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Trace elements composition of leachate from Henchir El Yahoudia landfill and lake water of Sebkhat Sejoumi[#]

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Abstract
Landfill leachate samples collected from observation boreholes and spills within closed municipal solid waste (MSW) landfill in Henchir El Yahoudia, and lake water of Sebkhat Sejoumi that is an isolated salt lake closed to the landfill, are analyzed for determing the concentration of 74 major and trace elements including potentially toxic elements (PTEs). The concentration of five non-metal trace elements, B, S, As, Se, and Br, are showing abnormally higher concentrations in comparing with the regulation values. Five toxic heavy metals, Ti, Cr (total), Co, Ni, and Hg, also indicate higher concentration above the regulation levels. These elements are considered to be pollutants caused by solid waste disposal in the landfill. The trace element composition of lake water of Sebkhat Sejoumi is similar to that of the leachate in non-metal elements, B, S, As, Se, and Br. However the heavy metals composition of lake water does not correspond to that of leachate except Ti and Cu, where the concentration of heavy metals in lake water is very low in comparing with that of leachate. The relative depletion of heavy metals is possibly due to some natural attenuation processes such as cation adsorption, cation exchange, and precipitation during transportation and standing of water in the lake basin.
Key Words
Trace elements, Landfill leachate, Contaminant transport, Non-metals, Heavy metals, Natural attenuation

I. Introduction

Solid wastes accumulated in landfills decompose by a combination of chemical, physical, and biological processes. Those decomposing reaction processes occur as infiltrative water percolates through the solid waste materials in landfill. As a result, various organic and inorganic compounds leach out from the solid waste landfill. The products of the complex combination of reactions are potentially transported further by the percolating leachate and by the landfill gases produced. Thus landfill leachate contains many constituents, and its quality is heterogeneous.

The landfill leachate often migrates surrounding environment through groundwater of spills owing to a lack of appropriate shielding of landfill. In this case the migration provokes environmental pollution especially in the local hydrosphere. Such situation can be found in the Henchir El Yahoudia landfill, that was closed in 1999, and adjacent Lake Sebkhat Sejoumi of which lake basin is completely isolated without major inlet and outlet. The lake water is mostly supplied by rain water and runoff in winter season, and the lake water is almost evaporated in summer season. Therefore the quality of lake water is easily affected by the inflow of the landfill leachate and wastewater.

In this paper we report the result of trace element analysis of landfill leachate and lake water collected from the municipal solid waste (MSW) landfill and Lake Sebkhat Sejoumi in Henchir El Yahoudia area, and discuss about the behaviour of trace element and environmental risks based on the regulation.

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II. Samples

The samples analysed were collected from the open standpipe piezometers and leachate spills/pools in closed MSW landfill at Henchir El Yahoudia, where landfill leachate continuously pollute the Lake Sebkhat Sejoumi that is an isolated salt lake basin without major inlet and outlet. The sampling location is given in the locality map of Figure 1, and a typical field occurrence of leachate pools is shown in Plate 1.

Plate 1: Occurrence of the leachate pool LP2 in the Henchir El Yahoudia landfill

Table 1: List of samples for analysis

Sample ID	Type of sample	Sampling
LP1	Leachate pool within the landfill	February 2002, Nasser (2002)
LP2	Leachate pool within the landfill	February 2002, Nasser (2002)
LP3	Leachate pool within the landfill	February 2002, Nasser (2002)
LP4	Leachate pool within the landfill	February 2002, Nasser (2002)
OG1	Leachate (piezometer F.2.2)	March 2001, Kallali and Yoshida (2001)
OG3	Leachate (piezometer F1.16)	March 2001, Kallali and Yoshida (2001)
OR1	Leachate (piezometer F1.14)	March 2001, Kallali and Yoshida (2001)
OR3	Leachate (piezometer F1.24)	March 2001, Kallali and Yoshida (2001)
OR5	Leachate (piezometer SC13)	March 2001, Kallali and Yoshida (2001)
OR7	Leachate (piezometer F1.12)	March 2001, Kallali and Yoshida (2001)
L1	Lake water near the landfill	February 2002, Nasser (2002)
L2	Lake water near the landfill	February 2002, Nasser (2002)

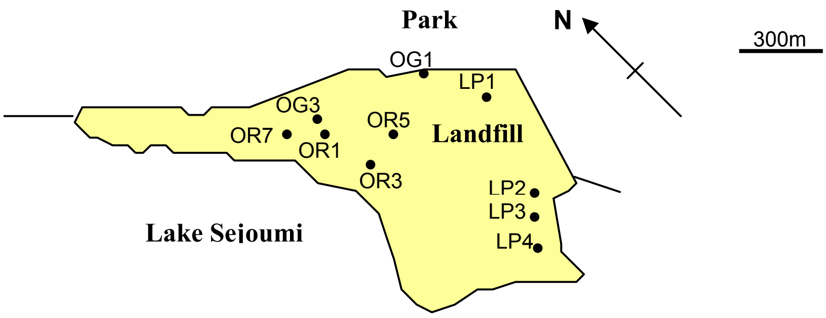

Figure 1: Sampling locality map

III. Analytical Methods

At first, the samples were treated by 30% H_2O_2 solution and organic matters contained in the samples were completely decomposed. Then the sample is prepared for pH<2 using HNO_3. Analysis was made by an Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Total 74 elements were measured: Li, Be, B, Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, I, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi, Th, and U.

IV. Results and Discussion

IV-1. Trace Element in the Landfill Leachate Samples

The results of trace element analysis of ten landfill leachate samples (LP series, OG series, and OR series) and two lake water samples (L1 and L2) are summarized in Table 2 and basic statistics is shown in Table 3. For the statistics, previous data of heavy metal analysis of leachate samples collected from the same landfill by Sothom et al. (2000) are incorporated.

Table 2: Result of trace element analysis of landfill leachate and lake water (ND: not detected)

ELEMENT	Li	Be	B	Na	Mg	Al	Si	P	S	Cl	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge
unit	ppb	ppb	ppb	ppm	ppm	ppb	ppb	ppb	ppm	ppm	ppm	ppm	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
LP1	620	ND	6380	10813	13.51	2910	20400	116.6	380	16900	5440	121.7	19.6	2200	520	11536	78.4	5120	185.9	1079	258	1083	4.8	3.6
LP2	1180	ND	8900	17512.5	414.3	3970	26150	55.88	2300	39050	7783	154.9	20.6	2610	1810	23952	60	5780	355.7	2066	692	889	6	7.4
LP3	860	ND	5690	10541.5	215.5	310	42090	27.69	1100	21330	3508	125.5	26.6	360	390	2177	33.3	6460	193.8	945	689	203	1.2	2.7
LP4	490	ND	2860	8848.94	67.77	1070	22700	30.98	230	13580	3561	91.18	16	900	340	4368	48.3	3620	167.5	756	179	220	2	3.2
OG 1	322	ND	2891	6622.38	294.6	1645	22141	32.83	273	11123	2069	121.7	24.08	420	154	1595	42.14	1827	72.17	587.3	404.6	705.6	1.4	1.82
OG 3	336	ND	1211	5929.66	29.27	1743	21420	62.73	84	7455	4754	71.15	20.37	434	105	1422	66.5	5313	65.87	454.3	339.5	117.6	1.47	1.19
OR 1	333	ND	3015	5041.51	19.18	1341	22257	49.47	162	9360	4843	73.75	27.36	360	99	1805	34.56	1647	63.63	464.4	231.3	167.4	1.8	1.8
OR 3	336	ND	15596	5950.41	27.41	6216	30520	80.34	147	7238	5609	82.12	24.43	525	84	1398	32.76	1197	103.46	534.1	170.8	166.6	1.61	2.1
OR 5	392	ND	1988	3900.37	255.1	441	22540	13.54	56	8484	1257	85.83	22.61	161	133	1029	26.6	812	51.59	427.7	196.7	63.7	0.49	1.12
OR 7	297	ND	2619	4871.98	13.36	405	24201	46.4	63	5121	5033	57.43	18.72	441	108	1885	23.4	2826	80.73	376.2	163.8	305.1	1.35	1.8
L1	1734	ND	6840	104417	7721	214	2526	5.48	5550	227556	490.1	929.9	14.42	342	638	166.8	412.7	646	8.44	18.2	2343	98.4	0.74	3.04
L2	1496	ND	7108	108458	6331	270	1852	4.996	5302	188270	432.2	1185	17.1	246	626	80	364.9	920	8.1	9.2	3005	61.4	0.62	2.06

ELEMENT	As	Se	Br	Rb	Sr	Y	Zr	Nb	Mo	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Cs	Ba	La	Ce	Pr
unit	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
LP1	1010	151	26500	1927.2	3404	1.9	1094	18.7	32	ND	ND	5	2.5	1.2	0.1	559.9	37.7	ND	6400	12.7	622.1	2.8	2.8	1.1
LP2	1800	404	78810	2964.6	4909	1.7	192	39	82	0.7	ND	ND	1.8	1.8	0.4	511	87	1.5	15410	4.7	413	1.4	1.1	0.5
LP3	350	246	44410	1645.2	3341	0.6	122	9.6	68	ND	ND	ND	2.9	1	0.1	171.2	37.1	ND	8610	4	267.5	0.9	0.9	0.2
LP4	400	150	29040	1215.4	1485	0.7	139	9.2	21	ND	ND	ND	ND	1.2	ND	330.9	21.6	ND	8690	3	469.6	1.2	1.2	0.2
OG 1	553	106.4	14287	482.37	8389	0.77	74.9	6.51	16.1	ND	1.19	ND	0.42	1.05	0.35	201.7	13.44	0.91	346990	2.87	624.8	0.91	1.19	0.14
OG 3	735	78.4	9604	1074.5	1467	0.77	42.7	3.5	23.8	ND	ND	ND	1.33	1.19	0.28	138.9	18.76	ND	201439	6.72	561.7	0.91	1.26	0.21
OR 1	747	77.4	11979	976.41	1747	0.63	84.6	4.95	7.2	ND	ND	ND	0.54	ND	0.18	98.01	79.65	0.54	178722	4.32	395.7	0.72	0.81	0.09
OR 3	469	82.6	12159	1077.02	2221	0.63	113.4	4.97	10.5	ND	ND	ND	0.56	1.4	0.42	267.3	23.66	ND	92491	5.46	747.7	0.63	0.84	0.14
OR 5	763	87.5	12628	397.18	5327	0.28	24.5	3.36	8.4	ND	0.42	ND	ND	ND	0.14	138	15.12	0.63	178430	0.84	496.9	0.21	0.28	ND
OR 7	180	46.8	6894	611.19	1194	0.36	58.5	4.77	15.3	ND	ND	ND	0.54	1.17	0.27	185.9	9.9	ND	87291	2.88	341.9	0.54	0.54	0.09
L1	572	1645	379652	101.46	32505	0.2	2.4	2.12	9.6	0.28	4.96	0.4	0.9	0.9	0.06	8.96	6.84	4.92	3608	0.46	43.8	0.84	0.1	0.16
L2	586	1559	350674	97.22	41039	0.26	1.6	1.28	10.6	0.26	5.92	ND	0.34	0.52	0.04	5.48	7.52	4.58	2728	0.34	55.02	0.76	0.06	0.06

ELEMENT	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Th	U
unit	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb
LP1	2.6	0.9	0.6	1.2	0.5	0.6	0.4	0.4	0.3	0.4	0.3	15.5	0.7	44	0.1	ND	1.9	0.4	1.2	3	ND	58	1.3	3.5	2.6
LP2	1.4	ND	0.2	1.7	0.1	0.3	0.2	0.2	0.1	0.2	0.1	3.1	0.7	44	0.3	0.6	ND	0.3	ND	ND	ND	15	0.8	2	11.7
LP3	1	ND	0.1	0.7	0.1	0.1	ND	0.1	ND	0.1	ND	1.8	ND	34	0.2	1	ND	0.1	ND	1	ND	40	0.7	2	9.3
LP4	1.1	ND	ND	0.4	ND	0.1	ND	0.1	ND	ND	ND	1.9	ND	36	0.1	1.6	ND	0.1	ND	1	ND	29	ND	1.3	2.1
OG 1	1.12	ND	ND	0.07	ND	0.07	ND	ND	ND	ND	ND	1.05	ND	42	0.07	1.61	1.61	0.07	0.49	1.4	ND	34.3	ND	0.91	2.31
OG 3	0.98	ND	ND	0.28	ND	0.07	ND	ND	ND	ND	ND	0.77	ND	21.7	0.07	3.43	0.63	ND	ND	ND	0.07	73.5	0.42	ND	1.89
OR 1	0.72	ND	ND	0.09	ND	0.09	ND	ND	ND	ND	ND	1.26	ND	20.7	0.09	6.66	0.81	ND	ND	ND	ND	21.6	ND	ND	3.87
OR 3	0.7	ND	ND	0.07	ND	0.07	ND	ND	ND	ND	ND	1.82	ND	21.7	0.07	1.82	0.42	ND	ND	ND	ND	14	0.42	0.42	1.89
OR 5	0.35	ND	ND	0.07	ND	ND	ND	ND	ND	ND	ND	0.42	0.7	30.8	ND	4.83	ND	ND	ND	ND	ND	14.7	0.98	ND	2.8
OR 7	0.45	ND	ND	0.36	ND	ND	ND	ND	ND	ND	ND	0.81	ND	21.6	ND	3.15	ND	ND	ND	ND	ND	37.8	ND	ND	2.25
L1	0.4	0.3	ND	0.06	ND	ND	0.1	ND	ND	ND	ND	0.06	3.06	ND	0.1	14.2	ND	ND	ND	0.8	ND	26.8	0.32	1.18	3.58
L2	0.36	ND	ND	0.04	ND	ND	0.08	ND	ND	ND	ND	ND	1.86	ND	0.1	13.64	ND	ND	ND	ND	ND	10.8	0.42	1.58	4.32

The concentration of following twenty-two trace elements is very small showing near the detection limit or below the detection limit (ND) in given samples of leachate and lake water: Be, Ru, Rh, Pd, Te, Sm, Eu, Tb, Dy, Ho, Er, Tm, Yb, Lu, Ta, Ir, Pt, Au, Tl, Bi, and Th.

The concentration of dissolved elements in the leachate samples collected from leachate pool (LP series) is much higher than that from landfill's interior (OG and OR series), which may be caused by a condensation effect of natural evaporation on leachate pools.

Table 3: Basic statistics of trace element composition in landfill leachate. The data of some heavy metals, Cr, Ni, Zn, Cd, and Pb, are integrated with previous data by Sothom et al. (2000).

Element	Unit	Detection Limit	N	Mean	Minimum	Maximum	Standard Deviation
Li	ppb	1	10	516.6	297.0	1180.0	292.5
Be	ppb	0.05	0	--	--	--	--
B	ppb	20	10	5115	1211	15596	4369
Na	ppb	50	10	8003	3900	17513	4100
Mg	ppb	50	10	135	13	414	147
Al	ppb	1	10	2005.1	310.0	6216.0	1879.9
Si	ppb	1	10	25441.9	20400.0	42090.0	6528.3
P	ppb	20	10	52	14	117	30
S	ppm	1	10	479.5	56.0	2300.0	709.8
Cl	ppm	1	10	13964.1	5121.0	39050.0	10096.4
K	ppb	50	10	4386	1257	7783	1871
Ca	ppb	50	10	99	57	155	31
Sc	ppb	0.05	10	22.04	16.00	27.36	3.62
Ti	ppb	10	10	841	161	2610	850
V	ppb	1	10	374.3	84.0	1810.0	526.4
Cr	ppb	0.5	19	3062.5	60.0	23952.0	5651.5
Mn	ppb	0.05	10	44.60	23.40	78.40	18.32
Fe	ppb	10	10	3460	812	6460	2084
Co	ppb	0.02	10	134.04	51.59	355.70	94.59
Ni	ppb	0.2	19	611.6	--	2066.0	417.5
Cu	ppb	0.1	10	332.47	163.80	692.00	203.85
Zn	ppb	0.5	19	363.7	30.0	1083.0	308.4
Ga	ppb	0.05	10	2.21	0.49	6.00	1.75
Ge	ppb	0.05	10	2.67	1.12	7.40	1.85
As	ppb	1	10	700.7	180.0	1800.0	456.0
Se	ppb	0.5	10	143.0	46.8	404.0	107.8
Br	ppb	5	10	24631	6894	78810	22253
Pb	ppb	0.1	10	1237.11	397.18	2964.60	775.63
Sr	ppb	0.01	10	3348.361	1194.480	8388.800	2291.112
Y	ppb	0.01	10	0.834	0.280	1.900	0.536
Zr	ppb	0.5	10	194.6	24.5	1094.0	319.9
Nb	ppb	0.01	10	10.456	3.360	39.000	11.016
Mo	ppb	0.1	10	28.43	7.20	82.00	25.87
Ru	ppb	0.05	1	0.7	0.7	0.7	--
Rh	ppb	0.01	2	0.805	0.42	1.19	--
Pd	ppb	0.2	1	5	5	5	--
Ag	ppb	0.05	8	1.32	0.42	2.90	0.98
Cd	ppb	0.05	17	17.06	1.00	40.00	16.71
In	ppb	0.01	9	0.249	0.100	0.420	0.125
Sn	ppb	0.05	10	260.29	98.01	559.90	160.06
Sb	ppb	0.05	10	34.39	9.90	87.00	27.42
Te	ppb	0.05	4	0.90	0.54	1.50	0.43
I	ppb	1	10	112447.3	6400.0	346990.0	112998.0
Cs	ppb	0.01	10	4.749	0.840	12.700	3.227
Ba	ppb	0.05	10	494.09	267.50	747.74	146.71
La	ppb	0.01	10	1.022	0.210	2.800	0.708
Ce	ppb	0.01	10	1.092	0.280	2.800	0.676
Pr	ppb	0.01	9	0.297	0.090	1.100	0.325
Nd	ppb	0.01	10	1.042	0.350	2.600	0.634
Sm	ppb	0.05	1	0.9	0.9	0.9	--
Eu	ppb	0.01	3	0.300	0.100	0.600	0.265
Gd	ppb	0.01	10	0.494	0.070	1.700	0.555
Tb	ppb	0.01	3	0.233	0.100	0.500	0.231
Dy	ppb	0.01	8	0.175	0.070	0.600	0.188
Ho	ppb	0.01	2	0.300	0.200	0.400	--
Er	ppb	0.01	4	0.200	0.100	0.400	0.141
Tm	ppb	0.01	2	0.200	0.100	0.300	--
Yb	ppb	0.01	3	0.233	0.100	0.400	0.153
Lu	ppb	0.01	2	0.200	0.100	0.300	--
Hf	ppb	0.02	10	2.84	0.42	15.50	4.51
Ta	ppb	0.05	3	0.70	0.70	0.70	0.00
W	ppb	0.1	10	31.65	20.70	44.00	9.75
Re	ppb	0.01	8	0.125	0.070	0.300	0.083
Os	ppb	0.05	9	2.74	0.60	6.66	1.98
Ir	ppb	0.05	5	1.07	0.42	1.90	0.65
Pt	ppb	0.01	5	0.194	0.070	0.400	0.147
Au	ppb	0.05	2	0.85	0.49	1.20	--
Hg	ppb	0.1	4	1.60	1.00	3.00	0.95
Tl	ppb	0.01	1	0.07	0.07	0.07	--
Pb	ppb	0.1	19	111.47	10.00	870.00	193.68
Bi	ppb	0.05	6	0.77	0.42	1.30	0.34
Th	ppb	0.05	6	1.69	0.42	3.50	1.08
U	ppb	0.05	10	4.07	1.89	11.70	3.48

--: No meaningful statistics is available owing to a lack of sufficient population.

Table 4: Median concentration of trace elements in municipal landfill leachate in USA (adopted from Qasim and Chiang, 1994)

Sb	As	Ba	Be	Cd	Cr	Cu	Fe	Pb	Mn	Hg	Ni	Se	Ag	Tl	Zn
4.52	0.042	0.853	0.006	0.022	0.175	0.168	221	0.162	9.59	0.002	0.326	0.012	0.021	0.175	8.32

(Unit: mg/l)

Median concentration of trace elements in MSW landfill leachate is summarized in Table 4. In comparing with our present data with the Table 4, the Henchir El Yahoudia landfill leachate is relatively abundant with Cr, Ni, As, Se, Hg, and Pb, while poor in Mn, Fe, Cu, Zn, and Tl.

Table 5: Tunisian regulation for the quality of wastewater (element basis only)

NORME TUNISIENNE N.T 106.002 (1989) Protection de l'Environnement - Rejet d'Effluents dans le Milieu Hydrique

Element unit	S mg/l	F mg/l	P mg/l	B mg/l	Fe mg/l	Cu mg/l	Sn mg/l	Mn mg/l	Zn mg/l	Mo mg/l	Co mg/l	Br mg/l
Domain public maritime	2	5	0.1	20	1	1.5	2	1	10	5	0.5	0.1
Domain public hydraulique	0.1	3	0.05	2	1	0.5	2	0.5	5	0.5	0.1	0.05
Canalisations publiques	3	3	10	2	5	1	2	1	5	5	0.5	1

Element unit	Ba mg/l	Ag mg/l	As mg/l	Be mg/l	Cd mg/l	Cr(VI) mg/l	Cr(III) mg/l	Sb mg/l	Ni mg/l	Se mg/l	Hg mg/l	Pb mg/l	Ti mg/l
Domain public maritime	10	0.1	0.1	0.05	0.005	0.5	2	0.1	2	0.5	0.001	0.5	0.001
Domain public hydraulique	0.5	0.05	0.05	0.01	0.005	0.01	0.5	0.1	0.2	0.05	0.001	0.1	0.001
Canalisations publiques	10	0.1	0.1	0.05	0.1	0.5	2	0.2	2	1	0.01	1	0.01

According to the Tunisian regulation values for wastewater quality (Table 5), ten elements, Be (not detected from all the samples), Mn, Zn, Mo, Ag, Cd, Sn, Sb, and Pb, are showing lower concentration below the regfulation level, respectively, but the concentration of thirteen elements, B, P, S, Ti, Cr, Fe, Co, Ni, As, Se, Br, Ba, and Hg, fully or partly exceeds above each regulated value. In particular five non-metal trace elements, B, S, As, Se, and Br, are showing abnormally higher concentrations in comparing with each regulation value (Figure 2). Other five toxic heavy metals, Ti, Cr (total), Co, Ni, and Hg, also indicate higher concentration than the regulation levels.

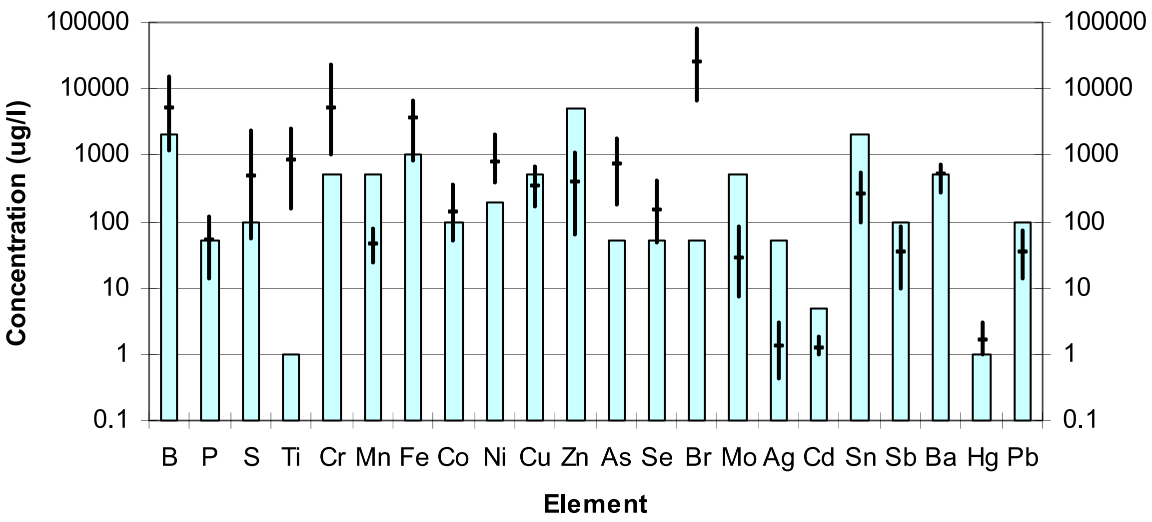

Figure 2: Concentration of trace elementes regulated by Norm Tunisienne N.T.106.002. Each regulation value is shown by box, and observed maximum-average-minimum values are indicated by solid crosses.

IV-2. Trace Elements in Lake Water Samples

The composition of trace elements in the lake water samples of Sebkhat Sejoumi at Henchir El Yahoudia area is shown in Table 2 (L1 and L2). Except the characteristics of brine of salt lake, where Na, Mg, Ca, and Cl are relatively concentrated, the composition of trace element is similar to that of the landfill leachate described in previous section. The concentration of five non-metal elements, B, S, As, Se, and Br, is higher than each regulation level. The concentration of Ti is also showing abnormal high values, while that of other heavy metals such as Cr, Co, Ni, and Hg, is below the regulation value.

The similarity in trace element composition suggest us that the landfill leachate more or less affects the composition of lake water in Sebkhat Sejoumi. Relative lower concentrations of major heavy metals are possibly due to dilution and precipitation (inmobilization) in lake basin under slightly alkaline conditions (c. pH8). Immobilization effects of the heavy metals by cation adsorption and cation exchange processes are also assumed during leachate migration and inflow to the Lake Sebkhat Sejoumi basin. However other natural attenuation processes (Table 6) are not significant because the concentration of non-metal, anionic element species are generally not depleted in the lake water. The lake water in the Sebkhat Sejoumi basin, recharged in winter rainy season, is almost all evaporated in summer season, which may accelate a natural condensation process of trace elements in the lake water.

Table 6: Major attenuation mechanisms of various trace elements (based on Qasim and Chiang, 1994)
* Difference of concentration between landfill leachate (LF) and lake water (LK)

Element	Major attenuation mechanism	Factor affecting attenuation	Description	Mobility in clay	Present Study*
Al	precipitation	pH	Al readily forms insoluble oxides, hydroxides, silicates in pH>7. Al may be soluble in pH<7.	low	LF>LK
As	Precipitation and adsorption	pH type of clay	In aerobic environment As reacts with Fe, Al, Ca, and other metals to form slightly soluble arsenate; maximum removal of arsenate occurs when the pH is between 4 and 6. Arsenite removal is maximum in the pH range of 3 and 9. Smectite clay adsorbs twice as much arsenic as kaolinite clay.	moderate	LF=LK
Ba	Adsorption, ion-exchange, and precipitation	CEC (cation exchange capacity), pH, and presence of clay	As the CEC increases, adsorption of Ba also increases; alkaline conditions and free lime favour attenuation by ion exchange and chemical precipitation. Attenuation is also favoured by a high clay percentage and the presence of other colloidal materials.	low	LF>LK
Be	Precipitation anf cation exchange	CEC and type of clay	Mobile in both high and low pH due to hydrolysis; highly attenuated in soils containing smectite and illite.	low	LF=LK (all ND)
B	Adsorption, pecipitation or coprecipitation	Influenced by the activities of Al and Fe(III)	Adsorbed as borate on inorganic surfaces and precipitated or coprecipitated with hydrous iron or alminum oxides.	high	LF<LK
Cd	Precipitation, adsorption	pH, redox potential	Hydrolysis at normal pH; attenuation of Cd is very significant between pH 6 and 8, precipitation occurs at near neutral, anions such as phosphate, sulfide, carbonate effectively attenuate Cd by precipitation.	moderate	LF>LK
Ca	Precipitation, cation exchange	pH, CEC, and type of clay	Readily forms carbonate that precipitates in alkaline conditions. Since Ca is seldom adsorbed but often eluted, hardness of groundwater beneath a landfill	high	LF<LK

			increases. Smectite eluted Ca more significantly than illite or kaolinite.		
Cr	Precipitation, cation exchange, and adsorption	Redox potentiall, form of Cr, pH, type of clay, and soil texture	Attenuation mechanism depends on the form of Cr (Cr(III) or Cr (VI)). Redox potential has a marked effect on Cr attenuation. The concentration of Cr in the soil is reduced by adsorption on organic matter, clay minerals, and hydrous oxides of Fe, Mn, Al, and precipitation as an oxide. Smectite is more effective than kaolinite clay.	low for Cr(III) high for Cr(VI)	LF>LK
Cu	Adsorption, ion exchange and chemical precipitation	Type of clay and pH	Soil pH is the most important factor controlling removal of copper with a given adsorbent. Some Cu compounds dissolve under acidic conditions. In the pH range of 5-6, precipitation of Cu compounds can occur when Cu concentrations are high. Complexing with organic matter is high. Soil materials favoring attenuation of Cu include colloidal matter, free lime, hydrous oxides of Mn and Fe, high clay content, and organic matter.	low	LF<LK
Fe	Precipitation, cation exchange, adsorption, and biological uptake	CEC, pH, and redox potential	Fe compounds are attenuated moderately in soil. The for of Fe (Fe(II) or Fe(III)) affects attenuation.Fe attenuation increases with increase in CEC. Mobility is converted to ferrous iron due to reducing conditions created by anaerobic growth.	low for Fe(II) high for Fe(III)	LF>LK
Pb	Adsorption, cation exchange, and precipitation	pH and type of clay	Attenuation increases as the pH rises above 5. Smectite has a higher removal efficiency than kaolinite. Pb forms poorly soluble precipitates with sulfate, carbonate, phosphate and sufide anions. Soil materials favouring attenuation of lead includes organic matter, clays and free lime. Pb has a strong affinity to organic matter that results in complexion and immobilization. It is attenuated more than many other divalent heavy metals.	low	LF>LK
Mg	Cation exchange and precipitation	pH	When pH is between 7 and 14, Mg forms carbonate and hydroxide precipitate. It is attenuated modelately in clayey soil.	moderate	LF<LK
Mn	Precipitation and cation exchange	Redox potential, valence of manganese, and type of clay	Mn normally exsists as insoluble oxides. Under reducing conditions Mn(II) is formed. This increases solubility. Adsorption of Mn is highest in smectite, intermediate in illite, and lowest in kaolinite. Soil material favouring Mn attenuation are clays, organic matter, hydrous metal oxides and free lime. Alkaline condition and an abundance of anions such as sulfide and carbonate will improve retention.	high	LF<LK
Hg	Adsorption, precipitation, and redox reactions	PH, type of clay, and colloidal matter in soil	Attenuation mechanisms usually cause the volatilisation of Hg. Bacteria convert inorganic Hg into toxic mono- or dimethyl Hg. Clayer soils attenuateHg by adsorption with Fe oxide, organic matter, and clays. Maximum attenuation under alkaline conditions. Attenuation is improved by colloidal matter in clays, and Fe oxides.	high	LF=LK
Ni	Sorption, precipitation	Surface area, CEC, clay	Removed by hydrous metal oxide precipitates. Factors favouring retention include alkaline conditions,	moderate	LF>LK

		content, pH	high concentrations of hydrous metal oxides, and free lime.		
K	Precipitation and cation exchange	pH	K is well attenuated in clayey soil. Attenuation is maximum under neutral to alkaline conditions.	moderate	LF>LK
Se	Adsorption, and anion exchange	pH and type of clay	Present in soils as an inorganic anion, and associated with Fe, Na or Ca. Microorganisms oxidize or reduce it repeatedly. Se removal by smectite is significantly higher than that by kaolinite. Maximum removal is in the pH range between 2 and 4.	moderate	LF<LK
Na	Cation exchange	CEC	May be totally attenuated but since it is a monovalent ion a low concentration of sodium could pass through the soil.	low to high	LF<LK
Zn	Adsorption, cation exchange, and precipitation	pH, type of clay, CEC, and organic matter	Attenuated under alkaline condition by clays, organics, hydrous metal oxides, and free lime. Attenuation is maximum in the pH range of 6 to 8. It also precipitates with a variety of anions including carbonate, sulfate, silicate and phosphate. pH and organic matter also affect the attenuation of Zn.	low	LF>LK

V. Conclusions

(1) The trace element composition of landfill leachate and lake water collected from Henchir El Yahoudia area was determined.
(2) The landfill leachate in the area is relatively abundant with Cr, Ni, As, Se, Hg, and Pb, while poor in Mn, Fe, Cu, Zn, and Tl.
(3) On the basis of regulation of wastewater standard, the landfill leachate exhibits cautious levels of concentration of non-metal trace elements, B, S, As, Se, and Br. Five toxic heavy metals, Ti, Cr (total), Co, Ni, and Hg, are also showing concentration levels above the regulation. The contamination of these toxic elements are probably caused by solid waste disposal in the landfill.
(4) The trace element composition of Sebkhat Sejoumi lake water is similar to the leachate in non-metal elements, B, S, As, Se, and Br. However the toxic heavy metals composition of lake water is not correlated with that of leachate, where their concentration in lake water is very low in comparing with that of leachate, except Ti and Cu.
(5) The relative depletion of heavy metals is possibly due to some natural attenuation processes such as cation adsorption, cation exchange, and precipitation during transportation and standing in the lake basin.

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