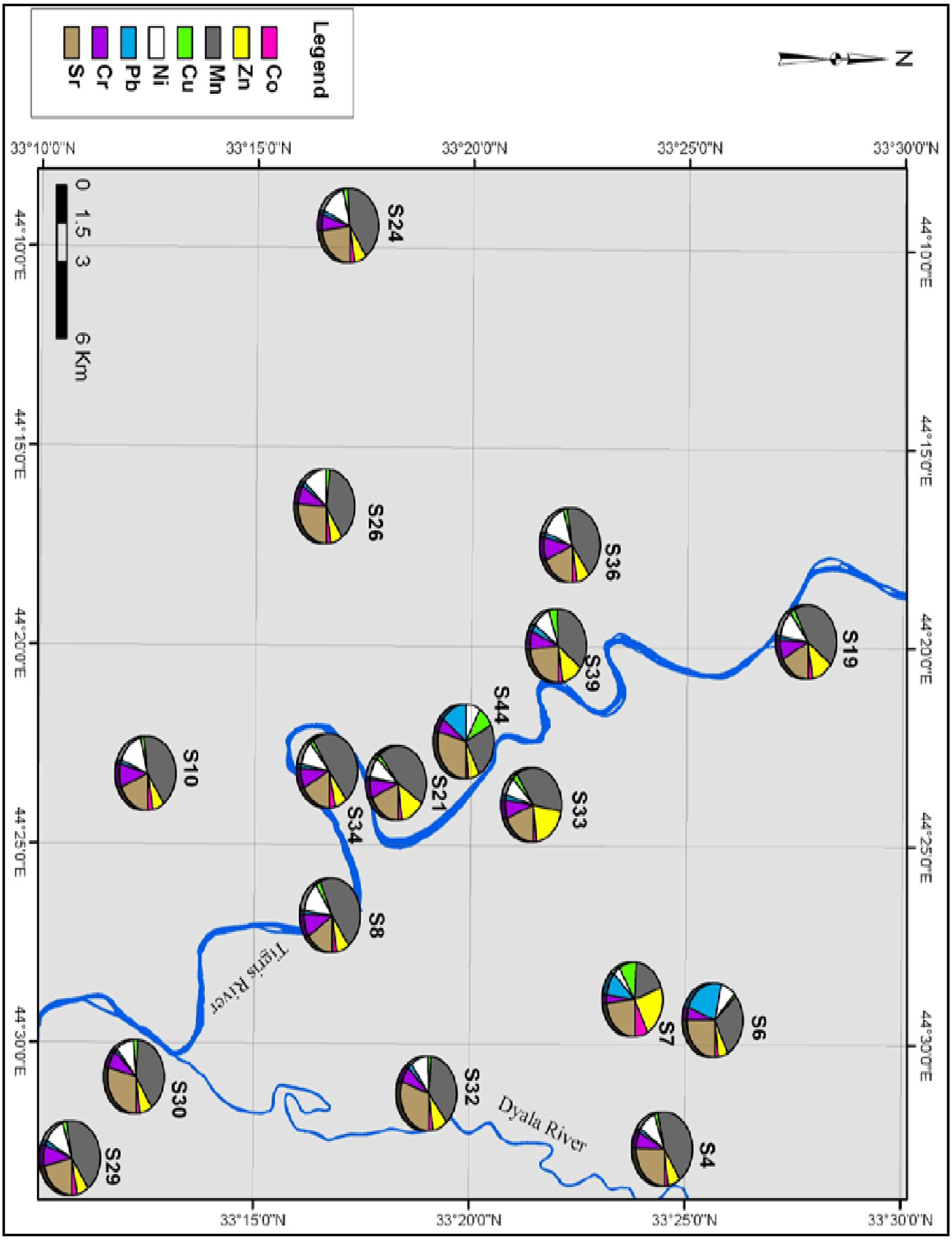

Fig.14: Distribution of trace elements in surface sediments samples

No significant changes in the concentration of trace elements in the river sediments with the flow direction. Mn and Co have the highest and lowest concentration values respectively, among the analysed trace elements in all river sediment samples analysed. Mn concentrations were also found to be the highest in surface samples but lower than its concentration in river sediments samples. Whereas, Cr and Ni show higher concentrations in the river sediments. Subsurface sediments are characterized by high content of Sr as compared with surface and river sediments samples. Generally, agricultural areas have the highest concentrations of Mn, Ni, and Cr and lowest concentrations of other trace elements in comparison with the other land use areas. The sediments of industrial areas are characterized by the highest concentrations of Pb, Sr and Zn whereas the highest concentrations values of Co and Cu were found in the urbanized areas of Baghdad.

Different statistical procedures were used to analyse the geochemical variables of the analysed samples, as follows:

Geochemical anomalies have been identified by setting threshold values, which mark the upper and lower limits of the normal variations for a particular population of data. Values within the threshold values are referred to as background values and those above and below as anomalies (Reimann *et al*., 2005). The threshold value can be estimated by:

Mean ± 2 std. dev. ----------- (1) (Hawkes and Webb, 1962)

In which the positive and negative output of the above equation refer to the upper and lower threshold values respectively. Positive and negative anomalous values represent above the upper and below the lower threshold limits respectively. The background and threshold values of the present data are shown in Table (7).The distribution of the positive and negative anomalous values of the trace element in the surface sediments samples are shown in Figs. (16, 17, 18 and 19).

The surface distribution patterns of the analysed trace elements proved to be of complex nature throughout the study area, in which, detailed statistical analyses were carried out to investigate the main factors affecting these distribution patterns. Statistical correlation was necessary to investigate the interrelationships of the trace elements and the other variables including pH, OM, CEC, grain size, Fe_2O_3, opaque minerals, chlorite and zircon. First, correlation coefficient(r) matrix was calculated and, r values greater than 0.5 were regarded significant at level of significance 0.05 (Davies and Wixson, 1987). Table (8) shows the results of correlation coefficient calculation matrix which was used later in factor analysis calculations.

Factor analysis R-mode was used to reduce the complex patterns of correlation among the variables by grouping them into a single set or relationships and extracting a few hypothetical parameters, which can be easily explained (Al-Bassam and Al-Allak, 1985). In the present study, R-mode factor analysis was applied on sixteen surface sediments samples using the principle components method to extract, the main factors that may be useful in interpreting the total variance observed in the data. Factors with eigenvalue greater than one were retained for the interpretation. The retained factors were subjected to varimax rotation, which redistributes the variance of each factor to maximize the relationship between the interdependent soil variables (Table 9).

Table 6: Mean, median and standard deviation of the trace elements of the studied samples compared with reported limits previous studies of Baghdad City and the world

		Co	Zn	Mn	Cu	Ni	Pb	Cr	Cd	Sr	Fe_2O_3
Surface sediments samples											
		Co	**Zn**	**Mn**	**Cu**	**Ni**	**Pb**	**Cr**	**Cd**	**Sr**	**Fe_2O_3**
		(ppm)									**(%)**
Mean	**Agricultural**	30.3	106.3	562.0	29	163.0	27.3	121.0	< 1	258.3	5.0
	Industrial	26.3	125.0	518.3	33.0	129.3	87.3	114.2	< 1	317.3	4.4
	Urbanization	35.4	118.3	467.7	58.0	131.4	72.6	110.1	< 1	285.9	4.1
Mean		30.7	116.4	507.6	41.9	135.8	66.8	112.8	< 1	294.2	4.4
Median		29.0	83	510	26	130	28	108	< 1	270	4.5
Std. dev.		12.7	61.5	94.1	42.4	37.7	98.4	25.6	0.0	105.2	0.8
Al-Basssam *et al*. (1985)						218	15	623			
Hanna and Al-Hilali (1986)		23			45	187	96	581			
Al-Maliky (2005)		27.5	133.3	1923.3	91.9	111.4	153.7	250	5.25		
Al-Basssam *et al*. (2009)							102.9				
Abdullah (2010)		6.42	113.1	107.7	25.34	82.04	108.7	75.27	4.02		30058 (ppm)
Lindsay (1979)		8.0	50.0	600	30.0	40	10	100	0.06	200	38000 (ppm)
Subsurface sediments samples (Al-Ammary site S4)											
		Co	**Zn**	**Mn**	**Cu**	**Ni**	**Pb**	**Cr**	**Cd**	**Sr**	**Fe_2O_3**
		(ppm)									**(%)**
Mean		25	85.7	527.4	22.0	121.4	22.3	103.1	< 1	387.1	4.3
Median		25	82.0	526.0	22.0	123.0	22.0	105.0	< 1	394.0	4.3
Std.dev.		0.0	9.18	27.4	1.2	9.90	1.3	10.4	0.0	47.3	0.30
River sediments samples											
		Co	**Zn**	**Mn**	**Cu**	**Ni**	**Pb**	**Cr**	**Cd**	**Sr**	**Fe_2O_3**
		(ppm)									**(%)**
Mean		27.0	105.0	586.8	28.6	138.8	31.80	121.8	< 1	192.6	4.85
Median		28.0	111.0	550.0	30.0	146.0	32.0	130.0	< 1	177.0	4.40
Std.dev.		2.1	32.3	86.6	9.76	32.86	7.40	23.3	0.0	56.38	0.52
Al-Jebori (1997)		44.1	262	540	235.4	130	42.5	84.9	1.9		
Rabee *et al*. (2009)				399 – 500	68 – 109	40 – 66	54 – 75		0.3 – 1.8		

Table 7: Background and threshold values of trace elements concentration of surface sediments samples in the study area

Elements (ppm)	Background value (ppm)	Threshold (ppm)	
		Upper	Lower
Co	29	56.0	5.4
Zn	83	239.4	– 6.5*
Mn	510	695.8	319.3
Cu	26	126.7	– 84.8*
Ni	130	211.1	60.4
Pb	28	263.6	– 129.9*
Cr	108	163.9	61.7
Sr	270	504.7	83.7
* Theoretical values			

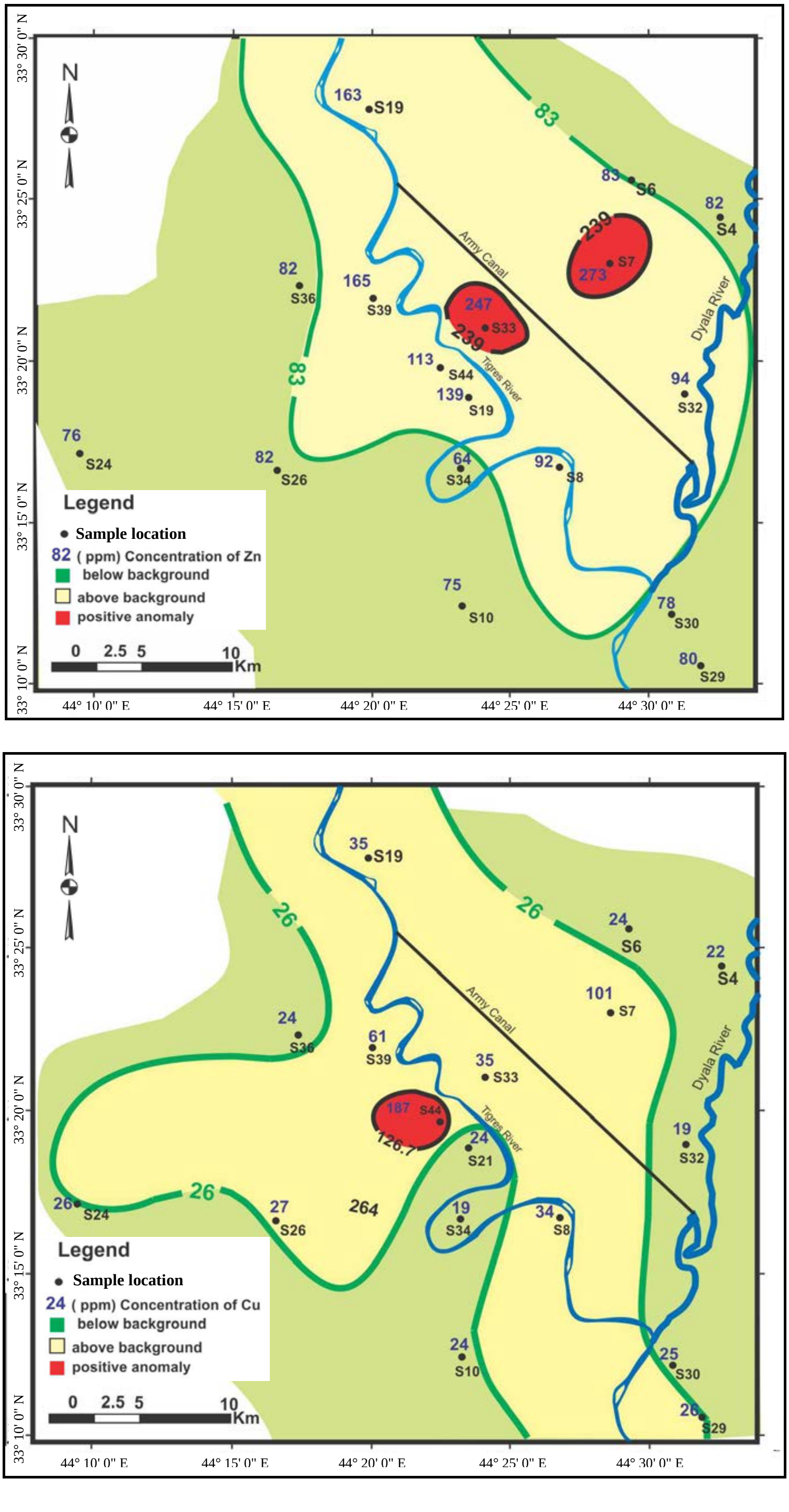

Fig.16: Geochemical maps of Zn and Cu

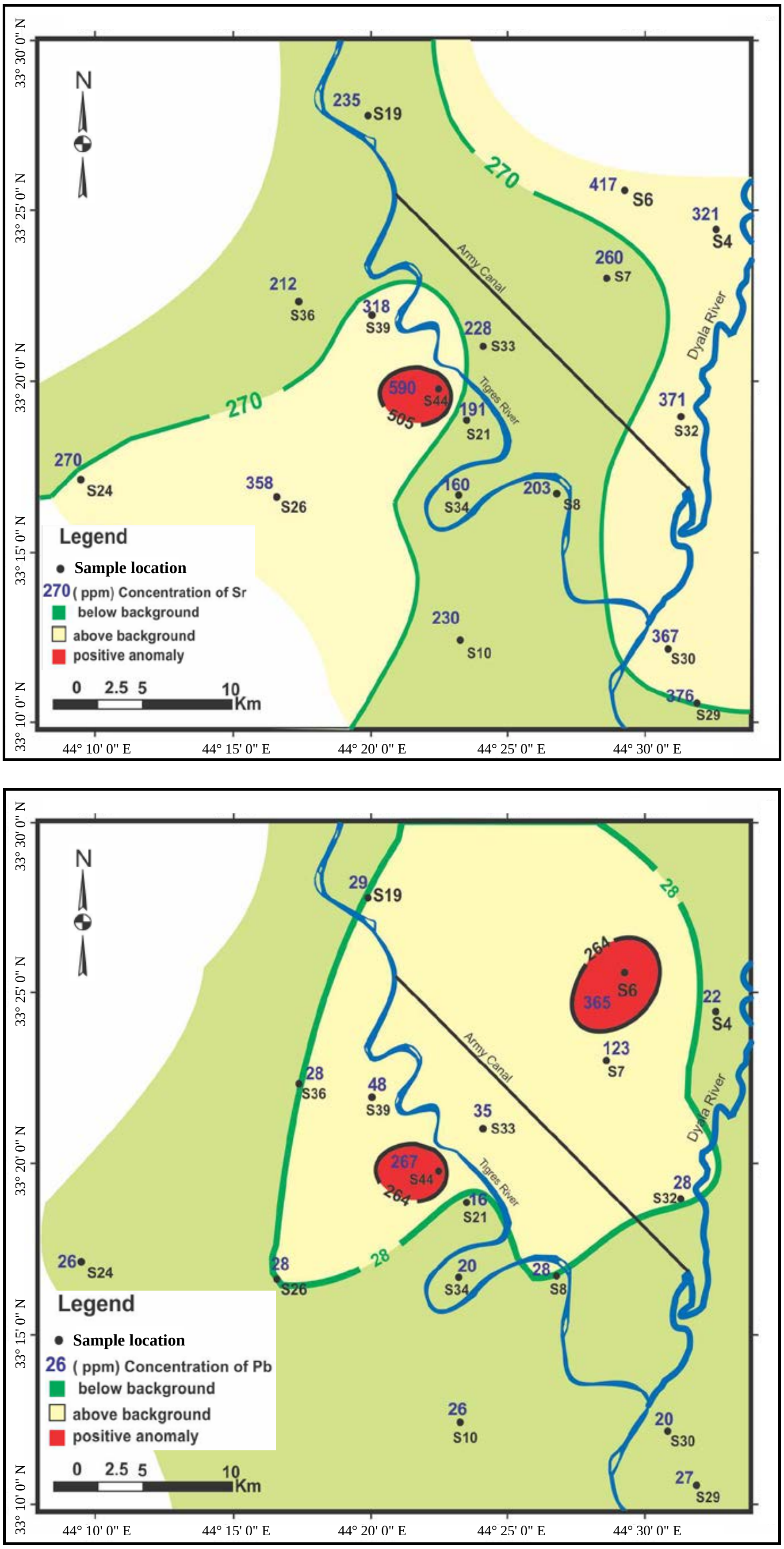

Fig.17: Geochemical maps of Sr and Pb

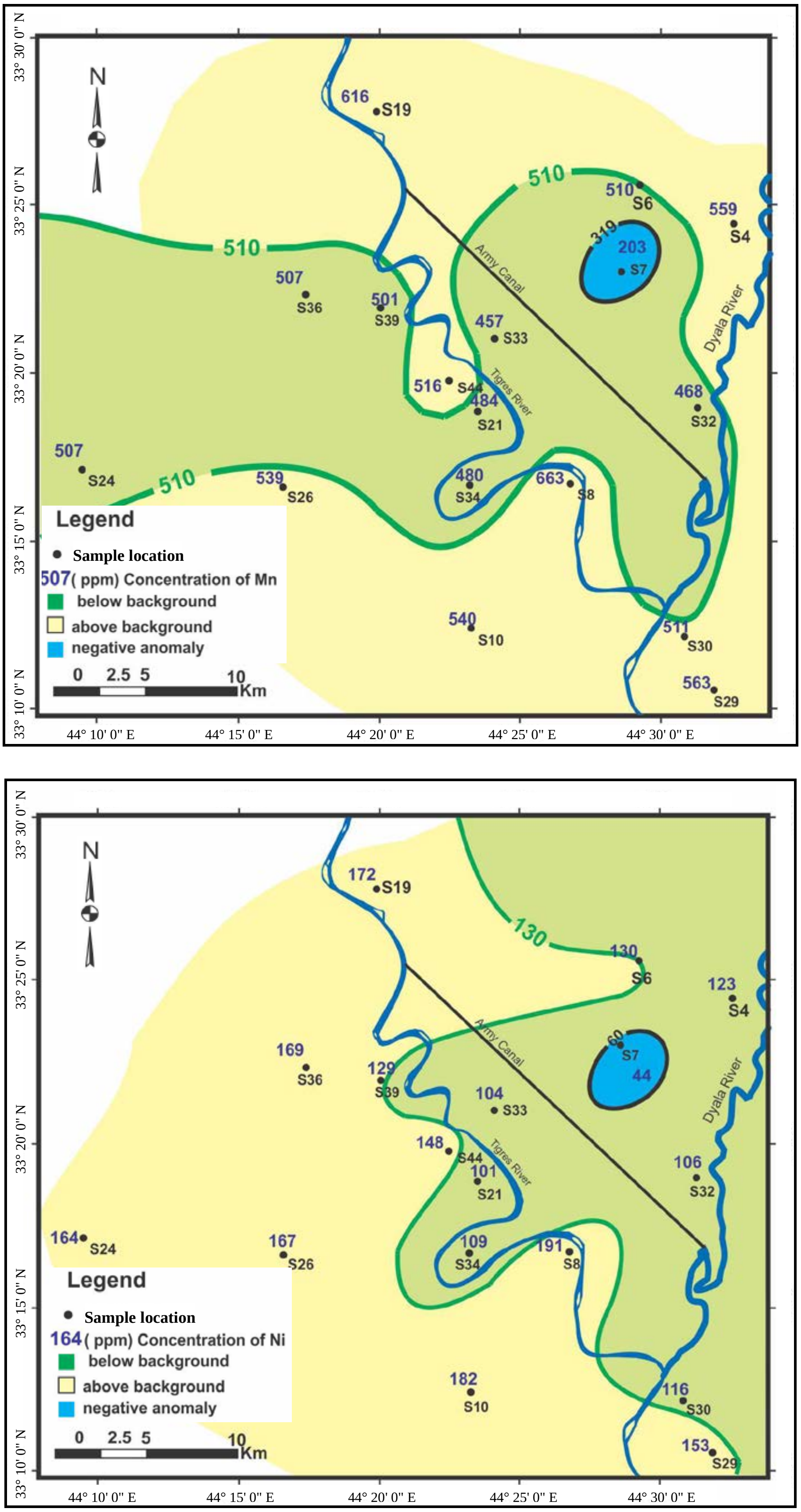

Fig.18: Geochemical maps of Mn and Ni

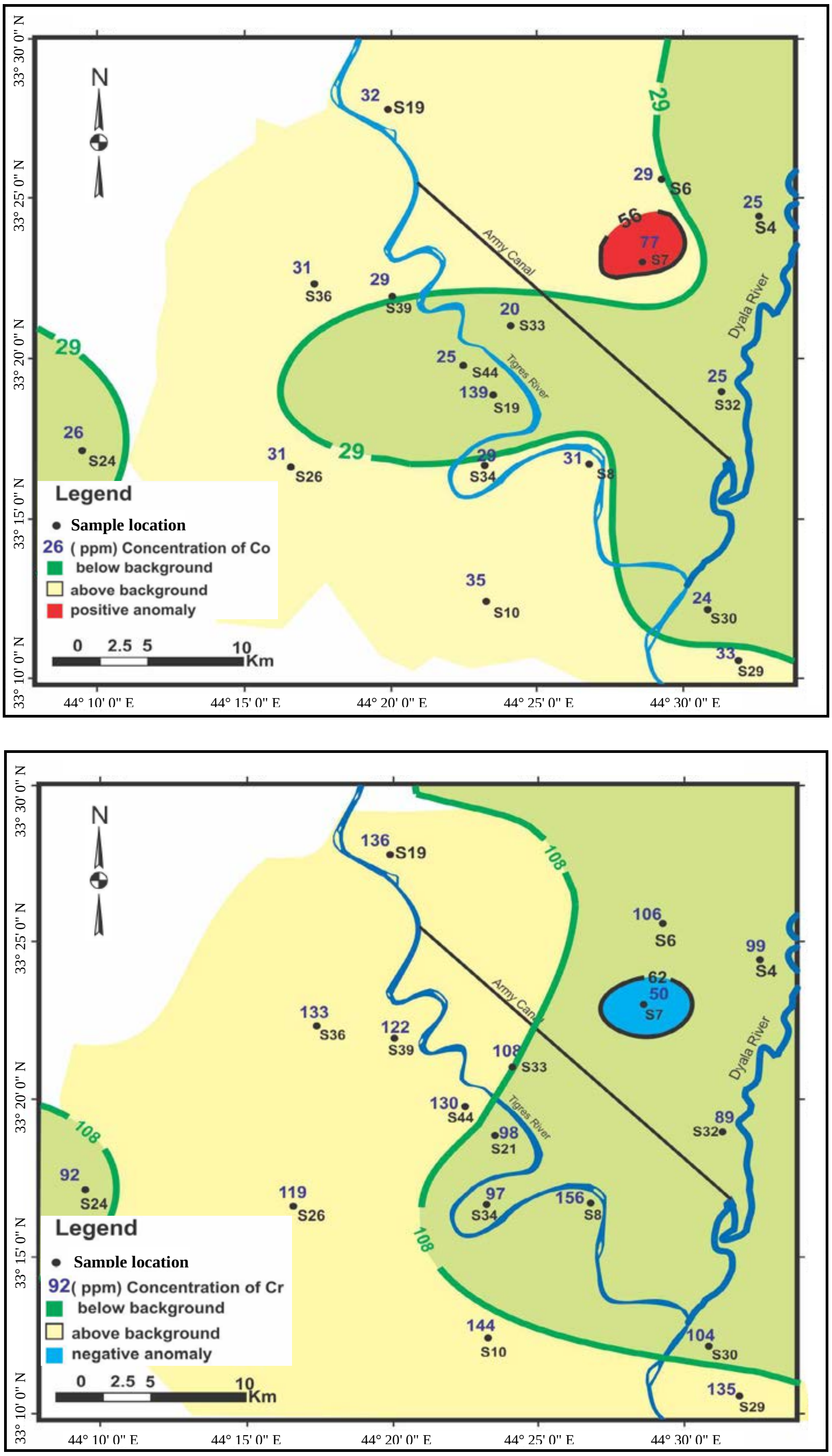

Fig.19: Geochemical maps of Co and Cr

Table 8: Correlation coefficient matrix of grain size, mineralogy and chemical elements of surface sediments samples

	Co	**Zn**	**Mn**	**Cu**	**Ni**	**Pb**	**Cr**	**Sr**	**Fe_2O_3**	**pH**	**OM**	**CEC**	**Sand**	**Silt**	**Clay**	**H.F.**	**L.F.**	**Opaques**	**Chlorite**	**Zircon**
Co	I																			
Zn		I																		
Mn	0.56		I																	
Cu				I																
Ni	0.76		0.73		I															
Pb				0.52		I														
Cr	0.68		0.71		0.79		I													
Sr				0.70		0.69		I												
Fe_2O_3			0.62		0.79				I											
pH				– 0.53		– 0.56		– 0.73		I										
OM											I									
CEC	– 0.53	– 0.78			n							I								
Sand			– 0.62		– 0.58				– 0.68			– 0.63	I							
Silt					0.51					– 0.61		0.59	– 0.85	I						
Clay			0.61						0.69				– 0.82		I					
H.F.				0.75				0.54								I				
L.F.				– 0.75				– 0.54								– 1.0	I			
Opaques						0.62												I		
Chlorite											0.51							0.51	I	
Zircon																				I

Table 9: Varimax rotated component matrix and total variance explained by each extracted factor

	Component					
	1	**2**	**3**	**4**	**5**	**6**
Co	0.75					
Zn				– 0.82		
Mn	0.81					
Cu		0.85				
Ni	0.91					
Pb			0.72			
Cr	0.91					
Sr		0.67				
Fe_2O_3	0.63					0.55
pH					– 0.72	
O.M					0.89	
CEC				0.92		
sand				– 0.57		– 0.52
silt				0.65		
clay						0.77
H.F.		0.96				
L.F.		– 0.96				
opaque			0.95			
chlorite			– 0.80			
zircon						– 0.69
	30.2	22.5	11.1	10.1	8.9	6.4
Variance explained %						
Total variance explained = 89.1% Note: only values of r > 0.5 are presented						

▪ **Radioactivity Measurement of Selected Soil Samples**

The activity concentration of U^{238}, Th^{232}, K^{40} and Cs^{137} of some selected surface sediments samples through the study area, and the comparison with other values obtained for Baghdad area in previous periods are shown in Table (10). The activity concentration of U^{238}, Th^{232}, K^{40} and Cs^{137} range from (7.5 ± 0.2 – 15.8 ± 1.2), (10.2 ± 0.8 – 17.5 ± 0.7), (246.2 ± 10 – 349.4 ± 12) and (ND – 3.9 ± 0.3) respectively. Concentrations of uranium in the world soil ranges from 0.7 to 11 ppm, and it may sometimes reach a value of 15 ppm especially in farmland soil due to the extensive use of phosphate fertilizers, mean and median values of uranium in the world soils are 1 and 2 ppm respectively (Shahabuddin *et al.*, 2010).

DISCUSSION

According to grain size analysis, silt is the predominant fraction in all of the flood plain sediment samples as compared with sand and clay fractions. Due to the fact that Baghdad natural surface is composed mainly of flood plain deposit, it is expected that the silt domination represents energy controlled deposits, whereas sand lenses represent buried river channels. In this regard, the appearance of clay rich sediments represents the distal part of the flood plain (away from the main river channel) such as local depressions or pools within the flood plain.

Generally, types and concentrations of the heavy minerals in the samples taken horizontally and vertically are similar to those of the Tigris River sediments. Heavy minerals seem to be nearly of similar distributions in surface, subsurface and river deposits.

Translucent heavy minerals were derived from natural geological sources (igneous, metamorphic and sedimentary rocks) in northern and northeastern parts of the country, whereas opaque heavy minerals may be of natural origin or added as industrial mineral wastes. Opaque minerals have the highest ratios and concentrations in the surface sediments of northeastern parts of Baghdad and decrease in the southern parts. This is in good matching with their distribution in the river sediments.

Human industrial activities and improper waste disposal may have contributed and to some extent, controlled the behaviour of heavy minerals in some areas of the city. Urbanized areas, especially, Sadr province, are characterized by the highest concentrations of opaque heavy minerals. The above distribution of the opaque minerals may be linked with the transport and depositional energy of the river as well as with human influence.

The clay mineral assemblage identified in this study is common in all Iraqi soils and Quaternary fluvial deposits, some of them are detrital such as chlorite, which is derived from Fe-Mg rich source rocks and their alteration products and others may be authigenic or partially authigenic, such as palygorskite and montmorrilonite which are usually developed in the arid environment (Millot, 1970). Kaolinite may be partly detrital derived from igneous rocks rich in K-feldspar indicating moderate temperature, humid and acidic environment (Millot, 1970). Illite is mostly of detrital origin resulting from weathering of mica-rich rocks (Carroll, 1970).

Quartz is of detrital origin whereas, calcite is mostly detrital, from the disintegration of carbonate rock units and possibly partially of authigenic origin. Gypsum is formed authigenically, it is derived mainly from SO_4^{2-} rich groundwater enriched by sulphate from gypsum-rich rock units such as Fatha Formation (Middle Miocene). This process reflects the arid and warm climatic conditions of Iraq.

CEC decreases with increasing particle size, the different type of clay minerals present in the studied samples give variable and low values of CEC. Mean value of CEC in subsurface sediments is greater than both surface and river sediment samples values. The CEC values show clear increase with depth (Fig.3) and agricultural areas have the highest mean value of CEC relative to other types of land use areas.

The trace elements concentrations show a narrow range in all the studied samples. Their values, in general, are different from those of the previous studies in Baghdad area (Al-Basssam *et al*., 1985); (Hanna and Al-Hilali, 1986); (Al-Maliky, 2005); (Al-Basssam *et al*., 2009); (Abdullah, 2010) and than those of the world average soil (Lindsay, 1979) (Table 6). Mean concentration of trace elements (Mn, Ni and Cr) of the river sediment samples of the present study were found to be higher than that found by Al-Jebori (1997) and Rabee *et al*. (2009). Surface sediments or soil in heavily populated areas is subject to the influence of human activities and hence it is continuously evolving and cannot be compared with unpolluted soils of the world. Moreover, being flood plain deposits, their trace elements content is highly dependent on parent rocks type and composition in the source area.

Generally, the trace elements concentration order in the analysed surface sediments samples can be expressed by the following sequence, Fe > Mn > Sr > Ni > Zn > Cr > Pb > Cu > Co > Cd, whereas for the river sediments, the order is, Fe > Mn > Sr > Ni > Cr > Zn > Pb > Cu > Co > Cd, and in the subsurface sediments samples they have the following sequence, Fe > Mn > Sr > Ni > Cr >Zn > Co > Pb> Cu > Cd.

Spatial distribution maps of trace elements (Figs.16, 17, 18 and 19), show more anomalous zones in Rasafa than Karkh side, specifically at Sadr province (S7), which is a heavily populated and industrialized area. These anomalous zones are positive for Co and Zn and negative for Mn, Cr and Ni. Positive anomalous concentration of Zn was also noticed at Sheikh Omar area (old urbanized and industrial area S33). Hameediya area (S6), which is characterized by dispersion of primitive lead smelters, show positive anomaly of Pb.

In Karkh side, positive anomalies of Pb, Sr and Cu in Sheikh Marouf area (old urbanized and industrial area S44) were observed. Positive anomalies may reflect point source pollution, mostly related to improper industrial activity, whereas negative anomalies may suggest active drainage and consequent mobilization of some trace elements, some of which may have infiltrated from the soil to the groundwater. Dust storms may be considered as additional factor in supplying the area by some of the trace elements as the prevailing wind direction is mostly from Karkh towards Rasafa side. Lead may be an example of such source (Al-Bassam *et al*., 2009).

Significant correlations among Cr, Co, Mn and Ni, and Pb with Cu were noticed (Table 8), which reflects the natural geochemical affinity of the analysed elements and their tendency (Rankama and Sahama, 1950). Manganese has negative correlations with sand fraction and positive correlation with clay fraction and Fe_2O_3, reflecting the geochemical association with the fine fraction and the effect of the source area on the behaviour of these elements. Cobalt and Zn have negative correlations with CEC showing that there is little control of clay minerals on these elements other factors such as source rocks and weathering, may be the main factors producing this distribution. pH has negative correlations with Cu, Pb and Sr indicating the effect of this parameter on the mobility of these elements in soil (Manahan, 1994).

Significant positive correlation of Sr and Cu with heavy fraction were also observed. In order to investigate the association of Sr and Cu with heavy fraction, both elements were analysed in the heavy fraction separated from surface sediment sample (S19). The results show that the heavy fraction contains Cu and Sr concentrations of 192 ppm and 1763 ppm respectively, as compared with those of the bulk sample, which contained 35 ppm and 235 of Cu and Sr respectively.

Six factors were extracted from Table (9), which interpret about 89% of the total variance of the present study data as follows

Factor 1: This factor explains 30.2% of the total variance (the most significant factor). It is characterized by high loading of Cr, Ni, Mn, Co and Fe_2O_3. Association of these elements reflects the effect of Fe-Mn oxides, in which, iron oxides can affect heavy metals retention and bioavailability and can be regarded as sink to the heavy metals due to their geochemical affinity (Silveria *et al*., 2003). This factor is highly related to the source of the derivatives from the basic, ultra-basic, and metamorphic rocks at the northeastern parts of Iraq.

Factor 2: This factor accounts for about 22.5% of the total variance (significant factor). High positive loading of Cu, Sr with heavy fractions is observed. This is closely confirmed with the correlation coefficients results and can be attributed to the local pollution source of industrial nature as well as to the heavy mineral fraction present in soil.

Factor 3: This factor has a remarkable loading of Pb and opaque minerals and negative loading of chlorite. Variance explained by this factor is about 11.1% (less significant factor). Presence of Pb reflects the anthropogenic effects on the surface sediments of the study area, mainly the combustion of fuel and dispersion of local primitive Pb-smelters.

Factor 4: Cation exchange capacity and silt have high positive loading, whereas Zn and sand fraction have negative loading on this factor which interprets 10.1% of the total variance. Thus, it can be considered as insignificant factor and may be due to statistical coincidence of values.

Factors 5 and 6: Both factors are insignificant; they explain less than 10% of the total variance. The fifth factor is characterized by positive loading of organic matter and negative loading of pH, which might reflect the influence of organic matter on lowering the soil pH by forming humic acids locally (Hoyu, 2005). Factor 6 show positive loading for clay fraction and iron oxide and negative loading for sand and zircon. This factor may be related to the energy of the depositional processes influencing the grain size distribution of the flood plain sediments.

No clear variations in the activity concentration of U^{238}, Th^{232}, K^{40} and Cs^{137} can be notices between Karkh and Rasafa side, the highest concentration of uranium was observed at Tuwaitha site (S30) (Table 10), Comparing this activity concentrations with other values obtained from Baghdad area in previous periods (Marouf *et al*., 2000), it is obvious that the present study results are in general, lower in concentrations. This may be due to the efficiency of removal and clean up of radioactive contamination from this site. Comparing the activity concentrations of uranium of the studied samples, with those of the world average soil, it is clear that the present values are within normal range.

Table 10: Activity concentrations of the nuclides in the selected surface sediments samples of Baghdad area of the present and previous studies

Sample No.	U – 238	Th – 232	K – 40	Cs – 137
	Ra – 226	Ra – 228		
	Activity (Bq/Kg)	Activity (Bq/Kg)	Activity (Bq/Kg)	Activity (Bq/Kg)
S4	13.7 ± 0.9	17 ± 1.2	301.6 ± 11.1	n.d.
S6	13.3 ± 0.7	14.4 ± 1	292.5 ± 10.4	1.7 ± 0.2
S7	7.5 ± 0.2	10.2 ± 0.8	251 ± 1	n.d.
S21	12.3 ± 0.6	13 ± 0.6	284.9 ± 11	2 ± 0.2
S24	13.5 ± 0.6	15.5 ± 1.2	246.2 ± 10	3.9 ± 0.3
S27	13.8 ± 0.8	12.8 ± 1.0	253.9 ± 10	1 ± 0.2
S29	12.7 ± 0.3	14.6 ± 1.1	266.5 ± 10.6	1.6 ± 0.2
S30	15.8 ± 1.2	16.4 ± 0.5	315.6 ± 10.9	2 ± 0.2
S33	10.8 ± 0.5	11.3 ± 1	249.6 ± 10.3	2.2 ± 0.2
S36	13.6 ± 0.6	15 ± 0.6	266.7 ± 10.6	0.5 ± 0.1
S39	14.8 ± 0.8	16.4 ± 1.3	349.4 ± 12	3.5 ± 0.2
S42	13.6 ± 0.4	17.5 ± 0.7	321.7 ± 11.93	n.d.
S44	12.8 ± 1	13.1 ± 1.2	254.7 ± 11.43	0.7 ± 0.2
Mean	12.9 ± 0.7	14.4 ± 0.9	281.1 ± 10.1	1.91 ± 0.2
Range	7.5 ± 0.2 – 15.8 ± 1.2	10.2 ± 0.8 – 17.5 ± 0.7	246.2 ± 10 – 349.4 ± 12	n.d. – 3.9 ± 0.3
Marouf *et al*. (2000)	49.0 ± 6 – 80 ± 9.0			2.0 ± 0.8 – 10.8 ± 1.3
Al-Hassany (2003)				3.9 ± 0.8 – 7.9 ± 1.4
n.d.: not detected				
12 ×10^6 Bq/Kg of U^{238} is equal to 1 ppm (Eisebud and Gesell, 1997)				

CONCLUSIONS

Several conclusions can be drawn from the present study as follows:

- Parent rocks of the source area were a major factor influencing the distribution of the heavy minerals and trace elements in the studied sediments.
- Human activities (industrial and municipal) are additional major factors controlling the distribution of many of the heavy minerals and trace elements in the studied samples and resulted in a complex distribution patterns in which more anomalous zones in Rasafa than Karkh side can be noticed, specifically at heavily populated and industrialized area.
- Radiometric measurements revealed that Baghdad surface sediments are free from radioactive pollution.

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