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ORIGINAL ARTICLE

Heavy metal sources in Sultan Marsh and its neighborhood, Kayseri, Turkey

M. Gurhan Yalcin · Rifat Battaloglu · Semiha Ilhan

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Abstract Sultan Marsh (Turkey) is one of the largest wet lands of the Middle East and Europe. The aim of this study was to determine average concentrations of heavy metals, variations of the obtained values in a large scale, geogenic and anthropogenic sources of the pollution and effects of the pollution on the environment in Sultan Marsh. To these aims, a total of 176 surface soil samples (0–10 cm depth) were collected from 80 ha land in Sultan Marsh. Using a bench-top Spectro-Xepos X-ray fluorescence spectrometer, we analyzed all samples to determine the near-total concentrations of 26 chemical elements. Basic and multivariate statistics were used for statistical analyses. GIS mapping, a powerful tool for identifying possible sources of pollutants, was used to classify and identify the elements. Relatively high concentrations of the elements Fe, Pb, Zn, Sb, W, Mo, Co, Cu, Hg, Ni, Cr, Mn and Cd were found in Sultan Marsh, surrounding rocks (geogenic sources), mines of Fe and Pb/Zn, industrial facilities, residential and agricultural areas and major traffic routes (anthropogenic sources).

M. G. Yalcin (✉)
Faculty of Engineering and Architecture,
Department of Geology Engineering,
Nigde University, 51200 Nigde, Turkey
e-mail: gurhan46@nigde.edu.tr; gurhan46@gmail.com

R. Battaloglu
Ankara University, Forensic Medicine,
06800 Mamak, Ankara, Turkey

S. Ilhan
Faculty of Engineering and Architecture,
Department of Geology Engineering,
Cukurova University, 01330 Adana, Turkey

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Introduction

Sultan Marsh, in which 426 different bird species exist, is a tourist attraction. It is located between Develi, Yahyali and Yesilhisar in Kayseri province in the Central Anatolia in Turkey. The region occupies 80,000 ha land with its 17,200 ha lakes and the neighboring districts. Sultan Marsh with its mining, agriculture and tourism plays an important part in the country's economy.

Soils are environmental pollutants on rocks, air and water inter-surfaces. They have a tendency to become one of the most pollutant substances due to a variety of human activities (industrial, cultural, transportation, etc.). In fact, human activities may lead heavy metals to accumulate on soils. Polluted soils are considered as a source of pollution in surface waters, ground waters, living organisms and sediments (Tam et al. 1987; Yassoglou et al. 1987; Olajire and Ayodele 1997; Öncel et al. 2004). For the past several centuries, heavy metals in soils have caught attention for their extraordinary pollutant characteristics.

Heavy metal pollution, which accumulates in soils and takes a long time to detect, occurs due to city operations (Farmer and Lyon 1977; Kelly et al. 1996; Purves 1966; Li et al. 2001, 2004; Mielke et al. 2000; Tijhuis et al. 2002; Peltola and Astrom 2003). Similarly, it has been observed that the sources of heavy metals which have high concentrations, particularly Pb, are the city centers (Wilkins 1978; Davies 1978). Other sources which have been detected in scientific studies on various pollution areas (Fuge 2005) are waste burning (Harrison et al. 1981; Ho and Tai 1988), mining (Schumacher et al. 1997), industrial areas (Thornton 1991; Yalcin et al. 2006), polluted air, dust (Simonson 1995) and traffic (Öncel et al. 2004; Viard et al. 2004; Yalcin et al. 2007). It has also been shown that industrial activities performed in contact with soils, tire burning and braking on dirt roads play an important role in accumulation of heavy metals (Sadiq et al. 1989; Smolders and Degryse 2002; Adachia and Tainoshob 2004). Recently, a study by Demirezen and Aksoy has revealed that heavy metal pollution has serious influences on Sultan Marsh. In fact, they detected heavy metal (Cd, Pb, Cr, Ni, Zn and Cu) pollution in beds of sediments, water and plants (Typha angustifolia and Potamogeton pectinatus) (Demirezen and Aksoy 2004). Demirezen and Aksoy (2006) stated that there were biological indicators of serious metal pollution (Fe, Mn). It has been observed that heavy metal pollution exists in small or large quantities in Phragmites australis, Ranunculus sphaerosphermus plants and sediments. Indeed, the Cr rate was found to be very high in plants and sediments (Aksoy et al. 2005). The abovementioned studies performed in a small area and with fewer samples showed heavy metal pollution, but failed to detect pollution sources. For this reason, we attempted to determine heavy metal pollution in the entire study area with more samples and we thought that the results of geostatistics and GIS could give insight into the risk assessment of environmental pollution and decision-making for agriculture (Liu et al. 2005).

The aim of this study was to detect heavy metal concentrations in soils in the study area, and using GIS map techniques with multivariate analyses, to determine the variations of heavy metal concentrations in a large scale and natural and artificial sources of pollutants and to identify the possible unmarked sources of the pollution. To this aim, first, major pollutants were determined based on the previous studies. Later on, samples from specified stations were collected and heavy metal concentrations were detected by using a bench-top Spectro-Xepos X-ray fluorescence spectrometer. Marshes, canals and human activities in the study area caused difficulties in determining the geochemical features of natural soils. Therefore, crust, soil and some background values were compared with average values. Obtained values were used to perform multivariate analyses. Up to now, appropriate multivariate analyses have been used to estimate enrichment of the elements from different sources, correlations between them and activities of the sources in the mines to determine the potential of pollutants (Zhang 2005). In the past century, multivariate analyses and the GIS technique have been commonly used together in environmental studies. The study area is called the birds paradise in the Central Anatolia. Therefore, it is very important to protect this marsh against heavy metal pollution for maintaining ecological balance in the region.

Experimental

Study area

Sultan Marsh is located in Kayseri province, K34 section of a map drawn at the scale of 1/100,000. Its coordinates were 38°20′North and 35°16′East and its altitude is 1,074 m. Sultan Marsh is located in a triangular area formed by Develi, Yahyali and Yesilhisar cities in Kayseri province in the Central Anatolia Region. The region is surrounded by Mount Erciyes in the North (3,916 m), Develi city in the East, the Aladaglar (3373 m on average) of the Toros Mountain Range in the South and Yesilhisar in the West. Sultan Marsh has an international importance with its watery habitat. About 301 bird species exist in the study area, one of the most important incubation areas for birds in Turkey. Sixty-nine of these species regularly winter in the study area or visit the area while migration, while 18 species visit the area in extraordinary conditions. The number of brooding species is 119. This region has a rare ecosystem, where fresh and salt water ecosystems exist side by side. It is the only region in Europe where Cranes, Flamingos, Herons and Pelicans breed together. The region is an important gathering place for birds on the migration routes. Reeds (Prakmites communic), Scirpus ssp. and Carex ssp. exist in Sultan Marsh. Water lilies, lake ivies and mosses exist in the watery areas. Mammals like water rats, bats, foxes and rabbits, fish species like carps and some other little fish species, reptiles like water snakes and lizards, water turtles, frogs and leeches exist on islets and in water (Yüksel 1989; CKGM 1998) (Fig. 1).

Sultan Marsh has a typical Mediterranean climate of Anatolian Plate region. It is dry and hot in summers, cold in winters and there are big differences in temperature between night and day, summer and winter. It is the hottest in July and August (34.2–35.5°C) and the lowest temperature measured was –18.3°C. According to measurements of the last three decades, the average yearly rainfall is 363 mm on a square meter.

The study area is surrounded by an asphalt road. Total daily road traffic intensity (including automobiles, medium load commercial vehicles, busses, trucks

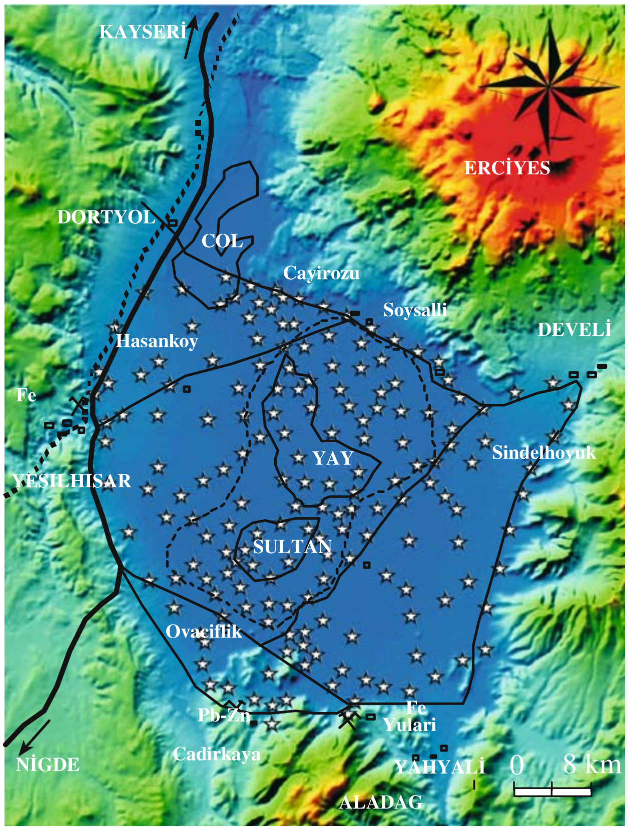


Fig. 1 Soil sampling locations in Sultan Marsh

and towing vehicles) is 5,247 vehicles in Yahyali Crossroad-Dortyol, 3,927 vehicles in Dortyol-Develi, 1,495 vehicles in Develi-Yahyali and 1,320 vehicles in Yahyali Crossroad (TD 2005). The region is important in terms of Fe and Pb–Zn mining. Fe and Pb–Zn mining is performed on Yesilhisar-Yahyali road, which is located in the south border of Sultan Marsh. There are Fe melting plants in the western border of the study area, in Yesilhisar and on Yesilhisar-Kayseri road (Yalcin and Battaloglu 2007). There is a leather factory in Cayirozu town, located on the Dortyol-Develi highway.

Regional geology

According to scientific studies, Central Anatolia, in which the study area Sultan Marsh is situated, is located in a Plio-Quaternary old neo-tectonic (Kocyigit and Beyhan 1998) structure. This structure is defined as Middle Anatolia Fault Zone (MAFZ) (Kocyigit and Beyhan 1998), which is in the K500D direction and extends to the northeast of Kayseri province. Here, the direction of fault zone makes a convolution to the south, which caused the formation of the Erciyes Pull-Apart basin (Kocyigit and Beyhan 1998; Dirik 2001). The study area was in the south section of this basin. Sultan Marsh is located in the Erciyes pull-apart basin. Volcanic activity of Erciyes is important in the formation of this basin. Erciyes Volcanic Cone is situated in the utmost east of a great volcanic range in the Central Anatolia (Erol 1999). Sultan Marsh is surrounded by Erciyes volcanic formations that belong to the Quaternary in the north, Mesozoic-Paleocene rocks (sediment or metamorphic rocks) in the south, Late Miocene volcanic formations in the east and Late Miocene volcanic formations and Paleozoic–Mesozoic metamorphic products in the west (Dhont et al. 1998) (Figs. 2, 3).

The formation of Sultan Marsh took place in the Pliocene–Quaternary period. Sultan Marsh was opened to outer drainage from time to time in the

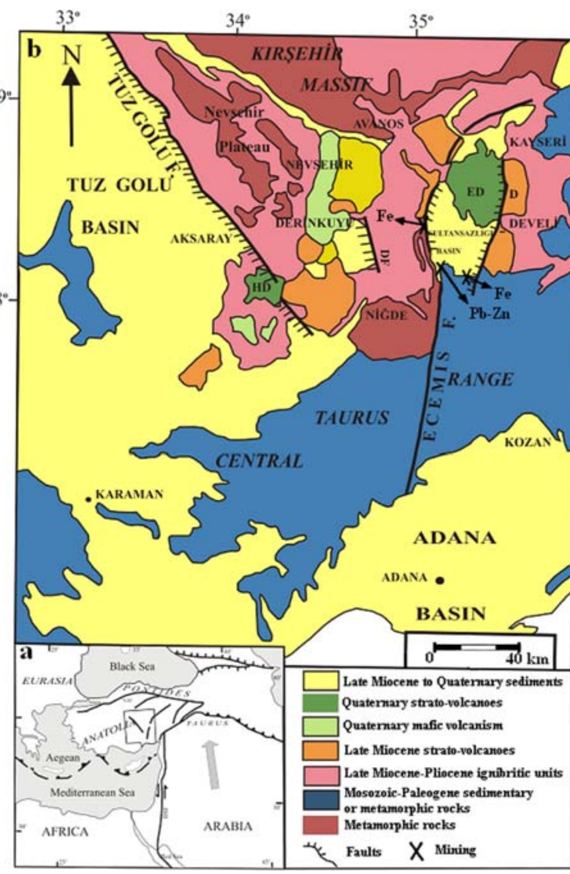


Fig. 2 **a** Geodynamic context of The Central Anatolia since the late Miocene. *Large arrows* show the Africa–Arabia and the Anatolia plate motions relative to Eurasia. *Thick lines* show the plate boundaries. *Rectangle* shows the location of **b**. *DSF* Dead Sea Fault; *EAF* East Anatolian Fault; *NAF* North Anatolian Fault. **b** Geologic sketch map of The Central Anatolia, compiled from the 1/2,000,000 geological map of Turkey MTA, 1989. *DD* Mount Develi volcano; *DF* Derinkuyu fault; *ED* Mount Erciyes; *HD* Mount Hasan; *KD* Mount Kara; *KcD* Mount Karaca; *KoD* Mount Koc; *MD* Mount Melendiz. (Dhont et al. 1998)

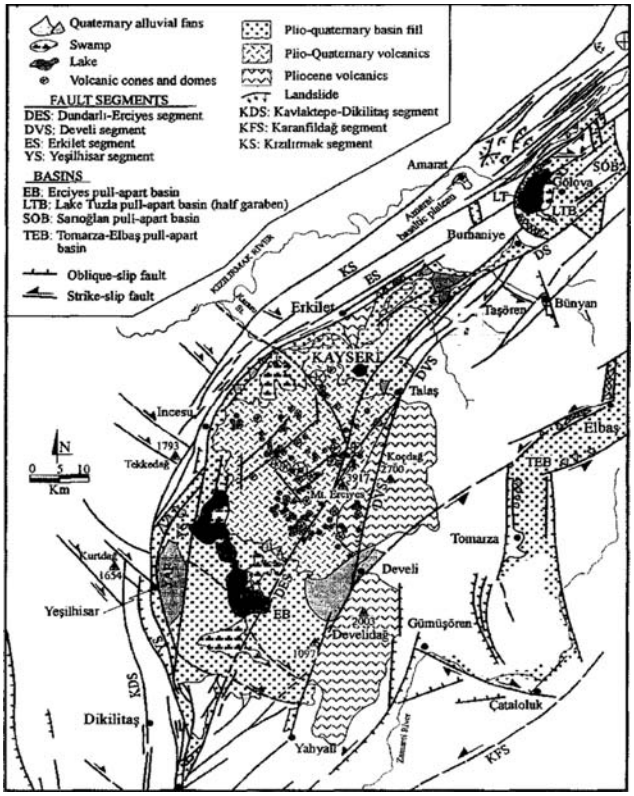


Fig. 3 Simplified map of the central part of the Sultan Marsh Region (Kocyigit and Beyhan 1998)

Pliocene. When the lavas of Erciyes Volcano flowing to the northwest flowed to Incesu valley in the Middle Pliocene, the basin was formed into a closed one again. In the back of lava brink, the first watery period (pluvial) lake (Desert Lake) came into existence. In the following periods, two more interconnected Pleistocene lakes (Yay and Sultan lakes) were formed (Fig. 1). Generally, Sultan Marsh collapsed in the Quaternary, which is the last stage of the regional development. On the other hand, Mount Erciyes gained elevation with volcanic eruptions (Erol 1999).

Sampling and chemical analyses

Soil sampling was carried out in November 2005. A total of 176 samples were collected from a nearly 17,200 ha area including mines and soil surfaces (0–10 cm depth) and grasslands (Fig. 1). The coordinates of the sample collection areas were determined with a GPS-12CX device (Garmin). The coordinates of the sample points were detected with GPS, and were plotted on a topographic map with the scale of 1/100,000. The sample shovel was made of hard plastic. Systematically collected samples were stored in 1 kg plastic bags. To minimize pollution, plastic bags were washed with 6 M HNO_3, rinsed with distilled water and used after drying with iron at 70°C. Soil samples were dried with iron at 105°C for 24 h. Dried samples were passed through a 2 mm plastic sieve and separated from pebbles.

Later on, samples were homogenized in an agate mortar and made into an average 2 mm particle size. The agate mortar where samples were homogenized were washed with 6 mol l^1 HNO_3 for each sample, rinsed with distilled water and used after dried.

Detection of the elements Ag, Al, As, Ca, Cd, Cl, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, S, Sb, Si, Sn, Ti, V, W and Zn were performed with a bench-top Spectro-Xepos X-ray fluorescence spectrometer in an electronic control system. The soil samples were analyzed after shaped into 32 mm diameter double sided film tablets. The detection system was a microprocessor controlled drift detector with Peltier cooling and energy resolution of FWHM < 170 eV, measured for the Mn K line with an input count vote of 10,000 pulses. Obtained results were expressed in milligram per kilogram.

Data analyses using computer software

Raw data obtained with chemical analyses were recorded in an MS Excel program. Simple statistical parameters and data in the file were used to show all characteristics of the region. Raw and converted data were analyzed with SPSS software and the multivariate analyses. SPSS software was used to classify elements with similar geochemical features into groups. Data were analyzed with multivariate analyses (coefficient correlation, cluster analyses, hierarchical cluster analysis, model summary and ANOVA). A map for regional distribution of chemical data was drawn with GIS Software and ArcView program.

Results and discussion

Basic statistics and comparisons

Some element contents of the samples collected from Sultan Marsh are shown in Table 1. According to the results of chemical analyses, arithmetic averages and maximum values of all elements in soil and crust exceeded the permissible cut-off values (Brooks 1972; Boyle 1975; Brady 1974; Connor and Shacklette 1975; Krauskopf 1979; Maynard 1983; Reimann 2003; Wedepohl 1969–1978, 1995). Based on the variation rates of maximum values obtained from the analyses in the soil, the elements can be listed as in the following: Mg, Fe, Al, K, Cr, Cl, Cd, As, W, Ni, Pb, Co, Ag, Mo, Cu, Hg,

Table 1 Heavy metal concentrations of the Sultan Marsh Soil (mg/kg)

Sample	Sb	W	Ag	Mo	Co	V	Cu	As	Sn	Hg	Ni	Zn	Cd	Pb	Si	Al	Fe	Ca	Mg	S	Na	K	Cl	Ti	Cr	Mn
1	5.7	0.7	5.9	23	55.0	117.0	32.0	8.6	6.9	1.9	181.5	65.6	4.1	17.9	151,200	44,270	35,840	107,000	47,340	4,698.0	7,570	10,240	4,070.0	2,733	283.0	617
2	7.3	6.7	3.9	22	24.0	135.0	26.8	6.5	6.5	1.7	137.6	79.5	3.8	19.1	144,000	35,790	29,430	116,100	27,940	5,257.0	2,870	9,107	420.1	2,503	568.0	706
3	5.5	6.5	2.5	23	24.0	88.0	26.9	7.7	7.2	1.8	134.8	53.8	3.9	17.4	138,600	31,590	26,830	116,600	38,150	22,880.0	5,320	8,823	6,263.0	2,215	506.0	646
4	5.4	7.1	3.2	22	57.5	181.0	41.6	9.0	7.0	1.8	281.6	70.8	4.7	17.6	152,200	43,530	47,310	54,100	18,160	539.7	1,990	7,109	69.0	2,235	305.0	698
5	5.7	7.0	8.6	23	56.1	158.0	41.8	7.1	7.8	1.7	274.5	69.6	4.1	13.4	155,100	44,060	44,670	60,270	30,230	26,010.0	1,900	8,461	266.0	2,190	308.0	633
6	5.6	7.4	5.5	24	39.8	135.0	44.5	11.8	7.2	1.8	272.6	61.4	3.9	14.0	161,800	39,730	43,370	72,700	33,730	12,620.0	20,150	11,430	796.7	2,980	346.0	758
7	5.5	5.8	3.1	21	40.4	88.0	17.4	3.6	7.2	1.8	90.4	49.7	4.2	16.0	207,300	50,110	29,970	74,180	23,650	484.8	6,180	18,360	266.3	2,332	335.0	692
8	6.4	5.1	2.4	21	36.0	73.0	12.1	2.1	7.0	1.4	64.9	40.5	4.1	20.0	258,800	60,140	25,080	22,680	22,500	344.2	8,980	17,770	129.9	2,289	327.0	664
9	5.3	5.3	5.3	21	32.0	73.0	15.8	5.6	5.9	1.6	69.8	48.1	6.0	19.5	250,100	57,880	28,150	27,030	23,220	4,911.0	7,690	17,900	187.9	2,474	518.0	777
10	5.1	5.0	3.1	20	24.9	105.0	10.3	4.4	12.4	1.6	45.7	41.8	4.3	19.2	253,800	57,450	26,450	25,120	20,420	5,337.0	10,300	18,390	173.9	2,551	751.0	711
11	4.5	4.9	4.1	21	25.1	74.0	11.1	4.7	6.7	1.2	42.9	56.5	4.0	23.5	216,200	47,460	24,370	35,770	18,730	5,642.0	9,740	16,560	152.2	2,148	445.0	589
12	4.7	5.3	7.7	22	28.8	21.0	9.2	4.9	6.2	1.6	44.8	39.4	4.2	19.6	244,500	52,440	24,170	52,430	30,920	375.3	7,530	19,170	69.8	2,146	637.0	561
13	5.1	4.8	6.1	22	16.8	19.3	8.6	19.9	6.9	1.8	17.7	22.3	4.2	12.8	183,900	21,910	22,580	87,540	59,770	2,049.0	17,710	13,460	2,396.0	1,125	330.0	335
14	5.8	5.5	6.0	24	19.9	86.0	13.4	8.6	7.3	1.8	49.0	42.7	4.1	20.0	203,500	46,930	23,210	81,910	41,700	361.9	2,690	17,530	58.0	2,246	388.0	610
15	5.0	5.1	3.6	21	21.0	80.0	14.4	7.4	6.8	1.6	46.9	47.5	4.2	22.1	23,3700	50,250	23,950	44,150	32,010	490.5	5,710	20,600	88.1	2,570	247.0	709
16	4.9	5.3	7.1	20	20.1	78.0	9.2	6.6	6.6	1.7	41.3	40.0	4.0	20.6	202,500	40,510	21,340	72,990	39,770	274.5	6,590	16,760	109.9	1,890	247.0	488
17	6.0	5.0	4.3	20	16.0	46.4	7.3	30.6	6.7	1.8	21.2	24.3	3.8	15.4	178,500	15,920	11,710	95,430	94,760	633.3	6,850	9,991	1,970.0	1,052	111.0	284
18	5.0	5.2	3.5	21	16.0	62.1	5.2	21.2	6.5	2.0	10.6	19.0	4.1	10.9	142,500	18,520	10,360	14,400	50,860	388.5	12,820	7,915	5,765.0	1,135	286.0	244
19	7.2	5.2	4.8	21	17.0	57.3	9.4	38.2	6.6	1.8	20.5	51.6	3.8	20.8	180,400	28,060	14,570	89,450	60,970	1,166.0	7,060	8,235	262.6	1,459	346.0	370
20	5.6	5.7	7.3	24	19.0	66.0	8.3	18.4	7.2	1.8	20.4	61.0	4.2	24.0	199,000	30,120	16,920	112,000	46,730	402.9	7,030	13,010	411.1	1,670	372.0	484
21	5.7	5.7	8.9	21	23.0	86.0	16.3	13.9	6.1	1.0	40.3	59.2	3.6	24.4	222,000	53,480	26,930	78,900	30,380	548.3	6,380	14,960	103.9	2,942	131.0	797
22	5.4	5.7	2.7	21	23.6	71.0	12.9	9.2	7.5	1.3	14.3	140.3	4.5	37.2	251,800	50,260	24,640	47,320	16,850	691.8	9,760	16,820	402.0	2,434	66.5	576
23	5.5	5.7	3.6	22	31.9	82.0	13.5	11.7	8.5	1.8	34.5	170.4	3.8	84.6	229,000	40,620	24,490	94,700	23,110	822.0	7,800	15,490	1,120.0	2,419	156.0	661
24	5.7	6.7	3.7	24	36.3	100.0	16.2	26.3	6.4	1.9	42.0	180.2	3.8	46.1	186,700	41,650	24,930	105,000	33,480	827.6	4,360	13,690	1,261.0	2,166	371.0	646
25	5.9	5.7	4.4	23	31.0	76.0	12.2	52.4	6.6	1.9	16.0	102.0	3.9	32.0	234,400	40,760	20,190	78,230	34,700	863.2	14,730	14,400	2,443.0	2,050	246.0	484
26	5.4	5.2	7.3	22	25.0	47.7	11.7	21.4	6.7	1.7	9.6	45.8	4.0	19.9	226,400	32,550	19,320	78,060	44,820	4,426.0	19,200	14,120	9,650.0	1,688	45.5	420
27	5.5	5.4	6.5	22	21.0	63.0	11.7	17.7	6.1	1.7	16.8	74.1	4.8	27.4	241,300	44,730	20,760	68,520	35,940	3,634.0	20,700	15,480	9,960.0	2,043	171.0	506
28	5.2	5.3	4.0	22	21.0	127.0	13.2	22.4	7.2	1.7	19.1	63.1	4.0	20.5	250,600	48,410	21,870	51,720	25,950	1,700.0	22,600	18,460	5,041.0	2,170	123.5	529
29	4.9	5.4	3.6	22	21.0	174.0	16.0	24.8	6.3	1.8	25.1	76.5	3.6	24.8	253,600	48,820	22,830	50,890	28,700	3,463.0	24,100	18,870	5,395.0	2,390	122.0	532
30	5.7	5.5	3.2	22	21.0	59.0	14.3	9.8	7.0	1.7	21.6	66.8	3.8	14.7	235,400	40,470	21,460	72,060	28,460	815.6	12,350	16,350	857.0	2,051	31.2	508
31	6.2	5.2	3.0	22	20.5	58.5	13.8	62.5	6.5	1.8	17.8	62.7	3.7	14.2	234,800	40,259	20,587	72,315	29,874	795.4	11,587	15,265	841.0	1,987	32.4	467
32	9.8	5.2	2.4	23	18.0	58.2	11.9	65.7	6.2	1.8	13.7	38.5	3.7	14.9	215,600	22,560	14,520	99,460	73,400	580.3	7,170	11,820	1,451.0	1,521	46.6	364
33	7.2	5.1	5.0	22	17.0	60.4	8.7	104.8	6.5	1.9	6.6	24.6	3.6	9.9	203,700	15,800	11,790	10,680	82,250	633.4	4,740	8,927	927.7	1,217	18.7	302
34	5.2	5.1	6.4	23	16.0	118.4	5.7	87.0	6.6	1.8	7.6	20.4	3.7	8.5	188,100	14,670	10,530	11,280	88,280	642.4	5,710	6,531	521.4	1,172	23.1	245
35	5.7	6.1	5.3	24	22.0	68.0	15.8	32.0	7.1	2.0	35.6	48.0	4.0	14.9	171,300	34,920	20,600	14,320	58,210	495.9	2,400	12,910	119.5	1,984	66.8	477
36	4.9	5.7	6.0	24	16.4	52.0	7.0	62.6	7.4	2.1	10.3	23.1	3.7	7.7	102,700	14,190	9,128	210,400	58,200	1,961.0	2,830	3,972	2,071.0	1,094	89.0	261
37	5.9	5.8	3.0	25	15.0	47.1	7.0	43.1	7.3	2.3	6.7	24.8	4.1	8.9	82,330	9,438	6,529	253,500	47,770	927.2	1,500	3,702	601.0	743	19.0	209
38	5.0	6.4	5.5	26	17.0	54.0	9.8	82.6	7.8	2.3	12.9	23.5	4.2	6.0	96,460	12,850	9,496	223,000	61,780	4,685.0	1,600	4,668	375.6	950	27.1	243
39	7.1	5.7	6.8	22	13.0	49.0	11.9	78.7	6.5	2.1	6.2	46.4	4.0	10.0	110,800	7,838	6,111	150,600	70,990	6,252.0	1,700	3,285	6,343.0	646.2	18.0	222
40	5.6	6.2	7.9	24	18.0	46.1	16.2	54.5	12.0	2.2	23.3	62.2	3.5	14.5	121,700	16,650	11,430	175,500	51,800	6,835.0	2,600	6,600	8,030.0	1,203	35.4	294
41	5.7	6.3	3.5	26	24.2	57.6	10.9	80.3	7.4	2.3	15.8	39.5	4.4	13.7	96,970	15,990	10,880	233,300	48,760	953.7	1,600	4,951	170.8	1,133	32.2	291
42	5.1	6.7	5.7	24	26.0	76.0	19.7	54.2	6.8	2.2	36.8	95.2	4.2	38.5	118,400	36,960	21,240	187,400	32,980	2,412.0	2,420	10,950	2,849.0	2,095	58.1	373
43	4.7	6.4	4.8	23	21.0	60.0	16.0	134.1	7.2	2.1	54.3	52.7	4.3	19.8	112,100	22,370	21,360	149,700	56,790	1,1760.0	5,320	8,183	7,520.0	1,555	158.0	364
44	5.7	6.9	5.0	23	24.0	105.0	38.6	15.9	7.1	2.0	121.2	74.9	3.9	20.2	128,400	37,210	26,800	152,700	29,660	2,072.0	1,500	11,150	205.7	2,194	172.0	440
45	5.8	6.2	3.4	23	24.0	95.0	24.0	16.2	9.2	1.9	36.1	95.1	4.0	52.7	159,100	46,770	25,860	134,200	27,500	3,501.0	2,340	14,770	1,034.0	2,826	205.0	447
46	7.3	6.3	4.5	22	30.7	93.0	27.1	16.7	7.8	1.4	38.3	98.0	3.7	48.1	168,100	53,620	31,410	116,600	19,590	2,552.0	2,460	16,200	324.2	3,127	86.4	505
47	5.7	6.7	5.5	24	25.1	74.0	14.2	10.5	7.2	2.0	64.4	87.8	3.7	53.4	151,600	37,270	22,720	156,800	21,570	1,114.0	3,730	10,930	372.9	2,189	200.0	486
48	5.2	5.9	3.3	24	23.0	90.0	17.8	10.6	6.8	2.0	23.0	63.7	4.1	48.5	131,800	35,170	21,220	182,400	18,300	1,046.0	1,600	10,670	199.9	2,146	71.0	494

Table 1 continued

Sample	Sb	W	Ag	Mo	Co	V	Cu	As	Sn	Hg	Ni	Zn	Cd	Pb	Si	Al	Fe	Ca	Mg	S	Na	K	Cl	Ti	Cr	Mn
49	5.8	6.3	3.9	24	24.0	73.0	16.5	7.4	7.5	1.4	34.6	67.8	3.8	69.8	138,500	40,870	23,740	168,400	14,260	885.4	1,600	11,680	94.3	2,426	110.0	491
50	5.3	5.7	5.5	21	58.0	150.0	32.2	7.4	6.6	1.8	37.7	62.6	4.0	15.0	218,100	65,910	46,900	54,000	15,990	735.1	6,530	9,519	55.9	4,571	102.4	1,323
51	5.7	5.5	5.9	22	36.2	127.0	18.7	6.2	6.4	1.8	41.4	61.7	4.3	13.4	221,100	53,880	36,210	73,280	22,330	1,161.0	9,730	11,360	306.4	3,291	189.0	826
52	5.1	5.7	5.8	23	29.9	155.0	14.0	20.0	6.8	1.8	14.3	72.2	4.1	17.6	230,600	52,380	33,270	63,790	43,880	18,090.0	5,440	10,780	207.1	3,027	114.0	742
53	5.4	5.3	9.5	22	17.0	158.0	10.9	123.9	7.8	1.9	9.1	25.7	3.4	9.5	179,300	16,170	14,130	12,230	62,000	1,940.0	2,940	7,128	1,342.0	1,327	24.7	361
54	4.9	5.2	6.1	21	17.0	90.0	11.3	133.6	7.1	2.0	4.8	36.0	4.2	12.1	176,600	20,040	12,920	12,190	82,230	895.3	5,530	6,754	505.1	1,399	38.4	302
55	5.1	5.4	2.7	23	17.0	51.6	5.7	136.0	6.6	1.9	4.6	24.1	4.5	8.8	151,500	21,280	13,300	11,120	63,650	2,557.0	16,000	7,441	1,614.0	1,707	75.1	261
56	5.6	5.2	5.0	21	29.6	62.0	24.3	9.7	6.7	1.6	26.2	57.5	4.0	16.2	272,700	55,040	24,400	45,660	17,430	1,981.0	13,160	16,850	459.7	2,511	115.1	553
57	5.0	5.5	3.2	22	24.2	58.0	19.8	5.0	6.3	1.6	20.1	151.2	3.2	15.3	268,000	61,940	25,970	29,750	8,570	1,087.0	15,390	16,350	429.7	2,575	194.0	584
58	5.3	5.3	3.2	21	23.1	82.0	18.9	4.0	7.2	1.6	22.8	87.7	3.9	30.4	274,200	68,350	28,550	27,420	10,100	440.6	14,450	16,610	238.1	3,277	173.0	601
59	6.1	5.1	5.4	20	25.0	99.0	21.1	3.3	6.4	1.6	15.0	61.9	4.4	21.3	259,800	57,700	27,380	35,110	7,950	383.5	16,040	15,430	353.2	2,724	151.0	540
60	5.3	5.1	2.7	22	30.3	82.0	25.4	3.3	9.2	1.6	20.7	63.9	4.0	70.7	262,200	73,240	30,670	25,850	8,220	1,260.0	15,390	14,930	209.5	3,183	138.4	641
61	5.1	5.1	5.4	21	31.6	82.0	20.1	6.1	6.4	1.0	19.1	59.5	4.0	22.8	267,500	74,840	30,280	23,080	8,170	620.8	12,880	14,990	171.8	3,304	128.8	634
62	5.1	5.1	2.6	21	29.0	121.0	25.3	24.2	6.9	1.2	19.0	64.4	4.4	26.3	24,1300	74,700	46,070	15,970	7,170	2,097.0	7,290	12,790	153.8	4,430	103.8	579
63	4.2	5.3	4.8	24	42.3	120.0	28.0	4.6	6.7	1.8	23.5	62.0	4.2	18.8	251,900	75,330	42,350	33,930	12,290	412.6	7,350	13,180	180.7	4,471	67.0	859
64	5.4	5.4	5.3	20	39.1	108.0	25.3	4.0	6.8	1.8	18.3	61.7	4.2	19.6	244,300	69,620	39,940	44,340	12,350	658.3	14,180	11,260	289.2	3,916	167.0	906
65	5.6	5.6	8.1	22	42.9	135.0	33.1	7.6	6.7	1.8	22.7	72.1	4.1	26.8	236,100	74,900	45,610	45,660	15,570	1,243.0	8,790	11,350	194.9	4,790	127.2	892
66	5.3	5.4	3.2	23	46.4	124.0	24.5	5.7	6.8	1.8	25.5	57.7	4.5	23.7	233,000	73,240	38,720	46,800	11,080	284.8	7,720	15,150	275.5	3,978	70.1	861
67	5.4	5.6	3.3	22	24.8	72.0	21.9	5.7	7.5	1.8	41.7	58.7	4.7	22.8	224,000	62,130	29,700	63,100	14,090	307.5	5,670	14,590	176.9	2,741	202.0	661
68	5.1	6.0	5.6	22	29.6	94.0	38.4	9.4	7.1	1.9	34.9	118.5	4.1	65.2	180,000	52,730	27,330	10,610	12,540	900.6	3,650	17,080	364.1	2,843	162.0	491
69	5.2	5.9	6.5	25	24.0	103.0	19.9	14.1	6.4	1.9	36.5	85.1	3.9	59.8	151,900	43,730	26,820	13,190	13,260	653.6	1,700	13,640	71.7	2,605	285.0	460
70	5.2	6.3	3.3	24	47.6	96.0	25.5	10.3	6.6	1.8	75.1	93.2	3.9	62.0	181,600	55,950	36,260	10,540	19,500	335.5	1,520	15,580	111.3	3,448	231.0	719
71	5.4	5.9	8.4	22	42.0	71.0	22.6	13.4	6.3	2.0	25.8	79.4	3.9	31.1	148,600	34,420	70,780	12,810	47,260	731.6	1,600	12,300	157.6	2,118	60.7	489
72	6.2	30.8	6.9	35	30.6	20.0	167.7	33.5	4.9	8.4	7.3	180.9	4.7	14.8	112,700	16,400	72,390	10,750	43,990	4,349.0	1,800	2,861	82.0	854	37.6	1,935
73	6.1	8.6	5.9	30	142.0	21.1	197.4	11.4	8.1	7.6	9.4	78.7	4.5	16.2	97,010	29,240	69,850	15,260	16,910	833.8	1,700	5,219	86.9	1,442	120.5	992
74	5.8	7.3	2.9	27	70.0	77.0	90.9	124.0	7.3	3.7	36.7	114.0	4.6	47.7	142,600	44,960	69,260	126,300	25,990	624.6	1,700	14,270	50.0	2,352	60.0	708
75	7.7	6.1	7.7	23	20.7	103.0	28.1	24.9	7.1	1.8	65.2	109.1	3.9	46.5	156,400	31,110	23,940	109,600	58,740	537.2	1,840	12,110	32.4	2,059	90.1	542
76	5.9	6.6	4.7	24	24.0	73.0	19.2	12.7	6.3	2.0	86.7	76.2	3.9	46.1	143,700	35,960	25,550	153,200	32,240	379.9	1,600	10,560	2.8	2,253	219.0	620
77	5.4	6.6	3.4	24	43.1	93.0	28.1	10.1	7.0	2.1	62.8	99.3	3.9	62.4	135,400	42,030	26,850	169,700	14,840	395.0	1,600	11,520	21.9	2,607	145.0	666
78	4.9	6.1	6.6	24	23.0	77.0	20.5	7.4	6.9	3.1	67.3	75.1	4.3	77.4	148,300	38,440	24,380	145,900	20,490	551.3	1,700	11,430	211.7	2,299	403.0	715
79	5.4	6.8	4.6	25	23.0	86.0	30.6	10.8	6.5	1.2	95.4	124.1	3.9	89.2	140,500	33,810	24,030	160,200	22,970	278.3	1,460	8,240	18.8	2,084	465.0	707
80	5.9	3.3	9.4	27	41.8	55.0	107.2	106.0	6.7	6.2	39.7	398.9	6.9	475.6	136,600	42,800	57,880	145,800	19,660	2,154.0	1,700	10,650	45.2	2,016	209.0	537
81	24.0	31.0	12.9	42	96.0	128.0	101.6	155.0	6.7	9.2	39.8	552.3	7.8	501.0	136,940	39,550	41,400	138,050	18,580	3,477.0	1,810	9,854	27.1	2,451	291.0	550
82	7.7	41.0	12.3	31	41.0	68.0	93.3	138.0	7.2	5.7	62.6	495.3	8.1	482.2	147,600	47,310	71,270	129,400	17,430	2,001.0	1,700	11,230	39.0	2,253	194.0	530
83	5.4	6.7	6.1	26	28.0	92.0	41.6	13.6	7.6	3.1	74.7	74.7	4.1	21.8	157,100	46,010	31,260	172,500	17,720	389.4	1,700	13,180	41.4	2,793	423.0	719
84	5.0	6.7	3.4	24	24.5	103.0	59.7	14.7	6.9	2.1	68.9	75.6	4.0	18.0	155,100	43,890	30,170	157,300	17,130	349.3	1,680	12,890	27.3	2,625	536.0	724
85	5.2	7.1	2.9	23	47.4	122.0	35.8	6.9	7.2	1.9	185.8	62.8	4.5	20.6	162,000	42,440	34,800	114,500	25,560	503.5	1,600	10,450	103.6	2,875	697.0	790
86	6.1	7.7	4.4	23	35.1	140.0	33.9	10.6	7.3	1.8	171.0	164.8	4.0	19.8	159,100	43,740	33,420	13,300	25,690	578.8	1,870	9,216	16.2	2,645	537.0	878
87	5.0	6.9	7.4	22	36.6	133.0	32.1	7.7	6.3	2.1	188.6	89.0	5.0	27.1	161,800	40,700	35,470	88,450	21,900	626.6	1,700	9,498	269.2	2,520	656.0	800
88	5.7	8.9	4.4	23	46.1	167.0	36.2	7.3	6.6	1.8	281.9	342.7	3.6	115.4	202,000	54,530	46,790	65,550	26,220	572.9	3,120	7,901	56.8	3,046	809.0	911
89	5.0	8.2	3.3	24	57.0	156.0	42.6	18.9	7.0	1.7	337.9	95.5	3.9	15.2	183,300	48,110	50,180	78,140	28,620	95.8	1,600	7,718	12.8	3,321	402.0	857
90	5.8	9.8	4.5	22	92.0	157.0	32.7	5.4	7.2	1.7	361.2	84.2	4.2	20.1	210,700	49,710	55,650	46,990	46,780	202.2	3,730	7,619	38.7	2,374	1,083.0	1,055
91	5.8	7.5	3.0	23	49.0	182.0	46.4	5.7	7.3	1.7	103.0	260.4	4.1	33.4	197,400	55,940	52,520	59,570	24,530	938.2	5,220	9,807	253.2	279.6	463.0	1,104
92	5.0	7.1	5.3	22	49.4	172.0	46.3	11.0	6.7	1.8	113.0	161.1	4.0	24.2	193,600	62,450	49,770	75,630	27,930	395.9	3,470	8,657	56.3	2,569	213.0	1,080
93	7.6	12.0	6.4	44	94.0	38.0	26.8	3.2	6.7	6.5	41.0	160.2	6.7	46.5	140,330	14,310	73,950	49,830	23,980	109.6	1,600	4,175	34.2	1,565	125.0	1,452
94	5.9	6.5	3.8	27	89.0	89.0	34.4	2.6	6.7	2.9	36.2	68.1	4.2	24.4	162,900	41,310	73,030	53,450	18,800	241.3	4,410	3,518	39.4	2,184	190.0	2,567
95	5.2	5.9	3.5	23	49.3	193.0	33.9	3.3	7.3	1.8	87.5	54.2	4.8	8.3	194,700	59,730	52,700	62,040	25,440	74.2	4,590	4,692	108.3	3,117	252.0	1,096
96	6.9	5.9	3.2	22	34.6	90.0	30.6	4.4	7.3	1.6	116.7	67.6	4.2	22.6	243,000	55,970	32,520	44,270	22,610	213.3	9,690	16,160	215.1	2,365	704.0	747

Table 1 continued

Sample	Sb	W	Ag	Mo	Co	V	Cu	As	Sn	Hg	Ni	Zn	Cd	Pb	Si	Al	Fe	Ca	Mg	S	Na	K	Cl	Ti	Cr	Mn
97	5.2	6.1	3.2	21	52.1	125.0	32.0	9.7	7.4	1.7	122.0	66.9	4.0	21.8	232,800	68,170	38,330	49,990	22,560	288.8	4,910	16,070	385.6	2,939	334.0	888
98	5.4	5.6	4.2	19	34.5	126.0	11.1	3.6	6.8	1.2	108.3	44.6	4.3	17.6	210,900	45,880	31,060	31,700	21,900	401.1	8,300	14,880	593.6	2,293	599.0	644
99	6.4	6.3	6.9	22	47.5	103.0	29.6	7.4	6.6	1.6	99.6	123.2	4.2	46.4	218,600	54,590	33,490	50,720	19,940	424.6	6,450	15,260	174.8	2,610	484.0	772
100	5.7	6.1	8.3	23	35.5	144.0	22.9	4.8	7.1	1.7	89.6	81.4	3.9	27.0	211,700	49,780	39,920	54,020	20,090	760.2	7,520	13,270	491.0	2,928	431.0	867
101	5.5	8.6	4.3	23	47.7	153.0	44.8	10.6	6.9	2.6	262.3	207.1	3.9	113.0	154,200	38,350	48,370	110,300	30,870	559.2	1,600	7,820	168.0	2,427	825.0	1,102
102	5.1	9.0	6.2	24	32.0	125.0	34.9	5.9	6.8	2.9	167.6	383.3	2.9	337.6	151,400	40,540	49,590	124,700	25,640	1,538.0	1,600	10,020	44.9	2,421	511.0	1,186
103	5.1	8.4	7.7	26	49.0	100.0	41.0	29.3	8.8	2.9	76.2	245.5	4.4	374.5	92,910	28,040	33,260	231,600	15,940	3,570.0	1,800	5,899	81.0	1,819	340.0	1,038
104	5.4	6	6.2	21	20	87	32	57	6.3	1.6	126.5	72.6	3.6	19.7	120,200	26,540	26,780	80,600	25,950	20,080	6,370	7,598	10,020	1,786	106.8	269.1
105	4.5	6.2	6.4	21	33.9	118	36.4	35.9	6.6	1.7	162.4	75.7	3.4	20.7	142,400	37,360	29,190	81,430	27,490	13,110	2,190	8,605	5,768	2,085	156	327
106	5.6	5	5.9	21	11	65.7	9.1	75.8	7	1.9	10.5	24	2.8	8.7	148,500	5,721	4,658	126,800	77,900	7,796	11,370	2,920	9,393	520.1	17	157.4
107	5.2	4.9	9.8	20	8.6	29.8	2.3	131.8	6.3	1.8	2.9	17	3.8	3.2	99,470	5,746	2,962	85,090	36,510	7,000	9,930	2,728	7,423	582.3	16	160.2
108	8.0	5.3	9.6	22	14	65.5	16.1	77.7	11	1.9	19.5	44.6	5.3	12.7	134,600	10,950	8,521	124,100	74,010	4,251	5,650	4,712	3,713	895	17	227
109	7.2	5.4	6.5	22	14	63.8	14.7	84.2	9.1	2	18.7	42.4	4.9	12.4	125,870	9,875	8,214	134,870	73,840	3,870	4,578	3,587	3,287	789	17	198
110	6.4	5.5	5.7	23	14	61.8	12.1	98.7	8.4	2.1	12.7	41.5	4.3	12.2	111,540	8,874	7,236	145,200	73,850	2,875	3,547	3,217	2,478	658	18	167
111	5.1	5.8	3.3	23	13	57.4	4.3	117.1	7.2	2.1	6.3	40	4	12.1	93,520	5,763	5,554	179,300	73,960	2,382	1,950	2,840	1,094	596.3	18	147
112	5.9	5.8	7.9	23	13	54.4	5.6	86.3	6.4	2.1	5.5	28.3	3.6	11	99,900	6,719	5,977	182,600	73,250	2,284	1,400	3,051	1,189	634.4	18	145.7
113	4.6	6	3.6	22	13	42.5	3.7	103.7	7	2.2	3	26.7	3.9	11.8	87,390	5,389	4,984	193,800	80,810	1,354	1,500	2,779	1,540	548.7	18	123
114	5.6	6.1	3.4	24	12	43.4	3.4	73.2	7.2	2.3	4.8	17.7	4.1	4	89,070	4,147	4,279	226,000	71,580	1,016	1,500	2,354	655.5	465.3	19	92.2
115	5.3	6.1	4.0	24	13	45.2	2.7	112.6	6.5	2.2	3.6	14.9	3.8	4.4	84,410	5,519	5,009	211,300	86,120	5,421	6,470	3,375	6,081	550	19	118
116	5.0	5.7	7.0	23	13	48.3	2.9	87.3	10	2.1	4	21.3	3.8	6.5	90,640	5,324	5,396	184,700	81,290	1,216	1,500	3,040	1,241	519.2	19	119.8
117	5.8	5.5	8.0	21	12	70.5	3.5	102.4	5.9	2.1	3.3	13.5	3.5	4.5	94,490	4,923	5,077	167,900	102,100	1,197	3,860	3,599	5,422	493.6	18	100.4
118	5.7	5	4.6	21	21	69	15.2	7.7	6.7	1.6	15.2	55.6	4.2	20.4	264,900	56,350	19,930	35,790	10,640	588.7	16,000	18,200	555.2	2,374	206	518
119	5.5	5.9	3.9	23	13	68.3	2.9	97.3	6.9	2.2	4.5	37.7	3.7	16.5	85,260	5,771	5,438	183,200	75,160	3,120	1,600	3,502	3,363	557.3	18	125
120	4.9	5.4	7.9	22	12	68.2	3.3	82.2	6.9	2	4.1	13	4.3	6.4	82,620	4,729	5,328	153,400	84,200	1,192	3,570	3,732	3,292	443.2	17	113.5
121	5.9	5.4	6.4	22	12	56.8	2.8	55.5	7.3	2.2	3.3	6.7	4.4	3.1	78,430	4,283	4,431	197,100	77,870	1,168	2,480	3,051	2,508	432	55	117
122	5.8	5.7	4.3	24	12	58	3.7	64	7.5	2.2	3.4	9.2	4.3	3.4	92,410	4,939	4,597	191,700	99,820	1,468	5,350	3,790	6,272	478.3	38	115
123	5.8	6	8.0	24	13	99.3	2.5	109.9	6.8	2.2	4.3	25.2	3.8	6.5	105,800	6,423	6,046	167,300	102,500	768.7	2,750	3,952	755.9	581.2	19	118.5
124	5.3	5.7	7.8	24	13	73.4	5	90.8	7.2	2.1	4.1	24.4	4.9	9.3	120,600	8,178	5,572	154,400	118,700	706.2	5,750	3,686	815.5	503.4	19	171
125	5.5	5.9	5.8	23	13	80.9	4.9	97.6	7.1	2.1	5.1	26.4	4.1	7.9	107,700	7,595	6,556	159,500	93,700	781.3	2,230	3,704	452.2	648.7	18	149
126	5.4	5.8	5.1	23	14	83.4	4.1	99.4	7.2	2.1	4.9	28.7	4	8.1	109,800	7,457	6,458	160,100	98,700	874.3	3,540	4,001	3,874	635.7	19	150
127	5.3	5.8	4.7	23	14	85.7	3.7	125	7.5	2.1	4.6	34.8	3.9	9.6	110,600	7,286	6,333	162,200	101,800	1,048	4,720	4,417	2,215	620.2	19	151
128	5.5	5.9	3.1	24	16	175	3.4	173.5	7	2.4	4.9	23.6	4	7.1	108,600	10,880	7,860	177,900	87,290	411.6	14,290	5,072	11,660	909	43	173
129	7.3	4.4	6.8	18	11	229.6	11.4	55.2	6.1	1.5	12.5	28.9	2.8	10.7	310,200	2,026	4,320	44,030	18,710	2,199	5,480	4,253	1,120	592	110	112.1
130	5.4	5.9	6.4	23	15	113.8	8.8	177.7	7.5	2.3	5.3	25.5	4.2	6.3	154,200	8,787	7,677	135,500	89,520	488.7	11,300	5,633	9,852	935	20	230
131	5.4	5.4	3.2	22	20	93	20.1	103.4	15.9	1.8	26.4	64.8	4	21	216,900	32,970	17,810	94,200	43,080	1,527	11,020	15,270	3,144	1,980	103.4	570
132	4.9	5.9	3.1	21	19	84	54.6	157.1	6.5	2	31.2	138.8	3.9	37.2	146,200	20,590	16,420	98,380	29,710	5,919	1,500	8,842	817.8	2,192	7,130	197
133	5.3	5.6	5.5	23	20	68	18.3	51.6	7.2	1.9	32	48.9	3.4	14.2	164,400	23,220	17,480	121,900	47,150	3,588	6,800	11,410	6,684	1,741	3,120	505
134	5.9	5.7	5.6	21	19	121	37	77.4	7.3	1.9	27.4	74	3.8	24.9	207,300	22,770	15,670	100,600	50,720	2,613	8,540	10,750	6,719	1,707	1,083	351
135	5.2	4.7	3.5	20	15	127.4	14.4	85.5	6.6	1.6	23.7	56.3	3.4	18.5	256,300	14,830	13,030	42,740	28,700	3,488	5,190	9,236	5,684	1,445	166.1	250
136	5.0	4.9	2.6	20	17	58.5	11.1	129.9	6.8	1.7	9.1	41.7	4.1	11.8	203,900	28,770	13,600	64,160	52,240	2,228	14,030	14,560	5,344	1,424	19.3	414
137	4.6	4.3	5.9	21	13	145.8	9.3	85.8	6.6	1.5	11.5	31.1	3.3	11.5	307,300	9,895	7,893	47,050	28,370	2,412	7,070	8,452	3,508	909	16.5	230.5
138	5.0	5.3	7.3	24	13	64.2	17.6	49.4	6.9	1.9	5.4	29	3.5	8.1	166,100	5,818	5,463	145,300	65,840	4,719	6,060	7,866	12,810	666	17	237
139	5.5	5.3	4	21	13	43.7	29.4	33.1	6.9	1.8	6.9	32.3	3.8	9.2	186,600	6,212	6,194	107,900	66,150	10,850	4,500	12,330	23,830	797	27.3	360
140	5.7	5.2	6.3	22	13	79.2	6.1	149.1	6.7	1.9	9.3	24.1	3.9	7.2	142,200	5,521	5,924	119,100	108,500	4,775	10,630	4,565	7,842	651.8	17	208
141	5.1	4.5	5.2	20	11	212.7	8.9	78.2	7	1.7	8.5	20.7	3.7	9	304,000	2,362	4,726	56,380	32,780	5,539	11,160	4,532	13,850	703	28.8	921
142	4.9	5	6.9	22	12	142.9	5.4	125.5	6.9	1.8	6.8	28.5	3.8	9.7	178,100	4,260	5,545	113,500	80,620	1,705	2,880	3,454	2,164	615.8	17	152.9
143	5.3	5.3	4.1	23	13	143.6	6.3	127	7	1.9	5.1	37.7	4	10	178,900	5,516	5,945	113,600	75,980	4,469	9,650	4,905	10,970	669	17	1,324
144	6.2	4.9	5.1	21	13	132.4	5.7	124.9	9.7	1.8	7.7	25.2	3.3	10.7	168,300	5,424	6,301	102,100	69,300	5,575	5,220	4,849	9,825	652.4	16	137

Table 1 continued

Sample	Sb	W	Ag	Mo	Co	V	Cu	As	Sn	Hg	Ni	Zn	Cd	Pb	Si	Al	Fe	Ca	Mg	S	Na	K	Cl	Ti	Cr	Mn
145	5.7	5.4	3.4	22	14	74.3	6	100.1	7	2	5.8	39.3	3.7	7	132,600	8,375	6,736	137,300	93,370	4,837	11,570	4,935	8,498	758	39.4	170
146	4.9	4.9	3.3	22	13	82.1	6.5	97	6.2	1.8	5.9	25.8	3.6	7.9	154,300	5,241	6,015	124,700	67,140	1,762	4,370	4,303	3,973	645.2	16	192.2
147	9.0	5.1	8.5	22	14	51.5	4.6	87.6	6.9	1.9	5	21.7	3.8	6.9	140,100	8,407	7,123	118,000	80,980	8,210	15,700	5,377	16,680	866	48.3	194.7
148	5.1	5.5	6.0	21	17	79.1	16.1	64.7	7	1.9	16.6	47.1	3.8	10.1	161,800	18,170	12,990	117,200	61,050	2,188	4,090	10,300	3,234	1,360	1,311	404
149	6.6	5.1	5.2	22	17	68.8	7	69.5	7.2	1.8	8.5	27.9	4	8.9	175,000	16,020	11,900	104,800	65,590	14,710	18,920	10,120	4,825	1,139	49.4	300
150	5.8	5.5	4.6	23	20	44	16.9	43.7	6.5	1.9	15	45.1	3.4	16.6	188,800	32,630	15,990	120,700	50,710	1,019	7,250	1,1670	1,488	1,922	90	385
151	5.4	6	4.4	25	18	55	8.2	65	6	2.1	13.9	33	4	12.2	132,800	20,980	12,310	170,800	56,180	781.2	4,860	7,454	2,238	1,502	122	328
152	5.4	5.7	3.2	23	13	60.9	3.3	115.8	7.1	2.1	2.8	20.1	3.8	6.8	103,700	6,143	5,810	169,300	106,500	533.3	3,880	3,977	1,692	602.7	18	124.1
153	5.5	5.8	3.4	23	13	61.1	3.4	100.8	7.4	2.1	3.2	22.4	4.1	7.4	101,250	58,745	5,541	187,500	98,746	586	3,540	3,874	1,235	589.1	18	125
154	5.6	5.9	3.8	24	13	61.6	3.6	67.5	7.6	2.2	4.1	24.4	4.3	8.7	90,530	5,474	5,262	212,500	73,250	1,445	1,500	2,418	696.1	509.7	18	125
155	5.8	6.3	3.3	23	21	103	11.5	53.1	7.3	2.2	26	76.3	4	26.4	171,960	36,640	17,540	175,900	37,670	1,081	1,500	10,600	400.9	2,067	44.1	310
156	5.7	6.4	6.1	23	18	61.7	12.9	170.1	8.5	2.1	30.5	52.4	3.5	16.9	127,000	17,480	13,030	161,000	79,460	1,584	2,290	5,964	208.5	1,268	64	300
157	5.8	6.2	6.6	24	21	72	11.3	22.2	7	2	40.7	56.9	4.2	26.5	123,300	27,920	18,500	169,000	35,660	787.1	1,600	8,546	97.1	1,947	105	409
158	4.7	5.6	6.1	22	15	71	9.4	202	6.3	2	11.7	40.5	4	10.6	175,100	13,030	10,330	97,460	108,200	369.4	1,400	4,391	20.6	939	40	258
159	5.6	7	8.9	23	26	12.8	44.3	18.1	7.6	1.6	142	76.5	3.8	38.1	174,800	44,270	29,240	138,500	31,880	418.7	2,660	11,380	154.1	2,566	419	687
160	5.1	7	3.3	23	26	124	26.6	9.6	6.7	1.6	151.3	76.5	4.2	37.8	167,100	41,970	31,860	128,100	26,500	339.1	2,540	11,220	46.5	2,621	582	712
161	5.9	6.6	3.4	21	43.1	125	25.8	9.3	7.3	1.8	156.6	60.4	4.3	21	165,700	44,330	32,070	112,500	26,890	356.6	1,910	11,600	309.8	2,819	506	737
162	5.2	6.8	4.3	23	25	112	30.3	16.6	6.6	2	136.7	58.7	4.1	17.8	153,500	40,110	28,960	137,100	37,610	2,446	1,600	10,760	552.6	2,355	406	636
163	5.3	5.5	4.1	18	33.6	120.0	12.1	4.6	6.7	1.1	112.2	44.9	4.2	16.9	241,200	45,960	31,130	31,750	22,410	389.6	7,840	14,820	567.9	2,186	552.0	621
164	5.1	5.8	3.1	20	48.5	120.0	28.0	8.2	6.8	1.5	112.0	56.2	3.4	17.8	212,600	63,420	36,640	47,450	21,730	263.6	4,730	15,680	367.3	2,754	302.0	806
165	5.8	5.7	3.1	20	32.1	86.0	28.6	4.3	7.1	1.5	104.3	57.9	4.1	21.5	234,000	54,560	31,680	43,680	21,940	201.8	9,610	16,110	221.2	2,321	701.0	711
166	5.0	5.5	3.1	21	47.8	118.0	26.0	7.1	6.1	1.3	101.1	51.1	3.2	16.2	201,740	61,230	34,530	45,630	21,640	245.3	4,550	14,090	342.5	2,627	301.0	785
167	5.1	5.2	3.7	22	22.0	83.0	14.8	7.6	7.1	1.7	47.7	48.3	4.3	22.8	233,900	50,680	24,240	44,520	32,220	462.1	5,820	20,800	89.2	2,610	267.0	716
168	5.9	5.5	6.1	25	20.2	93.0	14.8	8.8	7.8	1.9	51.0	43.5	4.4	21.0	205,630	47,250	23,980	82,270	42,100	362.2	2,740	17,680	59.0	2,324	389.0	650
169	5.6	8.7	4.3	20	73.0	114.0	30.4	5.2	7.1	1.5	288.2	75.3	4.0	19.3	201,230	47,340	50,130	43,210	43,120	187.1	3,510	7,421	36.1	2,374	892.0	938
170	4.9	4.9	3.6	20	25.0	85.2	10.8	4.6	9.1	1.4	43.2	46.3	4.1	20.3	231,640	51,610	25,150	28,240	19,510	5,021.0	9,800	17,390	163.1	2,412	523.0	621
171	5.6	5.9	3.9	24	15	69.4	3.2	98.5	7.1	2.4	5.9	39.6	3.9	16.9	99,660	5,835	5,643	182,400	75,340	3,230	1,650	3,623	3,439	567.8	25	143
172	5.4	4.3	6.2	20	12	163.2	10.1	66.5	6.4	1.5	11.7	29.3	2.9	11.2	309,300	5,560	6,210	45,140	20,120	2,210	5,890	4,352	1,340	612	64	131.2
173	5.9	5.4	3.4	22	16	74.8	8	90.4	6.7	1.9	6.9	38.8	3.7	11	151,540	9,163	7,858	128,150	91,140	2,164	9,840	5,046	9,632	869	41.2	190
174	7.2	5.2	5.2	23	17.3	62.5	8.9	112.4	6.7	1.9	6.8	45.8	3.7	17.2	247,600	18,430	17,130	10,950	83,450	643.5	4,790	8,978	956.6	1,253	21.8	342
175	5.3	5.9	4.5	24	18.7	56.2	8.2	45.7	7.4	1.9	21.2	43.3	3.7	29.5	143,400	24,250	14,338	175,350	26,300	953.0	1,850	6,793	171.0	1,876	99.4	346
176	5.3	6.3	5.5	23	26.5	85.4	25.8	9.8	7.2	2.0	34.4	98.4	3.8	56.5	163,700	48,360	24,840	132,500	15,370	1,004.0	3,680	11,660	368.2	2,642	196.3	489

Zn, Sb, V, Mn, Ti and Sn (Table 2). As described by Pekey, concentrations of important heavy metals in Sultan Marsh are shown in the form of box and whisker plot in Fig. 4 and concentrations of anthropogenic Fe, Mg, Zn, Pb, Cr, Co, Cu, Ni and Cd based on the frequency histogram (Pekey 2006) are shown in Fig. 5.

These metals with above threshold concentrations and their possible geochemical behavior in the soil endanger the environment in the region of interest. Generally, according to geogenic and anthropogenic sources, Fe, Pb, Zn, Sb, W, Mo, Co, Cu, Hg, Ni, Cr, Mn and Cd, which showed toxic effects in Sultan Mars, are used as indicators of pollution. It was striking that the industrial wastes with high toxic effects were from the north of Sultan Marsh, which was muddy and foul-smelling and showed As, Cr, Cu, Fe, Ni, Pb, Ti and Zn.

Multivariate analyses

According to the results of soil sample analyses and coefficient correlations between the metals, there was a strong *positive correlation* between **Sb** and W, Ag, Mo, Co, Cu, Hg, Zn, Cd, Pb; **W** and Ag, Mo, Co, Cu, Hg, Zn, Cd, Pb, Fe; **Ag** and Mo, As, Hg, Zn, Cd, Pb; **Mo** and Co, Cu, Hg, Zn, Cd, Pb, Al, Fe; **Co** and Cu, Hg, Ni, Zn, Cd, Pb, Al, Fe; **Cu** and Hg, Ni, Zn, Cd, Pb, Al, Fe; **As** and Hg, Mg, Cl; **Hg** and Zn, Cd, Pb, Fe; **Ni** and Zn, Al, Fe, Cr; **Zn** and Cd, Pb, Al, Fe; **Cd** and Pb, Fe; **Pb** and Fe; **Al** and Fe; **Mg** and Cl (Table 3).

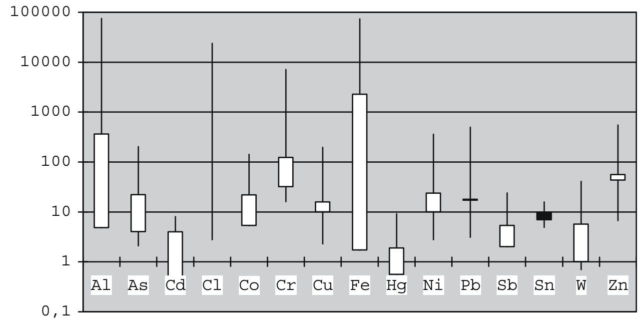


Fig. 4 Heavy metal concentrations in the soil of Sultan Marsh

Table 2 Comparison between element concentrations in Sultan Marsh soils, Crust (Upper crust: Wedepohl 1995) and soil (Northern Europe: Reimann et al. 2003) samples (in mg/kg) (revised from Zhang 2005)

	Crust	Soil	Sultan Marsh soils					Variation of average cnt. in soil (fold)	Variation of maximum cnt. in soil (fold)
			Min	Median	Max	Avg	SD		
Ag	0.07 (Krauskopf 1979)	0–0.56 (Wedepohl 1969–1978)	2.4	**4.8**	12.9	5.173743	2.013899	9.2	23
Al	7.744	4.83	2,026	**36,640**	75,330	33,276.18	20,595.17	6,889	15,596
As	2	4	2.1	**22.2**	202	48.62514	49.18817	12	50.5
Ca	2.945	0.9934	10,540	**95,430**	253,500	99,970.59	60,751.1	100,634.8	255,184
Cd	0.15 (Krauskopf 1979)	0.1–0.5 (Maynard 1983)	2.8	**4**	8.1	4.085475	0.722125	41	81
Cl	130	–	2.8	**429.7**	23,830	2,310.077	3,928.079	17.8	183
Co	11.6	5.3	8.6	**22**	142	28.22961	20.20998	5.3	26.8
Cr	35	32	16	**123.5**	7,130	305.8827	792.6461	9.6	222.8
Cu	14.3	10	2.3	**15.8**	197.4	22.76145	27.43244	2.28	19.7
Fe	3.089	1.7065	2,962	**22,830**	73,950	24,050.8	16,808.71	14,148	43,500
Hg	0.02	0–0.56 (Wedepohl 1969–1978)	1	**1.9**	9.2	2.097207	1.184935	3.75	16
K	2.865	1.5605	2,354	**10,020**	20,800	9,984.67	4,922.066	5,873	13,333
Mg	1.351	0.3437	7,170	**32,240**	118,700	44,142.63	28,196.18	128,432	349,117
Mn	527	426	92.2	**494**	2,567	535.0039	375.23	1.3	6
Mo	0–6	2–5 (Brooks 1972)	18	**22**	44	22.94413	3.350512	11	22
Na	2.567	0.8977	1,400	**4,720**	24,100	6,120.737	5,057.542	6,801	26,777
Ni	18.6	10	2.8	**23.7**	361.2	54.07486	72.39989	5.4	36.1
Pb	17	17	3.1	**17.9**	501	36.66536	79.22191	2.2	29.5
S	300	100–200 (Brady 1974)	74.2	**1,004**	26,010	2,602.809	4,242.595	2.6	26
Sb	0.2	2 (Boyle 1975)	4.2	**5.4**	24	5.806145	2.080104	2.9	12
Si	28.2×10^4	–	78,430	**165,700**	310,200	174,521.1	56,039.41		
Sn	2.5	10 (Connor and Shacklette 1975)	4.9	**6.9**	15.9	7.174302	1.310725	0.7	1.59
Ti	3,117	2,601	279.6	**2,059**	4,790	1,883.485	986.1129	0.7	1.8
V	53	37	12.8	**82**	229.6	91.1838	40.58736	2.5	6.2
W	1.2	1 (Brooks 1972)	0.7	**5.7**	41	6.530726	4.656827	6.5	41
Zn	52	43	6.7	**56.3**	552.3	74.6257	83.09409	1.7	12.8

cnt Concentration

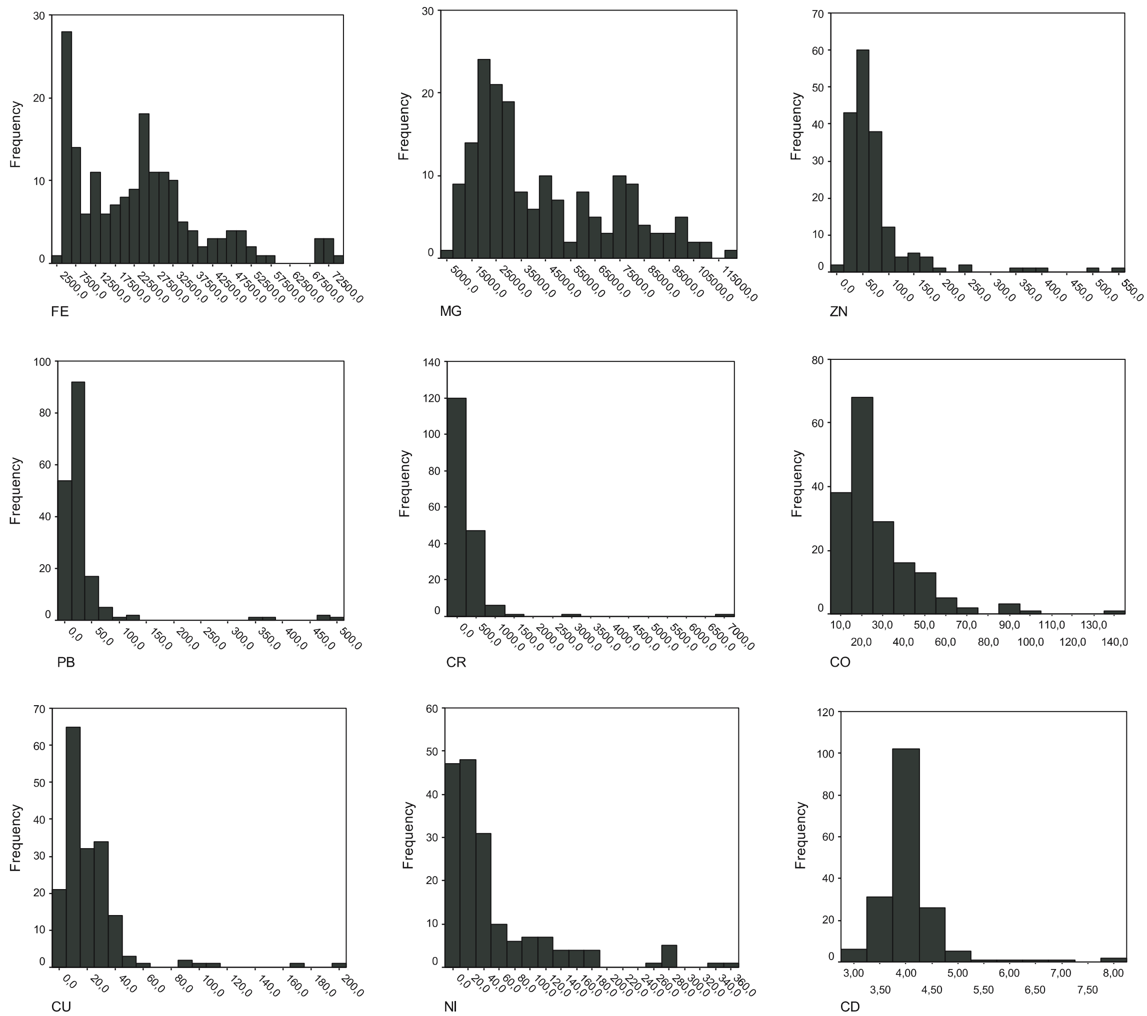


Fig. 5 Frequency histograms of Fe, Mg, Zn, Pb, Cr, Co, Cu, Ni and Cd (anthropogenic elements) in the soil of Sultan Marsh

A *moderate positive relation* was found between Sb and As, Ag and Cu, Cu and Cr, Zn and Cr and Cd and Al (Table 3).

There was a *negative relation* between Ag and Al; Co and As, Mg and Cl; Cu and Mg and Cl; As and Ni, Al and Fe; Ni and Mg and Cl; Zn and Mg and Cl; Cd and Cl; Pb and Mg; Al and Mg and Cl; Fe and Mg and Cl.

There was a moderate *negative relation* between W and Cl; Mo and Cl; Cu and As; Cd and Mg; Pb and Cl; Mg and Cr (Table 3).

The metals that strongly correlated with each other were thought to have the same possible pollution sources. High correlations between the metals were thought to be due to Fe–Pb–Zn mines (anthropogenic influenced ones) surrounding Sultan Marsh. Especially the sources of Sb and Ag were the Pb–Zn mine; the sources of W, Mo, Co, Cu, Hg, Ni and Cd were the Pb–Zn and Fe mines; the source of Al was the Fe mine; the source of As was not the Fe–Pb–Zn mines but the same as that of Mg in Sultan Marsh.

The Pearson correlation coefficients were used to classify the elements which were detected based on the chemical analysis results. Based on the comparisons between the groups and a method of calculation using the farthest neighbor, a dendrogram was formed (Fig. 6). Based on the correlations between the elements, four different groups were formed. The possible origins of the elements that formed similar groups were the same.

Accordingly, there was 24,050.8 ppm *Fe* on average in the study area, and the Fe rate was expected to be between 2,962 and 73,950 ppm (Table 2). This value was quite high compared to 3,089 ppm, the Clark concentration of Fe in crust, and 1.7065 ppm, the soil concentration. The Fe rate in the soil was enriched 14,148 times than the average rate. There was a highly positive correlation between Fe and W, Mo, Co, Cu, Hg, Ni, Zn, Cd, Pb and Al and a highly negative correlation between Fe and As (Table 3). Fe and As had different sources. In the dendrogram based on the

Table 3 Coefficient correlation between the elements in the Sultan Marsh soils

	Sb	W	Ag	Mo	Co	Cu	As	Hg	Ni	Zn	Cd	Pb	Al	Fe	Mg	Cl	Cr
Sb	1																
W	0.508[a]	1															
Ag	0.345[a]	0.354[a]	1														
Mo	0.515[a]	0.648[a]	0.292[a]	1													
Co	0.260[a]	0.327[a]	0.018	0.439[a]	1												
Cu	0.258[a]	0.578[a]	0.181[b]	0.507[a]	0.669[a]	1											
As	0.170[b]	0.100	0.207[a]	0.103	−0.394[a]	−0.168[b]	1										
Hg	0.526[a]	0.708[a]	0.367[a]	0.847[a]	0.459[a]	0.726[a]	0.205[a]	1									
Ni	−0.038	0.129	−0.087	−0.037	0.508[a]	0.278[a]	−0.442[a]	−0.092	1								
Zn	0.468[a]	0.667[a]	0.283[a]	0.514[a]	0.449[a]	0.577[a]	−0.085	0.569[a]	0.290[a]	1							
Cd	0.455[a]	0.594[a]	0.315[a]	0.596[a]	0.385[a]	0.415[a]	0.046	0.619[a]	0.036	0.525[a]	1						
Pb	0.467[a]	0.590[a]	0.387[a]	0.470[a]	0.301[a]	0.445[a]	0.057	0.561[a]	0.119	0.876[a]	0.572[a]	1					
Al	−0.053	0.050	−0.210[a]	−0.098	0.488[a]	0.281[a]	−0.698[a]	−0.140	0.389[a]	0.308[a]	0.171[b]	0.162[b]	1				
Fe	0.085	0.427[a]	0.035	0.377[a]	0.828[a]	0.707[a]	−0.520[a]	0.395[a]	0.533[a]	0.563[a]	0.405[a]	0.371[a]	0.655[a]	1			
Mg	0.005	−0.134	0.128	−0.037	−0.497[a]	−0.408[a]	0.709[a]	−0.020	−0.365[a]	−0.400[a]	−0.156[b]	−0.273[a]	−0.771[a]	−0.640[a]	1		
Cl	−0.016	−0.149[b]	0.070	−0.156[b]	−0.350[a]	−0.221[a]	0.367[a]	−0.086	−0.258[a]	−0.252[a]	−0.202[a]	−0.177[b]	−0.489[a]	−0.442[a]	0.394[a]	1	
Cr	−0.047	0.018	−0.103	−0.080	0.097	0.160[b]	−0.035	−0.044	0.222[a]	0.148[b]	−0.013	0.047	0.108	0.114	−0.185[b]	−0.096	1

[a] Correlation is significant at the 0.01 level (two-tailed)

[b] Correlation is significant at the 0.05 level (two-tailed)

N 176

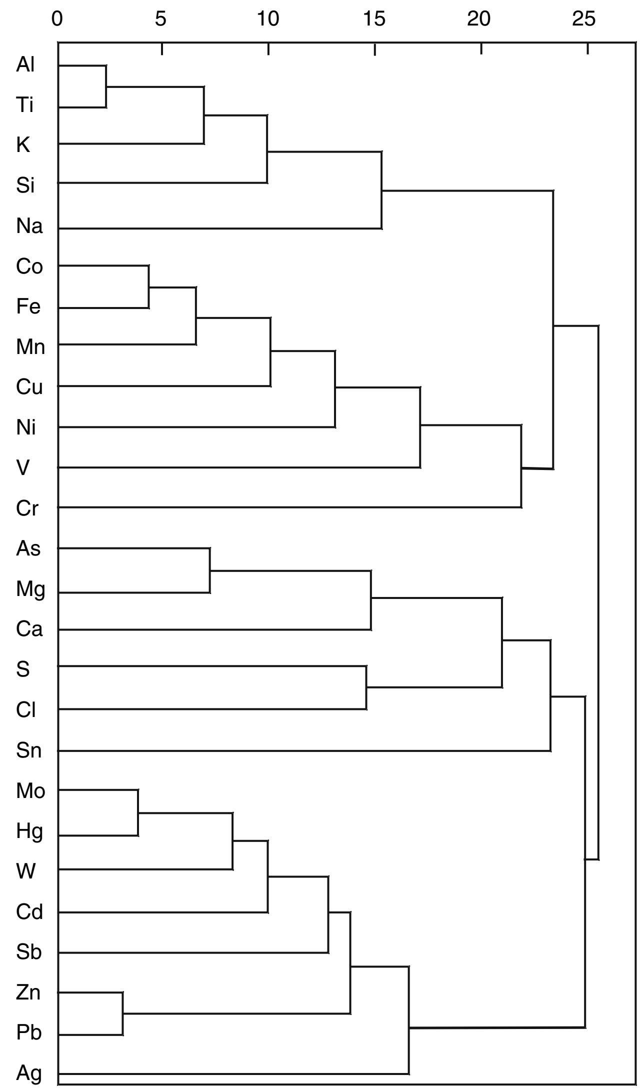


Fig. 6 Elements using cluster analysis based on Pearson's correlation coefficients

correlation coefficients of the elements, Fe formed a distinct group with Co, and it partook in the group of Mn, Cu, Ni, V and Cr (Fig. 6).

There was 36.7 ppm *Pb* on average in the study area and the Pb rate was expected to be between 3.1 and 501 ppm (Table 2). Compared with the concentration of Pb in crust and soil (17 ppm), this value was significantly high. The Pb rate in the crust soil was enriched about 2.2 times than the average rate. It showed a highly positive correlation with Sb, W, Ag, Mo, Co, Cu, Hg, Zn and Cd (Table 3). In the dendrogram prepared based on the correlation coefficients of the elements, Pb formed a distinct group with Zn, and it partook in the group of Sb, Cd, W, Hg, Mo and Ag (Fig. 6).

According to the hierarchical cluster analysis dendrogram based on the chemical analysis results, it was determined that the number of stations was enough. Similarities were observed between some stations (Fig. 7) and elements (Fig. 6). Generally, it was possible to divide similar stations into four groups. The

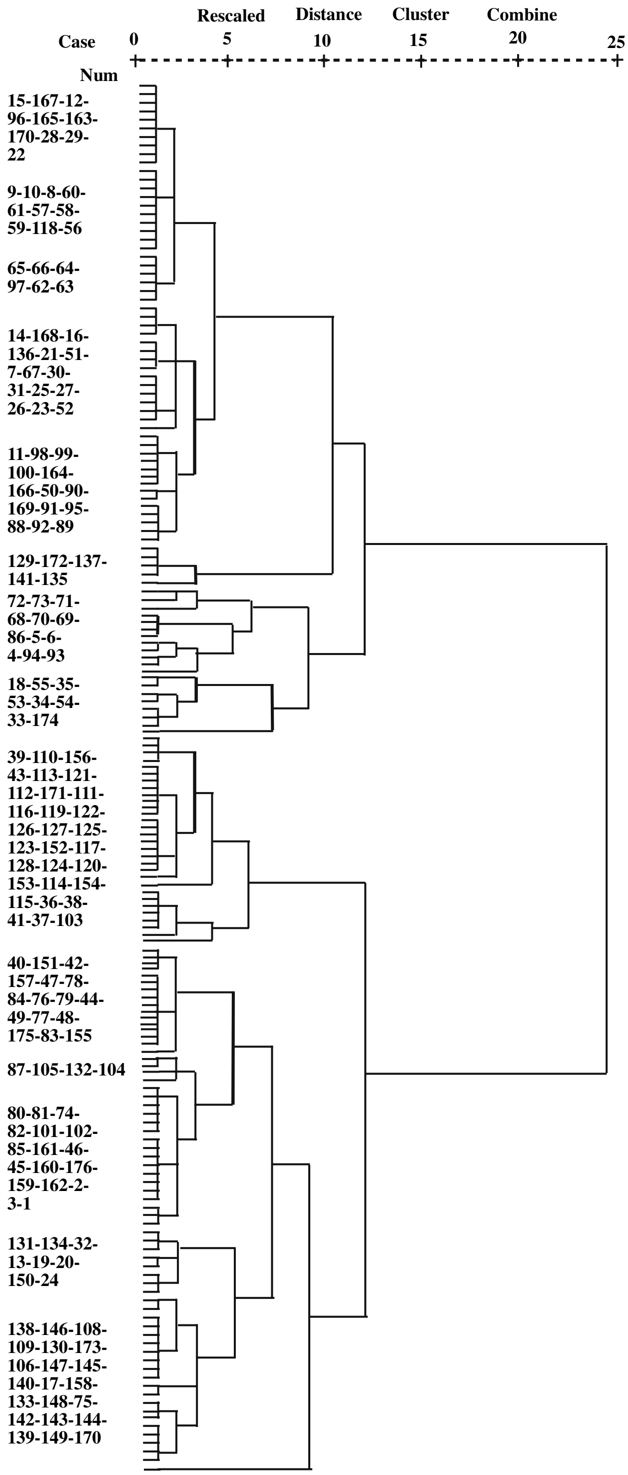


Fig. 7 Hierarchical cluster analysis dendogram of Sultan Marsh region soil samples

areas of similar stations consisted of mines of Fe and Pb/Zn, industrial facilities, residential areas, major traffic routes and agricultural areas. For this reason, pollution sources of similar stations can be considered the same (Fig. 7).

In the regression analyses of the chemical data on Fe, calculations were done according to a Model summary and ANOVA (Table 4). The explanatory power of the regression analyses for Model summary was $R^2 = 91.5\%$. According to ANOVA, 25 descriptive variables (Mn, Sb, Na, Sn, Cr, S, V, Ag, K, Cd, Ni, Cl, Cu, Pb, Ca, W, As, Mo, Ti, Co, Mg, Si, Zn, Al and Hg) had a high explanatory power for the variation of Fe element.

Spatial distribution patterns of pollutants

The objective of the project was to develop methodologies for comparing and integrating scientific analyses of soil, using GIS (Oudwater and Martin 2003). Geostatistics were used to construct regional distribution maps to be compared with the geographical, geologic and land use regional database using GIS soft-ware (Facchinelli et al., 2001). GIS mapping is a powerful tool in identifying the possible sources of pollutants (Zhang 2005). The GIS map technique was used to make a spatial distribution map for the pollution areas in Sultan Marsh (Fig. 8).

GIS maps provide valuable information for hazard assessment and for decision support (McGrath et al. 2004). The results of the chemical analyses and GIS maps which were carried out on the samples (Pb, Zn, Fe, Cu, Hg, Ni, Co, Al, Mn) from Sultan Marsh clearly indicated the effect of surrounding rocks (geogenic sources). Metals can be categorized into two groups; metals necessary for plants and animals namely Cr, Co, Cu, Fe, Mn, Mo, Ni, U, V, W and Zn and metals not necessary for plants and animals namely Ag, As, Cd, Hg, Pb, Pt, Tl, Sn and Zr (Haktanir et al. 1997). Depending on their soil contents, especially the metals not necessary for plants and animals may show their toxic effects quickly.

Fe and Pb–Zn metallic mines operating (anthropogenic influenced ones) in the region were the apparent pollution sources. Fe, Co, Hg, V and Cu elements which showed the highest concentration in the study area were associated with especially the Fe mine in the south border and the Fe melting factory located in the west border (anthropogenic influenced ones). In the maps in Fig. 8, all concentration ranges were determined with reference to the soil limit values to soils (Brooks 1972; Boyle 1975; Brady 1974; Connor and Shacklette 1975; Krauskopf 1979; Maynard 1983; Reimann 2003;

Table 4 Model summary and anova tables of regression data

Model summary

Model	R	R square	Adjusted R square	Std. error of the estimate
1	0.957(a)	0.915	0.901	5188.80852

Anova (b)

Model		Sum of squares	*df*	Mean square	F	Sig.
1	Regression	43,594,313,415.780	25	1,743,772,536.631	64.767	0.000[a]
	Residual	4,038,560,076.941	150	26,923,733.846		
	Total	47,632,873,492.722	175			

[a] Predictors (constant): Mn, Sb, Na, Sn, Cr, S, V, Ag, K, Cd, Ni, Cl, Cu, Pb, Ca, W, As, Mo, Ti, Co, Mg, Si, Zn, Al, Hg

[b] Dependent variable: Fe

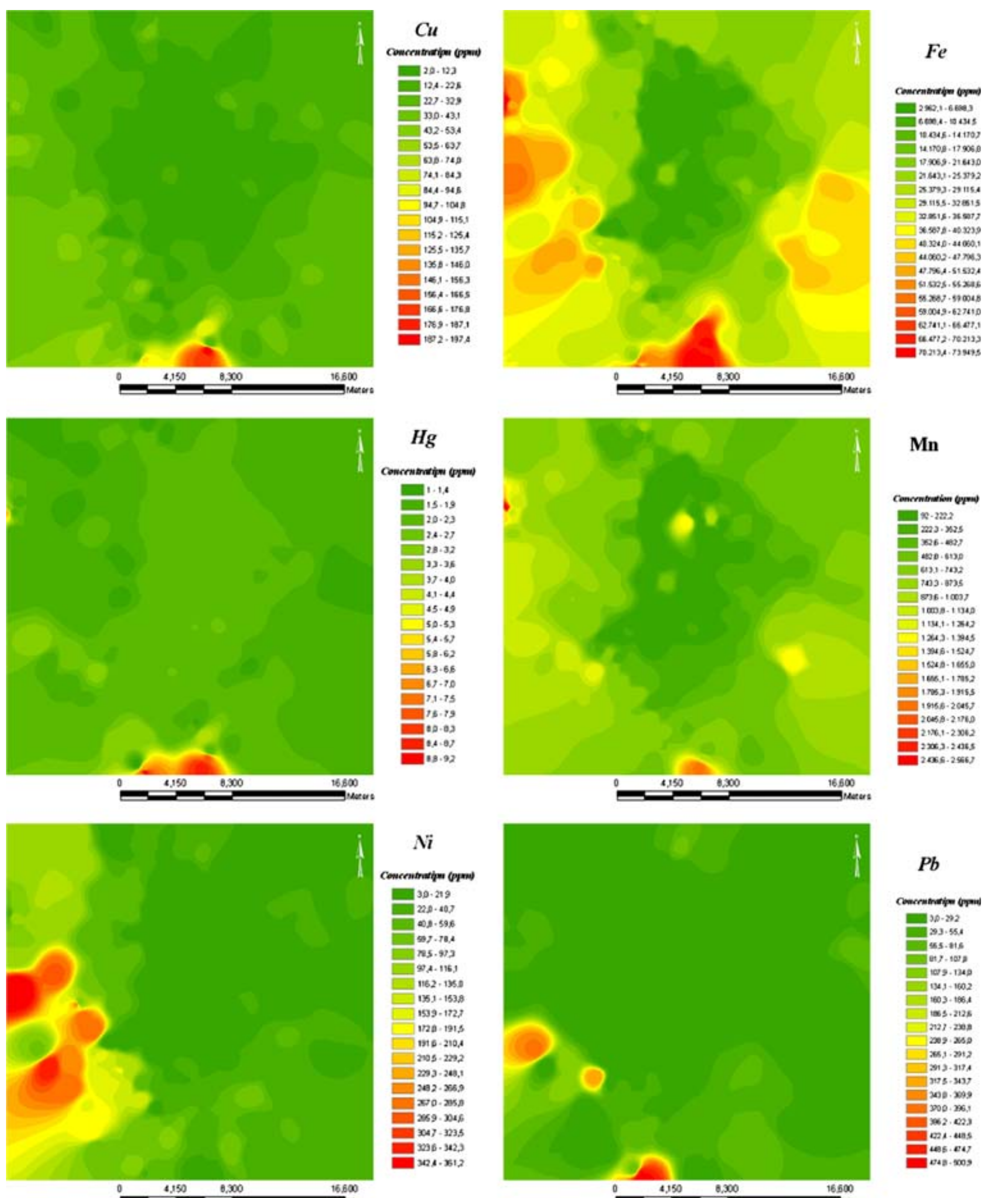
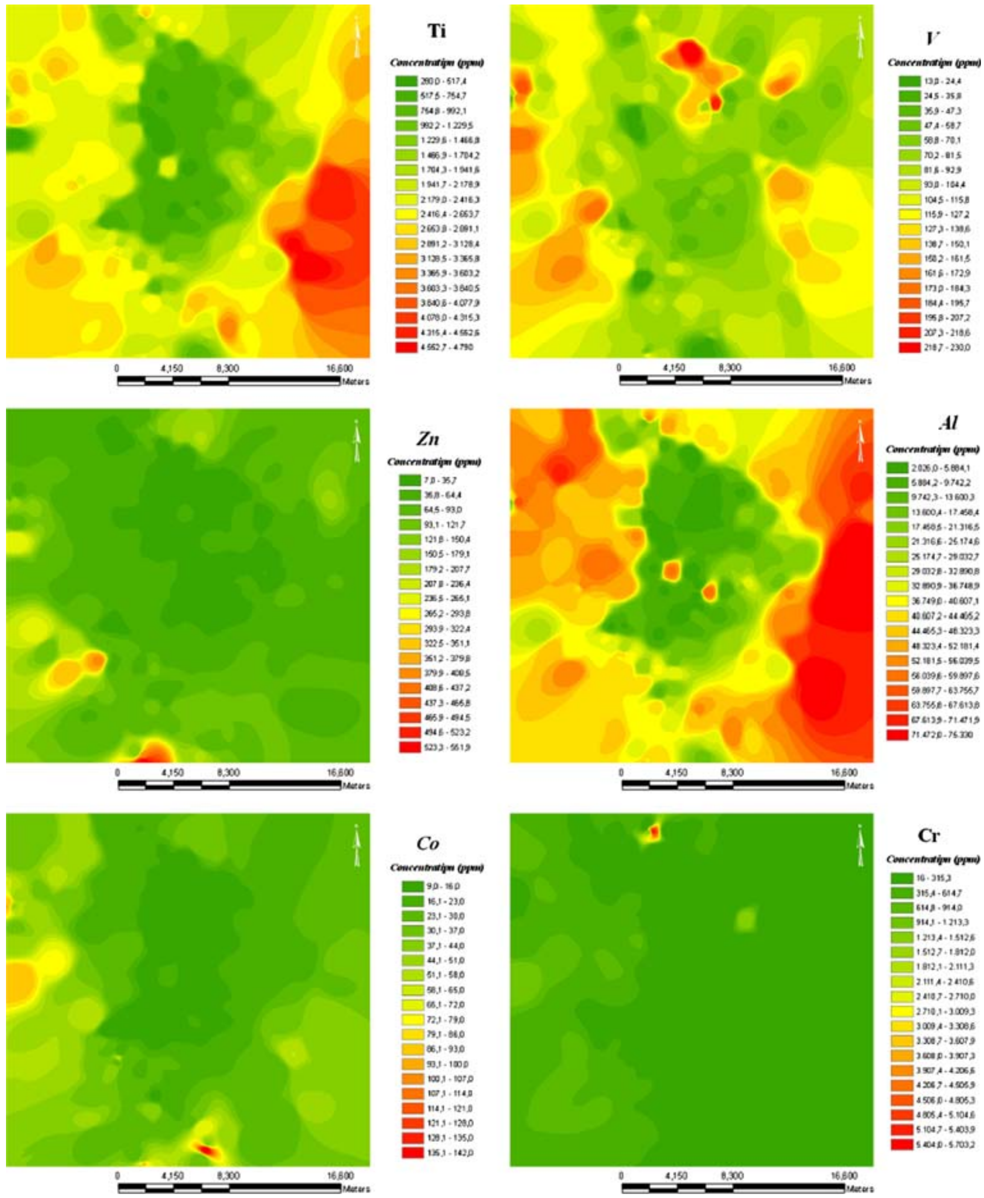


Fig. 8 Spatial distribution maps of Fe, Pb, Zn, Al, Co, Hg, Mn, Ni, Ti, V, Cr and Cu in Sultan Marsh

Fig. 8 continued



Wedepohl 1969–1978, 1995). The highest anomalies were observed in the samples that belonged to this Pb–Zn, Fe mines area. However, apart from these areas (between Yahyali, Develi and Dortyol) there was also traffic related pollution due to the traffic density in the area surrounding Sultan Marsh and industrial pollution in the residential areas (anthropogenic sources).

The pollution actually increased from the sides of the study area to its center. Iron causes organic corrosion and decreases oxygen. It turns into hydroxide and causes the precipitation of iron hydroxide. Similarly, iron bacteria rapidly increase in calm lakes of streams especially after floods and form iron piles in the lakes. High iron concentrations on the stream banks cause major changes in micro flora. When the Fe concentration in the streams exceeds 1 mg/l, fish may be harmed (Topbas et al. 1998). For this reason, *Fe* concentrations must certainly be kept under control. *Pb* and *Zn* elements, which showed an anomaly in the study area, were caused by the Pb–Zn mine located in the south border and the highest anomalies were observed in the samples that belonged to this area (anthropogenic influenced ones). However, apart from this area, traffic related pollution was high in Yahyali Crossroad and Yahyali Crossroad-Dortyol highway (anthropogenic influenced ones). Moreover, there was also traffic related pollution throughout the area where traffic existed.

Ni element showed a high anomaly which was due to Yahyali Crossroad-Dortyol highway and also a tyre anomaly along the traffic routes that surrounded the study area. The source of *Ti* and *Al*, which showed a high anomaly in the south section of the study area, was the same. It also showed a similar anomaly in the whole region that surrounded the study area. *Cr* element showed an anomaly especially around the leather factory in the north of the study area. It also showed a high anomaly due to Yahyali Crossroad-Dortyol highway. Physically polluted factory waste waters observed in the north section of study area flowed into the marsh basin via soil. Therefore, Ni, Ti, Al and Cr in this area were anthropogenic.

Along with Cr, Cu, As, Ni, Zn, Pb, Fe and Ti showed a high anomaly in small lake areas, where the wastes existed (anthropogenic sources). Factory wastes were muddy, foul-smelling and constituted major sources of pollution. Furthermore, sewer system wastes caused by the residential areas in the region flowed into the basin. Industrial wastes in the residential area with no waste treatment facilities were thought to increase the heavy metal contents. The metal rate in the soil samples taken from these areas was low. It may be that the metal rate was low in domestic wastes, which may have diluted the creek water.

Conclusions

Metals can be classified into two groups: those necessary for plants and animals, namely, Cr, Co, Cu, Fe, Mn, Mo, Ni, U, V, W and Zn and those not necessary for plants and animals, namely, Ag, As, Cd, Hg, Pb, Pt, Tl, Sn and Zr (Haktanir et al. 1997). Depending on their contents in soil, metals especially those not necessary for plants and animals may show their toxic effects quickly. Maximum heavy metal contents of all samples taken from Sultan Marsh exceeded the permissible soil and crust cut-off values. Based on the increases in their variation rates in soil, heavy metals can be listed as Mg, Fe, Al, K, Cr, Cl, Cd, As, W, Ni, Pb, Co, Ag, Mo, Cu, Hg, Zn, Sb, V, Mn, Ti and Sn. The sources of heavy metal contents having a high positive relation were thought to be the same with regard to the correlations in Table 3. As a result, the sources of Sb and Ag elements were the Pb–Zn mine; the sources of W, Mo, Co, Cu, Hg, Ni and Cd elements were the Pb–Zn and Fe mines; the source of Al was the Fe mine; the source of As was not the Fe–Pb–Zn mines but the same as that of Mg in Sultan Marsh.

The results of chemical analyses made on the samples taken from Sultan Marsh clearly showed the effect of surrounding rocks (geogenic sources). The elements Fe, Co, Hg, V and Cu which showed an anomaly in the study area originated from especially the Fe mine in the south border and the Fe melting factory located in the west border (anthropogenic influenced ones). Eutrophication was developed partially in the places where the pollution was dense and where there were calm waters in Sultan Marsh. A foul-smell was overspreading in these areas which were becoming swamps. It was thought that the micro flora would change greatly depending on the iron rate and that accordingly fish would not be able to live in the lakes of Sultan Marsh. Moreover, Fe pollution was observed around the roads that surrounded the study area and industrial facilities in the residential areas.

Pb and Zn elements which showed an anomaly in the study area were associated with the Pb–Zn mine in the south, Yesilhisar-Yahyali highway and leather factory in the north. Cr, Cu, As, Ni, Zn, Pb, Fe and Ti showed an anomaly around the leather factory located in the north of the study area (anthropogenic influenced). Factory wastes were muddy, foul-smelling and constituted major sources of pollution. In addition, Cr and Ni showed a high anomaly along Nigde-Kayseri highway. It may be due to major traffic routes and gas stations. The sources of Ti and Al which showed a high anomaly in the east section of the study area were the same. They also showed a similar anomaly in the whole area that surrounded the study area. Industrial wastes in the residential area where there were no waste treatment facilities were thought to increase the heavy metal contents. The metal rate in the soil samples taken from these areas was low. It may be that the metal rate was low in domestic wastes, which may have diluted the creek water.

The sources of detected heavy metal concentrations can be listed as the surrounding rocks (geogenic sources), mines of Fe and Pb/Zn, industrial facilities, residential areas, major traffic routes and agricultural areas (anthropogenic sources).

It can be concluded that heavy metals (Fe, Pb, Zn, Sb, W, Mo, Co, Cu, Hg, Ni, Cr, Mn and Cd) show high toxic effects in Sultan Marsh due to their high concentrations. It can be suggested that domestic wastes from the residential areas and factories should flow into Sultan Marsh after exposed to waste treatment and that immediate precautions should be taken to stop pollution in Sultan Marsh. For example, there should be protection areas.

In the regression analyses of the data from chemical analyses of Fe, ''Model summary'' significantly explained and ''ANOVA'' moderately explained 25 descriptive variables. The present approach illustrates the role of geostatistics in the evaluation of the chemical data and indicates geochemical opinions as the spatial proofs of the relationship between the elements.

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