



## Assessment of heavy metals contamination in the Nile River water and adjacent sediments: A case study from Khartoum City and Nile River State, Sudan

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### Abstract

The current study aims to investigate the heavy metals concentration and the degree of pollution in the water and adjacent sediment of the Nile River and its main tributaries at Khartoum City and River Nile State, Sudan. For this purpose, thirty-three water and sediment samples were collected from River Nile, Blue Nile, and White Nile. Water chemical properties and sediment physico-chemical properties were measured. Concentrations of heavy metals (As, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Ti, Zn) were determined for both sediment and water samples using inductively coupled plasma (ICP-OES). Enrichment factor (EF) and geo-accumulation index ( $I_{geo}$ ) were applied to quantify heavy metals pollution levels in sediment samples. The results revealed that only Fe metal detected in the water samples and its concentrations within the permissible maximum limit. This indicated that water is highly suitable for irrigation. Depending on calculated enrichment factor (EF) and geo-accumulation index ( $I_{geo}$ ), sediment samples were found to be enriched and polluted with Mn and Mo particularly at Berber site which may be a consequence of gold mining activities in this area. The study revealed a relatively strong to strong correlation between heavy metals of Co, Cr, Cu, Fe, Mn, Ni, Pb, Ti, Zn ( $r^2=0.84$  to  $0.99$ ) and significant negative correlation with Mo ( $r^2=0.58$  to  $0.73$ ). This study recommends regular monitoring of heavy metals in the Nile River and its main tributaries for conservation and protection from pollution.

**Keywords:** River Nile, heavy metals pollution, ICP-OES, enrichment factor, geo-accumulation index.

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### Introduction

From various water resources in the Sudan, the Nile River and its tributaries are considered to be the primary source of water for human, agriculture, livestock, and wildlife. Despite this importance, the Nile River water and its suspended sediments are subjected to the possibility of contamination by various hydrochemical pollutants; especially heavy metals from various reasons mainly sanitation problems.

Anthropogenic activities not only lead to increasing heavy metals concentrations in the environment, but also it can cause an unnatural enrichment, leading to metal pollution of the surface soils. The soil enriched

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with heavy metals can significantly cause an adverse impact on the population via inhalation, ingestion and dermal contact. The soil-accumulated heavy metals can also pose potential long-term hazards to plants and animals as well as humans that consume these plants (Singh and Kumar, 2006).

Nile River sediments considered as a group of metals that could be released to the overlying water from natural and anthropogenic processes such as dredging and bioturbation, may lead up to potential adverse health effects (Kim et al., 2010). On the other hand the presence of heavy metals in the Nile River sediments is influenced by the particle size of the sediments, this actually attributed toco-precipitation, sorption, and complexing of metals on particle surfaces and coatings (Sakai et al., 1986; Krishna and Govil, 2008).

In Sudan, research in the Nile River water and its adjacent sediment contamination with heavy metals derived as a result of anthropogenic activities and its impacts on environment is not yet clearly understood. Thus, there is a need for re-assessment of heavy metals in the Nile River water and its adjacent sediment to ensure environmental sustainability. The study was carried selected certain location at Nile River and its tributaries in Khartoum city and Northern state, Sudan. The main objectives of this study were: (i) To determine the chemical composition and concentration of heavy metals in the Nile River water (ii) To assess the degree of the heavy metals contamination in the sediment of the Nile River particularly, Khartoum city and Nile River state, Sudan with reference to international standard.

## Material and Methods

### Study area

The study was conducted in five different locations along the Nile River and its main tributaries at Khartoum State and Northern State (Table 1 and Figure 1). The sample from Northern State was selected to be handled as control since the area is remote area and expected to be free from pollution.

Table 1. Location of samples using geographical coordinate system (longitude/latitude)

Site	Longitude	Latitude	River	State
Blue Nile	15°30'58"N	32°38'33"E	Blue Nile	Khartoum
White Nile	15°32'02"N	32°28'53"E	White Nile	Khartoum
Shambat	15°39'34"N	32°30'49"E	Nile River	Khartoum
Wawasi	16°02'36"N	32°34'01"E	Nile River	Khartoum
Berber	17°49'22" N	33°59'59" E	Nile River	Northern State

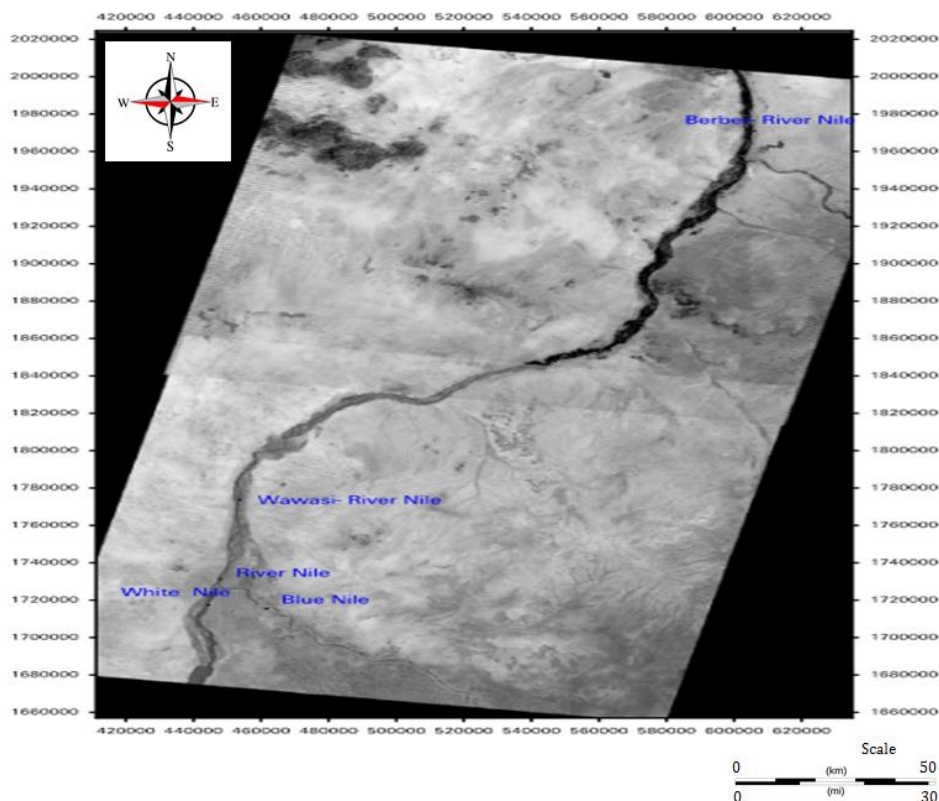


Figure 1. Distribution of sampling sites

## Sampling and physico-chemical analyses

For water sampling, at each location, the polyethylene bottles were rinsed at least three times before sampling. Three surface water samples from 10 cm depth (about 0.25 L for each one) were taken at each sampling site and placed into a 500 ml polyethylene bottle, well closed in order to avoid contamination. A counterparts of sediment samples were collected from 0-10 cm using grab sampler, immediately transferred to the laboratory for analysis in order to avoid changing of redox potential, pH, and pore water. In the laboratory, sub-sediment samples were air-dried ( $23\pm 1$  °C) and passed through 2mm sieve to obtain the fine fraction. The particles-size distribution of these samples was determined using particle size analyzer model (Mastersizer 2000, Malvern) and the textural class was obtained by using the USDA textural triangle according to [Soil Survey Staff \(2014\)](#). Fresh sediments and water chemical properties were determined according to the procedure described by [Binning and Baird \(2001\)](#). Soil pH was measured in 1:5 sediment suspensions using a digital pH meter model (3510, Jenway). The electrical conductivity (EC) was determined in 1:5 sediment extract using a conductivity meter model (4510, Jenway). Percentage of calcium carbonate (%CaCO<sub>3</sub>) was determined by Calcimeter. The samples were treated with 0.1N HCL; the volume of CO<sub>2</sub> from pure calcium carbonate and samples were recorded. Percentage calcium carbonate was then calculated according to [Horvath et al. \(2005\)](#). Soluble cations (Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>2+</sup> and Mg<sup>2+</sup>), and anions (Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup> and PO<sub>4</sub><sup>3-</sup>) were determined in the extracted solutions using ion chromatography model (Dionex™ IC 5000).

## Determination of heavy metals in the sediment and water samples

Microwave digestion oven model (CEM Mars 5) was used to digest the sediment samples. 0.5 gram of air-dried sample was used after a well-milled, and then placed into a microwave oven pipes, 10 ml of nitric acid (HNO<sub>3</sub>) was added to each pipe containing sample and well closed, then introduced into the microwave oven and digested using EPA-3051A according to the method described by [Link et al. \(1997\)](#). For extraction, digested samples were transferred quantitatively into 50 ml volumetric flask and the volume was completed by using distilled water. All digested sediment samples and water were filtered using Whatman No. 42. Concentrations of heavy metals (As, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Ti, Zn) were analyzed for sediment and water samples using inductively coupled plasma (ICP-OES) model (Optima 4300 DV, PerkinElmer Inc.)

## Assessment of heavy metal pollution levels in the sediment samples

In order to verify the quantity of heavy metal pollution levels in the sediment samples; two indices have been applied including the following: Enrichment Factor (EF), and the geo-accumulation index ( $I_{geo}$ ). Enrichment factor was calculated by using the equation described by Sutherland (2000), as follows:

$$EF_m = \frac{C_m(\text{sediment})/C_{Fe}(\text{sediment})}{C_m(\text{earth crust})/C_{Fe}(\text{earth crust})}$$

Where:  $C_m$  (sediment) is the metal concentration in the sediment sample;  $C_{Fe}$  (sediment) is the concentration of the reference metal (Fe) in the sediment sample;  $C_m$  (earth crust) is the metal concentration in the earth crust; and  $C_{Fe}$  (earth crust) is the concentration of the referenced metal (Fe) in the earth crust.

The EF values are classified into five categories: deficiency to minimal ( $EF < 2$ ), moderate ( $2 < EF < 5$ ), significant ( $5 < EF < 20$ ), very high ( $20 < EF < 40$ ), and extremely high enrichment ( $EF > 40$ ).

Whereas, the geo-accumulation index ( $I_{geo}$ ) was calculated by using the following equation:

$$I_{geo} = \text{Log}_2(C_n/1.5B_n)$$

Where:  $C_n$  is measured concentration of heavy metal in the sediment samples,  $B_n$  is geochemical background value in average shale (Turekian and Wedepohl, 1961) of element, and 1.5 is the background matrix correction factor due to lithogenic effects.

The index of geo-accumulation consists of six categories:  $< 1$  (unpolluted), 1–2 (moderately to unpolluted), 2–3 (moderately), 3–4 (moderately to highly polluted), 4–5 (highly polluted), and  $> 5$  (very highly polluted).

## Statistical analysis

The values of maximum, minimum, and averages were calculated, and Tukey significant difference was tested for means separation ( $P < 0.05$ ). All statistical analyses were performed by using statistical package for social science software SPSS Statistics version 16.0 ([IBM Corp., 2012](#)).

## Results and Discussion

### Chemical properties of the River Nile water and its main tributaries

The pH values of water samples for the River Nile and its main tributaries are alkaline (7.4-7.9), this is may be attributed to domination of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  cations as well as  $\text{HCO}_3^-$  anion among various measured soluble ions (Table 2). EC values were ranged from 0.09 to 0.14  $\text{dS m}^{-1}$  in all water samples. These findings were in line with those of previous studies (Osman and Kloas, 2010; Ali et al., 2017). Based on the average concentration values, the water soluble cations were found in the following order:  $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ , where, the soluble in the in following order:  $\text{HCO}_3^- > \text{PO}_4^{3-} > \text{SO}_4^{2-} > \text{Cl}^-$ . This result of soluble cations and anions orders agreed with those obtained by Ali et al. (2017).

Table 2. Summary statistics for the water chemical analysis of the River Nile and its tributaries

Location		pH	EC ( $\text{dS m}^{-1}$ )	Soluble cations (meq $\text{L}^{-1}$ )				Soluble anions (meq $\text{L}^{-1}$ )			
				$\text{Na}^+$	$\text{K}^+$	$\text{Ca}^{2+}$	$\text{Mg}^{2+}$	$\text{Cl}^-$	$\text{HCO}_3^-$	$\text{SO}_4^{2-}$	$\text{PO}_4^{3-}$
Blue Nile	Min	7.30	0.10	0.62	0.07	1.6	1.47	0.03	3.7	0.03	0.07
	Max	7.60	0.16	0.63	0.07	1.85	1.54	0.05	3.9	0.04	0.08
	Av.	7.47	0.13	0.63	0.07	1.70	1.52	0.04	3.79	0.03	0.07
White Nile	Min	7.40	0.09	0.78	0.09	1.13	1.69	0.11	3.49	0.03	0.07
	Max	7.50	0.10	0.82	0.09	1.16	1.73	0.15	3.54	0.04	0.08
	Av.	7.43	0.09	0.8	0.09	1.15	1.72	0.13	3.51	0.03	0.08
River Nile (Wawasi)	Min	7.30	0.09	0.26	0.02	1.88	1.22	0.01	3.26	0.07	0.07
	Max	8.60	0.10	0.30	0.03	1.92	1.31	0.01	3.32	0.09	0.08
	Av.	7.87	0.09	0.28	0.03	1.90	1.25	0.01	3.28	0.08	0.08
River Nile (Shambat)	Min	7.10	0.08	0.39	0.04	1.70	1.26	0.07	3.13	0.11	0.06
	Max	7.80	0.09	0.40	0.04	1.87	1.48	0.08	3.55	0.14	0.07
	Av.	7.40	0.09	0.40	0.04	1.80	1.37	0.08	3.34	0.13	0.07
River Nile (Berber)	Min	7.30	0.14	0.68	0.07	1.34	1.51	0.02	3.44	0.03	0.08
	Max	7.70	0.15	0.69	0.08	1.40	1.59	0.02	3.61	0.04	0.09
	Av.	7.47	0.15	0.69	0.07	1.38	1.54	0.02	3.52	0.04	0.08

### Physico-chemical properties of the River Nile sediment

The textural class of sediment samples from Berber site (control site), Wawasi 1, and White Nile was Sandy; the sand fraction was dominant with an average value amounted to 97.52 %, 95.29 %, and 93.18 %, for the three sites respectively. Contrary to that, the textural class of sediment samples from Wawasi 2, Bule Nile, and Shmabat is silt loam and dominated by silt fraction that amounted to 71.22 %, 54.52 %, and 51.18 %, respectively. Clay fraction was higher in the sediment samples from Shambat and Waswasi 2 sites as compared to other studied sites.

The pH values of sediment samples were alkaline ranged from 7.7 to 7.79 for Blue Nile site, 8.52 to 8.53 for White Nile site, 8.18 to 8.19 for Wawasi 1 site, 7.73 to 7.75 for Wawasi 2 site, 8.01 to 8.03 for Shambat site, and 8.17 to 8.24 for Berber site, with an average value of 7.78, 8.53, 8.19, 7.74, 8.02, and 8.21, respectively. The higher values of EC recorded at Wawasi 1 site, with an average value of 1.2  $\text{dS m}^{-1}$ . Meanwhile, this site showed higher values of soluble  $\text{Na}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Cl}^-$ , and  $\text{SO}_4^{2-}$ , with an average value of 3.76 meq  $\text{L}^{-1}$ , 11.80 meq  $\text{L}^{-1}$ , 6.66 meq  $\text{L}^{-1}$ , and 6.39 meq  $\text{L}^{-1}$ , respectively. Based on the average values, the sediment soluble cations were obtained in the following decreasing order:  $\text{Mg}^{2+} > \text{Ca}^{2+} > \text{Na}^+ > \text{K}^+$ . In contrast, the average values of the soluble anions were found in the following order:  $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{PO}_4^{3-}$ . The order of  $\text{Na}^+$ ,  $\text{K}^+$ , and  $\text{HCO}_3^-$  remains same as observed in the water samples (details are shown in Table 3).

### Heavy metals concentration in the River Nile water and its adjacent sediment

The concentrations of the heavy metals in the Nile River water and its main tributaries are shown in (Tables 4). The results showed that, in the River Nile water samples and its main tributaries, only Fe metal was detected (0.42 to 2.46  $\text{mg L}^{-1}$ ), with an average value ranged between 0.63 to 2.18  $\text{mg L}^{-1}$  at the different sites. The results indicated that the average values of Fe metal concentrations were lower than maximum acceptable concentrations limit for irrigation water (Ayers and Westcot, 1994). Contrary to Fe metal, the other heavy metals (As, Cd, Co, Cr, Cu, Mn, Mo, Ni, Pb, Ti, and Zn) were not detected in all sites (Table 4).

Table 3. Summary statistics for the sediment physico-chemical analysis of the River Nile and its tributaries

Location	Particle size distribution (%)			Textural class (USDA)	pH	EC dS m <sup>-1</sup>	Soluble cations (meq L <sup>-1</sup> )				Soluble anions (meq L <sup>-1</sup> )				
	Sand	Silt	Clay				Na <sup>+</sup>	K <sup>+</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Cl <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	PO <sub>4</sub> <sup>3-</sup>	
Blue Nile	Min	37.42	52.8	6.35	Silt loam	7.76	0.33	1.15	0.42	2.92	1.82	1.88	2.97	1.26	0.08
	Max	40.48	56.23	6.48	Silt loam	7.79	0.37	1.19	0.47	2.97	1.85	1.93	3.02	1.32	0.09
	Av.	38.95	54.52	6.42	Silt loam	7.78	0.35	1.17	0.45	2.95	1.84	1.91	3.00	1.29	0.08
White Nile	Min	92.26	5.90	0.50	Sand	8.52	0.90	2.64	2.11	3.32	7.32	4.22	5.40	4.88	ND
	Max	94.10	7.74	0.90	Sand	8.53	1.01	2.69	2.13	3.35	7.35	4.27	5.70	4.91	ND
	Av.	93.18	6.82	0.70	Sand	8.53	0.96	2.67	2.12	3.34	7.34	4.25	5.55	4.90	ND
River Nile (Wawasi 1)	Min	94.77	4.20	1.03	Sand	8.18	1.18	3.74	3.49	3.79	11.7	6.59	8.18	6.35	ND
	Max	95.80	5.23	1.50	Sand	8.19	1.21	3.78	3.52	3.82	11.9	6.72	8.24	6.42	ND
	Av.	95.29	4.72	1.27	Sand	8.19	1.20	3.76	3.51	3.81	11.80	6.66	8.21	6.39	ND
River Nile (Wawasi 2)	Min	12.92	70.62	13.09	Silt loam	7.73	0.46	2.35	2.03	2.94	6.14	2.88	7.60	2.25	ND
	Max	15.09	71.82	15.87	Silt loam	7.75	0.48	2.38	2.06	2.98	6.18	2.94	7.80	2.32	ND
	Av.	14.00	71.22	14.48	Silt loam	7.74	0.47	2.37	2.05	2.96	6.16	2.91	7.80	2.29	ND
River Nile (Shambat)	Min	36.58	50.61	11.66	Silt loam	8.01	0.48	2.39	3.71	2.59	3.35	3.38	5.64	2.60	ND
	Max	37.65	51.74	12.48	Silt loam	8.03	0.53	2.42	3.75	2.61	3.39	3.42	5.75	2.80	ND
	Av.	37.12	51.18	12.07	Silt loam	8.02	0.55	2.45	3.73	2.60	3.37	3.40	5.69	2.70	ND
River Nile (Berber)	Min	97.02	0.80	2.50	Sand	8.17	0.55	2.59	2.04	4.50	7.97	2.29	11.99	2.32	ND
	Max	98.01	0.94	1.05	Sand	8.24	0.58	2.63	2.07	4.70	8.20	2.33	12.15	2.43	ND
	Av.	97.52	0.87	1.78	Sand	8.21	0.57	2.61	2.06	4.60	8.09	2.31	12.07	2.38	ND

ND = not detectable

Table 4. Heavy metals concentrations in the water samples of the River Nile and its main Tributaries

Location		Heavy metals concentrations (mg L <sup>-1</sup> )											
		As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn	Ti	Zn
Blue Nile	Min	ND	ND	ND	ND	ND	0.96	ND	ND	ND	ND	ND	ND
	Max	-	-	-	-	-	1.16	-	-	-	-	-	-
	Av.	-	-	-	-	-	1.06	-	-	-	-	-	-
White Nile	Min						0.42						
	Max	ND	ND	ND	ND	ND	0.83	ND	ND	ND	ND	ND	ND
	Av.	-	-	-	-	-	0.63	-	-	-	-	-	-
Wawasi	Min	-	-	-	-	-	0.53	-	-	-	-	-	-
	Max	ND	ND	ND	ND	ND	0.97	ND	ND	ND	ND	ND	ND
	Av.	-	-	-	-	-	0.75	-	-	-	-	-	-
Shambat	Min	-	-	-	-	-	0.68	-	-	-	-	-	-
	Max	ND	ND	ND	ND	ND	0.90	ND	ND	ND	ND	ND	ND
	Av.	-	-	-	-	-	0.79	-	-	-	-	-	-
Berber	Min	ND	ND	ND	ND	ND	1.90	ND	ND	ND	ND	ND	ND
	Max	-	-	-	-	-	2.46	-	-	-	-	-	-
	Av.	-	-	-	-	-	2.18	-	-	-	-	-	-

ND = not detectable

Consequently, their concentrations in the water samples indicating high suitable for irrigation according to the previous authors (Ayers and Westcot, 1994). For sediment samples, As and Cd metals were remains same as observed in the water samples, and not detected (Table 5). These findings indicated that their values concentrations were lower than those in the common range of soil (Lindsay, 1979). The concentrations of Co, Cr, and Cu ranged from 4.2 to 25.7 mg kg<sup>-1</sup>, 3.2 to 54.3 mg kg<sup>-1</sup>, and 4.7 to 42.3 mg kg<sup>-1</sup>, respectively. This result indicated that the three metals concentrations were within the common range of soil according to Murthy (2008) although lower than their target value according to Dutch standards. Similarly, the concentrations of Fe, Mn, and Mo were in common range of soil according to the previous reference and their concentrations ranged between 3438 to 31140 mg Fe kg<sup>-1</sup>, 123.7 to 999.5 mg Mn kg<sup>-1</sup>, and zero to 2.6 mg Mo kg<sup>-1</sup>. The concentrations of Ni, Pb, and Zn were in range of 0.97 to 44.3 mg kg<sup>-1</sup>, zero to 9.5 mg kg<sup>-1</sup>, and 5.2 to 71.9 mg kg<sup>-1</sup>, respectively, which in common range of soil (Lindsay, 1979). The concentrations of Mo, Ni, Pb, and Zn were lower than target value of Dutch standard. Furthermore, the concentration of Ti was found in range of 102.8 to 1612 mg kg<sup>-1</sup>, with an average values ranged between 106.9 to 1604.5 mg kg<sup>-1</sup> at the different sites.

Table 5. Heavy metals concentrations in the sediment samples of the studied sites.

Location		Heavy metals concentrations (mg kg <sup>-1</sup> )											
		As	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Ti	Zn
Blue Nile	Min	ND	ND	15.70	23.80	28.30	26355.0	598.20	0.50	28.30	5.80	1597.0	53.70
	Max	ND	ND	20.60	37.90	30.50	26430.0	612.10	0.80	31.40	8.10	1612.0	58.20
	Av.	ND	ND	18.15	30.85	29.40	26392.5	605.15	0.65	29.85	6.95	1604.5	55.94
White Nile	Min	ND	ND	7.80	9.30	10.50	11548.0	156.70	ND	18.00	ND	723.8	22.80
	Max	ND	ND	9.20	11.20	12.30	11570.0	159.00	ND	20.00	ND	728.8	25.50
	Av.	ND	ND	8.50	10.25	11.40	11559.0	157.85	ND	19.00	ND	726.3	24.15
Wawasi 1	Min	ND	ND	4.20	7.80	4.70	9147.0	123.70	1.90	6.70	ND	562.7	15.30
	Max	ND	ND	5.30	9.00	6.10	9152.0	128.80	2.60	7.30	ND	566.6	19.40
	Av.	ND	ND	4.75	8.40	5.40	9149.5	126.25	2.25	7.00	ND	564.7	17.35
Wawasi 2	Min	ND	ND	22.30	48.20	37.50	31098.0	982.70	ND	37.80	6.80	1413.0	64.80
	Max	ND	ND	25.70	54.30	42.30	31140.0	999.50	ND	44.30	9.50	1427.0	71.90
	Av.	ND	ND	24.00	51.25	39.90	31119.0	991.10	ND	41.05	8.15	1420.0	68.35
Shambat	Min	ND	ND	13.50	37.40	22.50	25187.0	587.80	ND	25.80	5.80	982.6	47.30
	Max	ND	ND	16.90	42.00	27.50	25210.0	602.50	ND	30.70	8.90	993.2	53.10
	Av.	ND	ND	15.20	39.70	25.00	25198.5	595.15	ND	28.25	7.35	987.9	50.20
Berber	Min	ND	ND	ND	3.20	4.70	3438.0	187.20	0.88	0.97	ND	102.8	5.20
	Max	ND	ND	ND	5.70	7.90	3452.0	193.30	1.40	1.60	ND	111.0	7.70
	Av.	ND	ND	ND	4.45	6.30	3445.0	190.25	1.14	1.29	ND	106.9	6.45

ND = not detectable

In order to describe the pollution levels of heavy metals in the study area, two indices were applied including enrichment factor (EF) and geo-accumulation index ( $I_{geo}$ ). Recently, it has been reported that the EF is appropriate measure of geochemical trends and can be applied for contemplating on lithogenic or anthropogenic origin of heavy metals (Ye et al., 2011). Depending on the category and the obtained values of EF, all investigated metals were found to be in their minimum limits with  $EF < 2$ , except for Mn and Mo at the Berber area were obtained to be moderate and significant with an EF values of 2.42 and 11.09, respectively (Figure 2). On the other hand, EF values for heavy metals more than 2 considered as major concern contaminant as suggested by some researchers (e.g. Yongming et al., 2006; Ye et al., 2011). In this context the EF values for Mn and Mo at the Berber area were slightly contaminated. Furthermore, Hernandez et al. (2003) suggesting that the value of  $EF \leq 2$  indicates that the heavy metals may be as a result of crustal materials or natural weathering processes. Whilst, EF values higher than 2 indicate that the heavy metals are mainly due to anthropogenic inputs. Thus, the heavy metals of Mn and Mo having EF value higher than 2, indicating that these heavy metals might be enriched as a result of anthropogenic inputs might be probably from mining activities. Previously, it has been demonstrated that the geo-accumulation index ( $I_{geo}$ ) can be used effectively in explaining soil quality. Based on its category and the obtained values of  $I_{geo}$ , for Cr, Cu, Ni, Pb, and Zn, all sediment samples at all sites were unpolluted (Figure 3).

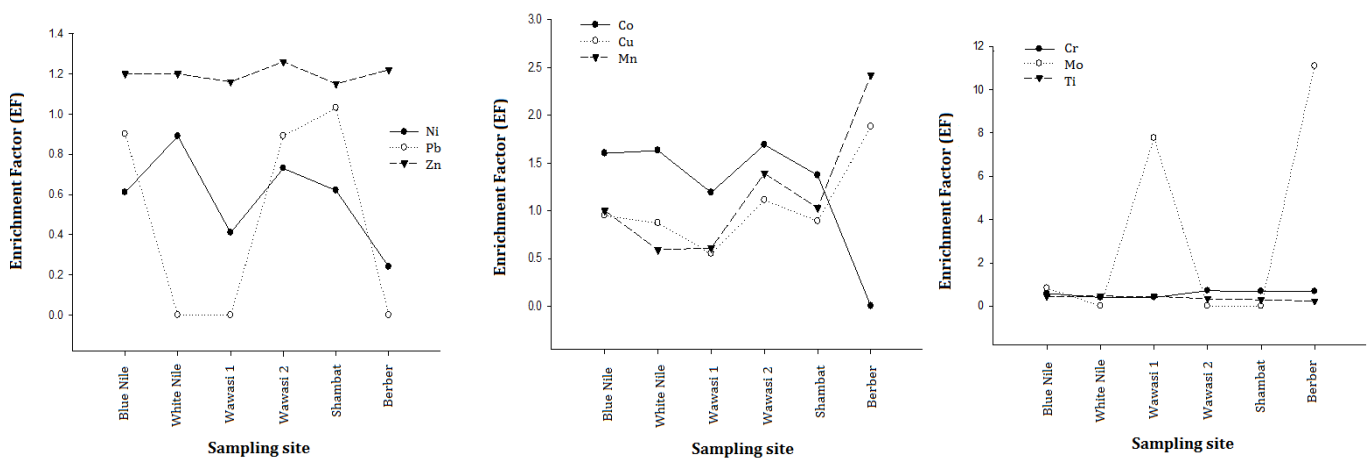


Figure 2. Enrichment factor (EF) values for heavy metals at different sites

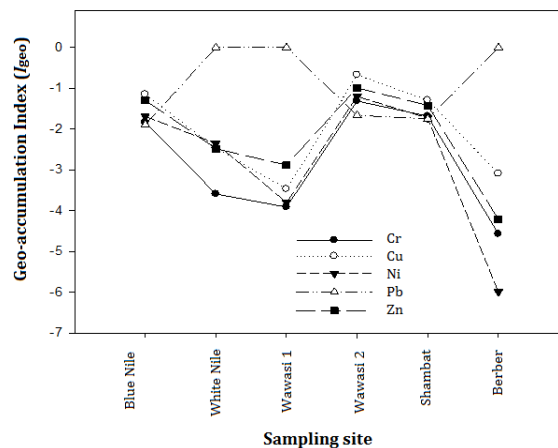


Figure 3. Geo-accumulation index ( $I_{geo}$ ) values for Cr, Cu, Ni, Pb, and Zn at different sites

### Correlation between the sediment solution composition and heavy metals

Table 6 showed the Pearson's correlation analysis between the different sediment solution composition and heavy metals. According to correlation's coefficient, clay content showed relatively strong positive correlation with silt ( $r^2=0.92$ ), Co ( $r=0.86$ ), Cr ( $r^2=0.96$ ), Cu ( $r^2=0.92$ ), Fe ( $r^2=0.90$ ), Mn ( $r^2=0.95$ ), Ni ( $r^2=0.88$ ), Pb ( $r^2=0.92$ ), and Zn ( $r^2=0.90$ ).

Table 6. Correlation coefficients matrix ( $r$ ) among physico-chemical properties and heavy metals of the sediment samples

	Clay	Silt	pH	EC	Ca	Mg	Na	K	Cl	HCO <sub>3</sub>	SO <sub>4</sub>	Co	Cr	Cu	Fe	Mn	Mo	Ni	Pb	Ti	Zn	
Clay	1.00																					
Silt	0.92**	1.00																				
pH	-0.77*	0.87*	1.00																			
EC	-0.62*	-0.72	0.72*	1.00																		
Ca	-0.36	-0.63	0.55*	0.85*	1.00																	
Mg	0.07	-0.25	0.32	0.51	0.77	1.00																
Na	-0.72*	-0.79	0.48	0.33	0.44	-0.01	1.00															
K	-0.54*	-0.73	0.54*	0.83*	0.92**	0.48	0.67	1.00														
Cl	-0.35	-0.48	0.54*	0.93**	0.87*	0.67	0.12	0.75	1.00													
HCO <sub>3</sub>	-0.27	-0.52	0.29	0.19	0.56	0.32	0.83*	0.66	0.10	1.00												
SO <sub>4</sub>	-0.52*	-0.65	0.66*	0.99**	0.88*	0.60	0.24	0.81*	0.97**	0.17	1.00											
Co	0.86*	0.97**	-0.78*	-0.58	-0.59	-0.29	-0.86	-0.68	-0.38	-0.64	-0.52	1.00										
Cr	0.96**	0.99**	-0.84*	-0.69	-0.56	-0.16	-0.80	-0.69	-0.44	-0.48	-0.61	0.96**	1.00									
Cu	0.92**	0.99**	-0.83*	-0.73	-0.63	-0.31	-0.75	-0.70	-0.53	-0.46	-0.66	0.97**	0.98**	1.00								
Fe	0.90*	0.99**	-0.81*	-0.62	-0.60	-0.22	-0.88	-0.72	-0.39	-0.63	-0.55	0.99**	0.98**	0.97**	1.00							
Mn	0.95**	0.97**	-0.86*	-0.73	-0.55	-0.24	-0.66	-0.61	-0.51	-0.32	-0.66	0.93**	0.98**	0.99**	0.93**	1.00						
Mo	-0.59*	-0.58*	0.15	0.52	0.55	0.20	0.64	0.68	0.55	0.41	0.50	-0.62*	-0.61*	-0.66*	-0.61*	-0.58*	1.00					
Ni	0.88*	0.94**	-0.69*	-0.56	-0.56	-0.24	-0.87	-0.67	-0.38	-0.61	-0.50	0.99**	0.95**	0.95**	0.96**	0.92*	-0.73	1.00				
Pb	0.92**	0.98**	-0.86*	-0.76	-0.64	-0.18	-0.80	-0.78	-0.51	-0.52	-0.68	0.92**	0.98**	0.95**	0.96**	0.94**	-0.58	0.90*	1.00			
Ti	0.69	0.90*	-0.76*	-0.53	-0.68	-0.25	-0.83	-0.71	-0.35	-0.79	-0.49	0.95**	0.85*	0.87*	0.93**	0.80*	-0.49	0.90*	0.84*	1.00		
Zn	0.90*	0.99**	-0.82*	-0.63	-0.59	-0.45	-0.85	-0.69	-0.40	-0.60	-0.55	0.99**	0.98**	0.98**	0.99**	0.95**	-0.61	0.98**	0.95**	0.93**	1.00	

\*P&lt;0.05, \*\*P&lt;0.01



Contrary to that, significant negative correlation were found with pH ( $r^2=0.77$ ), EC ( $r^2=0.62$ ), Na ( $r^2=0.72$ ), K ( $r^2=0.54$ ),  $SO_4$  ( $r^2=0.52$ ), and Mo ( $r^2=0.59$ ). Whilst, silt content showed relatively strong positive correlation with all studied heavy metals, except with Mo significant negative correlation were found between them ( $r^2=0.58$ ). In addition, soil pH revealed significant correlation with EC ( $r^2=0.72$ ), Ca ( $r^2=0.55$ ), K ( $r^2=0.54$ ), Cl ( $r^2=0.54$ ), and  $SO_4$  ( $r^2=0.66$ ). Also, relatively strong positive correlation were found for EC against Cl ( $r^2=0.93$ ) and  $SO_4$  ( $r^2=0.99$ ). On the other hand, relatively strong positive correlation were also obtained for Cl versus  $SO_4$  ( $r^2=0.97$ ). Moreover, heavy metals of (Co, Cr, Cu, Fe, Mn, Ni, Pb, Ti, Zn) showed relatively strong to strong positive significant correlation ( $r^2=0.84$  to  $0.99$ ) and significant negative correlation were found against Mo ( $r^2=0.58$  to  $0.73$ ).

## Conclusion

The findings of this study showed lower values of salinity in both water and sediment samples, and domination of sand fraction in the sediment samples in most studied sites. The heavy metals in this study were obtained in the following decreasing order: Fe > Ti > Mn > Zn > Ni > Cr > Cu > Co > Pb > Mo. Among the different studied heavy metals, the Nile River sediment was polluted with Mn and Mo particularly at the Berber site. The results of the Pearson's correlation for heavy metals in our study pointed out relatively strong to strong positive significant correlation between them ( $r^2=0.84$  to  $0.99$ ) and significant negative correlation were found versus Mo ( $r^2=0.58$  to  $0.73$ ).

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