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ORIGINAL ARTICLE

Heavy mineral distribution as related to environmental conditions for modern beach sediments from the Susanoglu (Atakent, Mersin, Turkey)

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Abstract Geochemical works were conducted on anthropogenically effective lithologic unit exposing along the Susanoglu coast in Mersin, Turkey. For this purpose, beach sand sediments from 33 stations were collected and heavy metal and oxide concentrations were analyzed. To determine the source of heavy metals (natural and anthropogenic), simple and multivariate statistical analyses were applied. According to factor analysis, three factors were determined. The first factor consists of SiO_2, Al_2O_3, Na_2O, K_2O, TiO_2, Cr, Ni, Cu and Mo and total variance is explained with 27.502% and expressed as "*natural process factor*". These elements (Cr, Ni, Cu, Mo) are closely associated with geogenic materials and came from same sources of ultrabasic rocks (ophiolite). The second factor consists of CaO, MgO, TiO_2, MnO, Ni, Pb, Zn and W and total variance is explained with 21.505% and expressed as "*anthropogenic factor*". These elements (Pb, Zn, Cd, V, W) are anthropogenic and are mainly due to the effluent or industrial input/activities and came from different sources of pollution in the study area. The third factor consists of Pb, Cd and Sb and total variance is explained with 9.748% and expressed as "*intermediate factor*". The factor analysis and the cluster analysis are in support of each other. Cr, Ni, Co, Cd, Hg and Mo concentrations are greater than Turkish acceptable values and they show toxic effect. Al, Cu, Pb, Cd and Mo concentrations in beach sand deposits in the Susanoglu coast are found as 1.44, 1.26, 1.21, 1.02 and 1.04 mg/kg and higher than those in Kızkalesi beach sands. However, all other heavy metal contents are determined in low concentrations.

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Introduction

Turkey has the largest beach sand system in Europe. The 845-km part of total coasts in 8,333-km length (about 10% total coasts) are covered by beach sands. A number of 110 sand dune systems along the Turkish coasts have been rapidly eroded or polluted (Uslu 1989). Coastal dunes are one of the most dynamic structures on the earth. These dunes extending behind the coast form dune ridges. Coastal dunes are continuously modified and based on their geomorphologic and ecologic characteristics, various wetlands and dry areas are formed. Sand dunes are necessary for river deltas, lagoons, estuaries and saltpans and they are important shelters for sea turtles, seals and various birds and some special rare plant and animal species living along the coast (Ongan 1997). Therefore, for mitigating environmental problems in coastal areas, it is very important to investigate concentrations and sources of toxic metals in dune sediments depositing in coastlines. Multivariate statistical analysis is the most common method used to explain the geogenic and anthropogenic sources of heavy metals in sediments (Facchinelli et al. 2001; Boruvka et al. 2005). Among these methods, factor analysis is often used (Child 1970; Lawley and Maxwell 1971; Jöreskog et al. 1976).

In the last century a number of works have been conducted on heavy metal concentrations in dune sediments in the coastal areas. Pollutant effects of mines on coastal sands are investigated by numerous workers (Caredda et al. 1999; Caboi et al. 1993; Ramirez et al. 2005). Heavy metal contents of sands and coastal deposits in the Mondego Cape in Portugal were examined and their possible sources

were determined (Vidinha et al. 2006). Some of important studies conducted in the study area include Everest and Seyhan (2006), Okyar (1991), Okyar et al. (2005), Demirel (2004), Burak et al. (2004), Ediger et al. (2002) and Kocak et al. (2005). However, concentrations and sources of heavy metals in the Susanoglu coastal dune sediments are first studied in the present work. The Susanoglu coast is very important since it is one of the widest coastlines and important touristic places in the region and, therefore, results of present work are imperative.

The environmental characterization of the Susanoglu (Mersin), based on a geochemical study of dune sediments, is the first purpose of this study. The aim is to identify the geochemical signature of the anthropogenic influences in this coastal environment overwriting the regional background, which is the lithology and geochemistry, controlled by Miocene carbonate rocks of the Tauride belt and Late Jurassic and/or U. Cretaceous ophiolites.

Experimental

Study area

The Susanoglu coast under investigation is located at eastern part of Atakent town between Kızkalesi and Silifke. The Atakent town is at 15th km of the Silifke–Mersin road. The antic name of town is *Corasium*. The city belonging to the Late Roman period was established by Flavius Uranius (367–375) who was the Isauria governor. Ruins of two separate necropolises, church, bath, cistern and warehouse are observed in the arc-shaped antic Atakent city. Today, the city is an important tourism center with its sun, sea and coast (Silifke 2007) (Fig. 1).

Regional geology

The study region is located in southern part of Miocene carbonate rocks of the Tauride belt (Fig. 1). Depositional environments of the sedimentary rocks in the central Tauride belt are described as "unit" (Ozgul 1971, 1976). Formations in the region were deposited in terrestrial conditions at the beginning of Miocene and then in marine conditions in the following periods. During the deposition, lithology was dependent on old topography and units were not significantly disturbed (Gedik et al. 1979). The *Bolkar Dağı unit* is represented by carbonate and clastic rocks together with olistostrome rocks with ages changing from Devonian to lower Tertiary. In addition, the Mersin ophiolite is also exposed in an area close to the Susanoglu coast. The *Bozkır unit* is composed tuff, basic, ultrabasic rocks (Mersin ophiolite) and serpantinite and also shelf units and oceanic crust rocks of Triassic-Senonian age

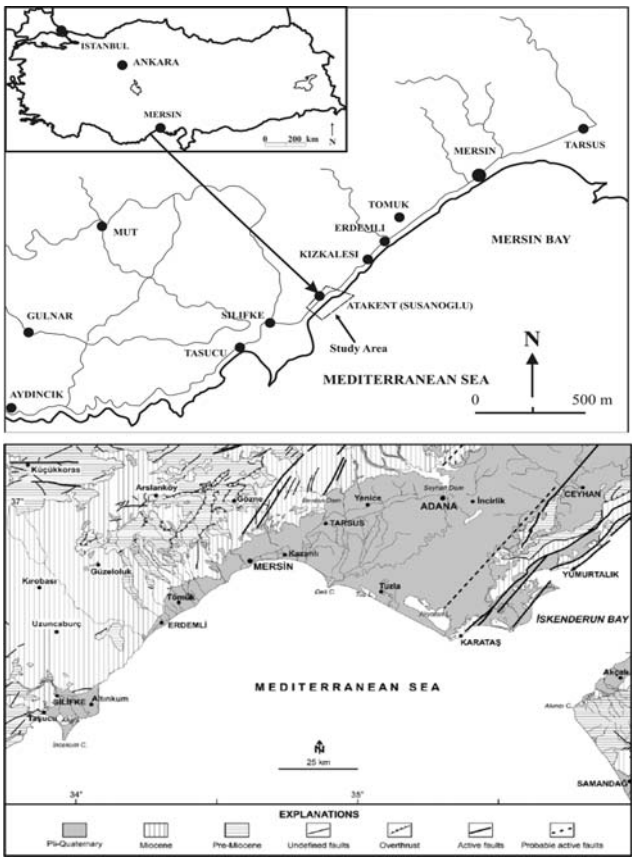


Fig. 1 The areas of the present study and The Tethyside tectonic units of Turkey (after Sengor 1987; MTA 2002)

(Yetis and Demirkol, 1986; Ozgul and Kozlu, 2002). The Mersin ophiolite, represented by approximately 6-km thick oceanic lithospheric section on the southern flank of the Taurus calcareous axis, formed in the Mesozoic Neo-Tethyan Ocean some time during Late Cretaceous in Southern Turkey (Parlak et al. 1996).

Sampling and chemical analyses

Sand samples were collected from the Susanoglu coast during September 2006. Coordinates of each sample was determined with Garmin brand GPS-12CX and marked on 1/25.000 scaled map. Samples from 33 locations were collected at a depth of 0–10 cm from the surface with the use of hard plastic shovel and stored in 2-kg plastic bags (Fig. 1). Samples were heated at 105°C for 24 h. Following the drying of sediment samples, they were homogenized in an agate mortar and pulverized to >2 mm grain size. The mortar was washed with 6 mol/l HNO_3 and rinsed with distilled water and dried before the each sample process. All samples were transformed to double sided film tablets in 32 mm diameter and their heavy metal and major oxide contents were analyzed with Spectro Xepos Bechtop

X-Ray Fluorescence Spectrometer. Results are given as % and mg/kg.

Data analyses using computer software

Identification of heavy metal groups and their inter relations are very important for source evaluation (Davis 1986). Since there are partial differences in the vertical column at the surface soils, their explanation requires some geochemical interpretation (Facchinelli et al. 2001). Therefore, raw data from chemical analysis were input to MS Excel program and simple statistical processes were performed on the raw data. This was followed by the application of multivariate statistical analysis to heavy metal data using the SPSS software and relevant figures were constructed with Corel 11 software.

Results

Coordinates and results of chemical analysis (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, S, Cl, Si %, Al %, Fe %, Ca %, Mg %, Na %, K %, Ti %, Mn, Cr, Cu, Ni, Co, Pb, Zn, Cd, As, Ag, Hg, Mo, Sb, Sn, V, W) of samples collected along the Susanoglu coast are given in Table 1.

Basic statistics of total element contents and correlation matrix

Minimum and maximum contents of Al, Fe, Mg, Ti, Mn, Cr, Cu, Ni, Co, Pb, Zn, Cd, As, Ag, Hg, Mo, Sb, Sn, V and W metals are 9,100–14,500, 12,100–16,500, 7,400–22,300, 600–800, 244–464, 125–711, 4.40–32.1, 93–277, 16–29.4, 3.50–7.7, 15.40–20.9, 3.60–5.5, 15.20–24.7, 2.60–7.8, 1.10–2.3, 20–63, 5.10–6.7, 6.80–8.9, 21.50–55.4, 5.50–8 mg/kg, respectively.

The content SiO_2 is found as <50%. Some metal contents such as Cr, Ni, Ti and Mg are not consistent with those of earth crust (Krauskopf 1979) and sandstone (Turekian and Wedepohl 1961) but consistent with ophiolitic rocks (Parlak et al. 1996) indicating that basic/ultrabasic rocks particularly ophiolites are the source rocks of beach sands (Table 2). Ti, Cr, Ni, Co, Cd, As, Ag, Hg, Mo, Sb, Sn and W contents of the Susanoglu beach sands show anomaly with respect to earth crust. Fe, Mg, Mn, Cr, Cu, Ni, Co, Zn, As, Ag, Hg, Mo, Sb, Sn, V and W concentrations are greater than those of sandstone and Ti, Pb, Cd, As, Ag, Hg, Mo, Sb, Sn and W contents are anomalous when compared to ultrabasic rocks. Cr, Ni, Co, Cd, Hg and Mo concentrations in Susanoglu beach sands are higher than Turkish acceptable limits and they show toxic effects.

Comparison of Susanoglu and Kızkalesi beach sands reveals that Susanoglu sediments are represented by increases in Al (1.44-fold), Cu (1.26-fold), Pb (1.21-fold), Cd (1.02-fold), Mo (1.04-fold), Si (1.63-fold), Na (1.07-fold) and K (4.41-fold) concentrations. All other metals have lower concentrations. High Al, Na and K concentrations in the Susanoglu area indicate the effect of K-feldspar which is also revealed by intense agricultural activity in this area. Moreover, Al, Cu, Pb, Cd and Mo contents of the Susanoglu area are higher than those of the Kızkalesi area.

With reference to the correlation matrix (Table 3) which indicates the correlation among different elements, the positive high relationship ($r^2 \leq 0.10$) among sand vs. contaminated elements (Cr vs. Cu, Ni, Mo, W; Cu vs. Ni, W; Ni vs. Mo, W; Pb vs. Zn; Mo vs. W) and the positive low relationship ($r^2 \leq 0.50$) among sand versus contaminated elements (Cu vs. Mo, Sn; Pb vs. W; Zn vs. Cl, W; Cd vs. Sb, V; As vs. V; Sb vs. V) indicates the presence of these elements in sand layers. The association of these elements (Cr, Ni, Cu, Mo) are absorbed from ophiolitic materials in the beach sediments rather than finer particles (Tables 1, 2). The above correlation of elements clearly indicates that they are geogenic in nature.

The negative high relationship ($r^2 \leq 0.10$) among sand versus contaminated elements (Cr vs. Cd, V; Ni vs. Cd; Mo vs. V) and the negative low relationship ($r^2 \leq$ less than 0.50) among sand versus contaminated elements (Ni vs. V; Cd vs. W) indicates the presence of these elements (Cd, V, W) in sand layers, are derived from different sources or industrial input/activities of pollution in the study area. The positive association of Pb versus Zn ($r^2 \leq$ less than 0.10) indicates that they are anthropogenic and are mainly due to the effluent or industrial input/activities and came from different sources of pollution in the study area.

Factor and cluster analysis

To identify the different factors that control the distribution of elements in the beach area, three factors were derived which are based on the eigenvalues and also the total variance (Table 4).

The first factor (Factor 1) explains 27.502% of the total variance with a high eigenvalue of 7.151 (Table 5). The first factor can be termed as "*natural process factor*". This is clearly identified by the association of SiO_2, Al_2O_3, Na_2O, K_2O and TiO_2. The association of the above elements also suggests the presence of heavy minerals in the dune sediments. The association of Cr, Ni, Cu and Mo along with these elements indicates that they are from a same geogenic source (ophiolites) and it is with the heavy minerals in the beach sediments (Tables 1, 2).

The second factor (Factor 2) explains 21.505% of the total variance with a eigenvalue of 5.591 (Table 5). In the

Table 1 XRF results of dune sediments from the Susanoglu shoreline

Sample	X	Y	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	Cl	Si %	Al %	Fe %	Ca %	Mg %	Na %	K %
AS-1	597431	4030809	42	2.1	2	13	1.8	246.3	1,689	19.43	1.12	1.21	9.11	0.74	0.43	0.77
AS-2	597377	4030793	50.55	2.6	1.85	18.75	2.14	306.1	1,927	23.63	1.38	1.29	13.4	1.29	0.39	0.9
AS-3	597325	4030766	51.37	2.73	1.89	19.49	2.07	299.2	1,891	24.01	1.45	1.32	13.93	1.25	0.72	0.9
AS-4	597210	4030681	37.74	2.36	1.84	22.89	2.39	425.8	2,007	17.64	1.25	1.29	16.36	1.44	0.43	0.73
AS-5	597164	4030634	42.44	2.38	1.93	21.68	2.14	376.8	2,102	19.84	1.26	1.35	15.5	1.29	0.43	0.79
AS-6	597119	4030588	50.77	2.56	1.85	20.23	2.14	316.1	1,951	23.73	1.36	1.29	14.46	1.29	0.56	0.88
AS-7	597078	4030537	31.96	2	1.84	19.06	1.69	383.9	1,735	14.94	1.06	1.29	13.62	1.02	0.15	0.62
AS-8	597046	4030495	38.19	2.38	1.86	21.81	2.19	568.8	2,160	17.85	1.26	1.3	15.59	1.32	0.4	0.75
AS-9	597026	4030450	32.15	2.06	1.85	21.49	1.93	337.9	1,625	15.03	1.09	1.3	15.36	1.17	0.34	0.64
AS-10	596985	4030385	42	2.42	1.86	20.9	2.15	340.2	1,940	20.19	1.28	1.32	15.41	1.39	0.44	0.72
AS-11	596951	4030312	32.1	2.54	1.96	21.85	2.67	375.5	1,674	20.19	1.34	1.37	15.61	1.61	0.46	0.82
AS-12	596933	4030263	45.58	2.72	1.89	20.62	2.43	363.6	2,302	21.31	1.44	1.32	14.74	1.46	1.3	0.73
AS-13	596915	4030215	34.03	2.27	1.98	23.97	2.52	387.2	2,030	15.91	1.2	1.39	17.13	1.52	0.37	0.68
AS-14	596884	4030108	26.11	1.86	1.98	20.27	2.03	500.9	1,732	12.2	0.99	1.38	14.49	1.23	0.17	0.53
AS-15	596869	4030058	41.07	2.72	2.08	22.48	3.26	443	2,351	19.2	1.44	1.45	16.07	1.97	0.49	0.81
AS-16	596859	4029973	39.6	2.52	1.97	24.89	2.71	434.9	2,086	18.51	1.34	1.38	17.79	1.63	0.52	0.75
AS-17	596838	4029920	37.1	2.07	1.98	22.07	2.23	468.6	2,033	17.34	1.09	1.39	15.78	1.34	0.4	0.7
AS-18	596822	4029871	26.9	1.85	1.98	20.17	2.04	408.8	1,491	12.57	0.98	1.39	14.42	1.23	0.17	0.56
AS-19	596809	4029791	30.03	2.1	2.02	23.8	2.51	549.3	2,209	14.03	1.11	1.41	17.01	1.51	0.22	0.61
AS-20	596803	4029718	27.46	2.14	2.36	22.06	2.99	450.1	2,373	12.84	1.13	1.65	15.77	1.8	0.17	0.61
AS-21	596803	4029630	40.53	2.44	1.96	24.93	2.52	494.2	2,164	18.95	1.29	1.37	17.82	1.52	0.49	0.76
AS-22	596780	4029547	27.97	2.04	2.17	23.84	2.55	451	2,296	13.07	1.08	1.52	17.04	1.54	0.17	0.6
AS-23	596763	4029473	20.79	1.73	2.07	23.3	2.34	674.1	2,186	9.7	0.92	1.45	16.65	1.41	0.18	0.47
AS-24	596750	4029387	26.7	2.06	2.12	28.1	2.82	543.3	2,021	12.48	1.09	1.48	20.09	1.7	0.29	0.55
AS-25	596742	4029287	32.97	2.43	2	29.02	3.1	506.1	2,202	15.41	1.28	1.4	20.74	1.87	0.47	0.67
AS-26	596732	4029218	28.83	2.43	2.1	31.74	3.69	446	1,506	13.47	1.29	1.47	22.68	2.23	0.28	0.59
AS-27	596725	4029118	25.56	2.15	2.21	28.51	3.46	621.2	2,706	11.95	1.14	1.55	20.37	2.09	0.25	0.51
AS-28	596725	4029008	25.37	2.17	2.1	33.61	3.23	660.6	2,326	11.86	1.15	1.47	24.02	1.95	0.3	0.5
AS-29	596710	4028904	18.49	1.71	1.99	33.5	2.94	572.6	1,859	8.64	0.91	1.39	23.94	1.77	0.18	0.38
AS-30	596699	4028806	28.86	2.27	2.17	30.33	3.15	501.1	2,162	12.55	1.2	1.52	21.68	1.9	0.18	0.55
AS-31	596689	4028719	21.91	1.91	1.82	37.32	3.37	557.4	2,698	10.24	1.01	1.27	26.67	2.03	0.16	0.42
AS-32	596682	4028652	24.1	2.19	2	33.85	3.51	449.9	1,367	11.26	1.16	1.4	24.19	2.12	0.19	0.48
AS-33	596693	4028577	31.99	2.37	2.18	26.9	3.19	702.5	5,438	14.95	1.26	1.52	19.22	1.93	0.3	0.67
Mean			33.73	2.25	2.00	24.44	2.6	459.5	2,128	15.91	1.19	1.39	17.47	1.56	0.36	0.66
Ophıolıtes (Parlak et al. 1996)											<27.6	<12.5	<20.9	<42.3		

first factor the association of CaO, MgO, TiO_2, MnO, Ni, Pb, Zn and W indicate that they are associated with the calcareous materials (Ca and Mg). In addition, all the elements (Pb, Zn, Ni, W) apart from Ca and Mg are polluted elements and it is not from a natural source. Hence, this factor can be termed as "*anthropogenic factor*".

The third factor (Factor 3) explains 9.748% of total variance with an eigenvalue of 2.534 (Table 5). This factor can be termed as "*intermediate factor*" indicating the association of Pb, Cd and Sb. Results of factor analysis are conformable with correlation matrix.

Using the results of chemical analysis Q-type cluster analysis was performed on the basis of Bray–Curtis approximation criteria with simple arithmetical average (Davis 1986; Tuysuz and Yahyali 2005). According to the hierarchical cluster analysis dendogram based on the chemical analysis results, the number of stations was found to be sufficient (Fig. 2). An evaluation of Q-type cluster at a random approximation level of 50% was performed for the study area and two groups were identified. The first group includes Al, Fe, Mg, Hg, Na, K, Ti, Cd, Ag, Pb, Sb, W, Sn, Cu, Mo, Zn, As, Ca, Co and Si elements which are

Table 1 continued

Ti %	Mn	Cr	Cu	Ni	Co	Pb	Zn	Cd	As	Ag	Hg	Mo	Sb	Sn	V	W
0.07	244	379	13.8	109.6	16	4.9	17.4	4.7	15.2	5.1	1.5	21	5.3	7.8	24	5.5
0.08	307	666	17.4	199.2	23.5	5.6	16.8	4.6	17.2	3.5	1.6	35	5.5	8.4	32	6.9
0.08	354	711	20.8	258	27	4.2	19.2	3.9	19.7	2.6	1.8	57	5.2	7.5	30.1	7.6
0.08	320	362	14	140.5	20.2	4.7	16.7	3.8	20.4	3.7	1.8	40	5.6	7.4	21.5	6.5
0.08	304	677	16	151.8	29.4	5.1	18.5	4.1	17.6	3.6	1.1	21	5.5	8.2	41.8	6.6
0.08	362	675	20.9	277	19	5.9	18.7	4	16.1	4.5	1.9	63	5.1	8.2	22.5	7.8
0.07	254	428	8.7	103.2	18.2	4.5	15.8	4.5	17.9	3.4	1.6	21	5.5	8.3	38.4	5.7
0.08	292	309	15.2	123.9	18	5.8	19.2	4.4	19	2.7	1.8	23	5.9	7.9	41.7	6.3
0.07	290	216	9.2	104.2	26.1	3.5	17.3	4	19	3.3	1.8	23	5.4	7.5	30.9	6
0.07	300	408	13.1	127.4	20.5	5.2	17.1	4.5	18.88	3.3	1.6	24	6	7.8	36	6.4
0.08	345	610	17.9	188.1	19	5	15.4	4.2	20.5	3.3	1.5	21	6	8.3	34.5	6.9
0.07	272	495	10.1	93.2	19	6.4	16.5	5.5	17	3.8	1.3	27	6.7	7.6	37	6.3
0.07	318	490	10.1	135.4	19	5.1	16.8	4.5	20.4	3.3	2.2	24	5.5	7.7	35.6	6.3
0.06	274	285	10.2	101.6	17	5.5	17	4.3	20.2	6.7	1.9	22	5.7	7.6	41.6	5.5
0.08	337	405	12.9	179.4	23.7	5.4	19.6	4.3	24.7	3.5	1.4	25	5.8	8	52.9	6.9
0.08	329	610	32.1	170.7	26.7	6.5	18.8	4.2	20	3.5	1.2	26	6.1	8.9	36.9	6.9
0.08	291	451	9.7	94.4	18	4.9	17.6	4.1	18	6.2	1.8	20	5.5	6.8	37.8	5.8
0.06	279	173	8.1	113.8	17	4.6	15.6	4.5	20.9	3.1	1.7	21	5.7	7.1	44.7	5.7
0.07	307	283	7.4	134	26.9	6.1	17.4	4.5	21.1	5	1.8	23	5.8	7.7	51.1	6.5
0.07	318	177	14.1	140.5	18.9	5.8	20.1	4.7	22.6	6.2	1.2	22	5.3	7.6	53.7	6.4
0.08	348	635	13.8	187.8	20.5	5.3	16.9	3.6	20.1	7.8	1.9	34	5.3	6.9	30	7.1
0.07	341	350	5.7	132	19	5.3	16.2	4.1	20.9	4	1.7	23	5.7	7.2	28.3	6.1
0.06	305	125	5.4	106	27.7	5.1	17.5	4.9	19.6	3.5	1.7	22	5.4	8.1	53.5	5.9
0.07	353	259	9.4	119.7	20.5	5.6	19.1	4.5	22.2	4.1	1.7	23	5.3	7.4	50.8	6.4
0.07	365	362	11.8	184.6	22	7.7	19.3	4.4	22	5.7	1.3	24	6.1	7.7	32.6	7.5
0.08	416	520	12.4	170	26.1	6.1	17.9	4.1	23.4	4.6	2.1	27	6.4	8.5	24.8	7.2
0.07	362	304	4.4	130.2	20	6.3	20.9	4.6	21.2	3.7	1.9	26	5.5	8.5	47.9	6.5
0.07	395	596	22.3	140.6	21	6.5	18.7	4.3	21.3	5.6	2.2	24	5.8	8	55.4	7
0.07	423	134	12.5	93	20.3	5.9	16.2	4.9	19.5	3.8	2	26	6.1	8.4	47.9	6.4
0.08	389	501	14.1	128.4	27.3	6.2	19.6	3.9	18.4	3	2.3	25	5.7	7.7	39.4	6.7
0.07	464	497	12.8	184.2	20	6.4	19.1	4.2	20.7	3.8	2.2	28	5.8	8.9	28.8	8
0.08	396	460	8.7	110.4	18.9	4.9	15.4	4	19.6	3	1.8	25	5.6	7.9	33.1	6.9
0.08	363	573	7.8	169.2	20	5.7	19	3.6	21.6	3.2	1.5	25	5.3	7	40.7	6.9
0.07	334	428	12.8	145.5	21.4	5.5	17.8	4.3	19.9	4.1	1.7	27	5.7	7.8	38.1	6.6
<0.09	<1,900	<7,480	Nd	<1,915	Nd	Nd	Nd								<169	

combined with Ni, Mn, Cr, S and Cl elements that comprise the second group. Results of factor analysis and cluster analysis are in support of each other (Fig. 2).

Model summary and ANOVA

The sufficiency of all data from dune sediments from the Susanoglu shoreline was checked by a Model Summary and ANOVA (Brady 1974; Yalcin et al. 2007; Yalcin and Ilhan 2008). The Model Summary was Square $R = 98.4\%$. According to ANOVA, 25 descriptive variables (Fe, W, Sb, Hg, Ag, Co, Cl, Ti, Sn, Zn, Cu, As, V, Na, Mo, S, Cr, Pb, Ca, Cd, Mn, Si, Mg, Ni, K) had a high explanatory power for the variation of Al element (Table 6). These results indicated that the number of samples from the area was sufficient. Some heavy metals in the beach and dune sediments from the Susanoglu shoreline showed abnormal values. Concentrations of some metals exceeded the background values. Regression analyses based on Al values showed that ''Model Summary'' was significantly sufficient and ''ANOVA'' with 25 explanatory variables was reliable.

Table 2 Statistical summary in the Susanoglu Beach and abundance of heavy elements in Earth Crust. Sanstone. their acceptable limits for Turkey and Kizkalesi Beach sediment

	Mean (A)	Min	Max	Earth crust (mg/kg) (Krauskopf 1979) (B)	Variation of average concentration in Earth crust (fold) (A/B)	Sanstone (Turekian and Wedepohl 1961) (C)	Variation of average concentration in Sanstone (fold) (A/C)	Ultrabasic (Turekian and Wedepohl 1961) (D)	Variation of average concentration in Ultrabasic (fold) (A/D)	Acceptable limit for Turkey (mg/kg) (TKKY 2005) (E)	Variation of average concentration in TKKY (fold) (A/E)	Kizkalesi Beach sediman Mean (Yalcin and Ilhan 2008) (F)	Variation of average concentration in Kizkalesi Beach dune (A/F)
S	459.48	246.30	702.5	300	**1.53**	240	**1.91**	300	**1.53**	2	**229.74**	861.49	0.53
Cl	2128.45	1,367	5,438	130	**16.37**	10	**212.85**	85	**25.04**	25	**85.14**	6635.07	0.32
Si	159066.67	86,400	240,100	282,000	0.56	368,000	0.43	205,000	0.78			97461.25	**1.63**
Al	11924.24	9,100	14,500	81,000	0.15	25,000	0.48	20,000	0.60			8267.17	**1.44**
Fe	13909.09	12,100	16,500	54,000	0.26	9,800	**1.42**	94,300	0.15			18803.63	0.74
Ca	174745.45	91,100	266,700	41,000	**4.26**	39,100	**4.47**	25,000	**6.99**			233647.98	0.75
Mg	15624.24	7,400	22,300	23,000	0.68	7,000	**2.23**	204,000	0.08			34993.03	0.45
Na	3636.36	1,500	13,000	24,000	0.15	3,300	**1.10**	4,200	0.87	125	**29.09**	3385.59	**1.07**
K	6560.61	3,800	9,000	21,000	0.31	10,700	0.61	40	**164.02**			1486.73	**4.41**
Ti	736.36	600	800	5	**147.27**	1,500	0.49	300	**2.45**			813.48	0.91
Mn	333.85	244	464	1,000	0.33	90	**3.71**	1,620	0.21			585.99	0.56
Cr	428.06	125	711	100	**4.28**	35	**12.23**	1,600	0.27	100	**4.28**	553.84	0.77
Cu	12.81	4.40	32.1	50	0.26	9	**1.42**	10	**1.28**	50–140	0.26	10.13	**1.26**
Ni	145.52	93	277	75	**1.94**	2	**72.76**	2,000	0.07	30–75	**4.85**	186.8	0.77
Co	21.41	16	29.4	20	**1.07**	0.3	**71.35**	150	0.14	20	**1.07**	28.2	0.75
Pb	5.51	3.50	7.7	12.5	0.44	**7**	0.79	1	**5.51**	50–300	0.11	4.55	**1.21**
Zn	17.80	15.40	20.9	70	0.25	16	**1.11**	50	0.36	150–300	0.12	19.75	0.90
Cd	4.32	3.60	5.5	0.15	**28.77**	0.09	47.95	0.9	**4.79**	1–3	**4.32**	4.21	**1.02**
As	19.91	15.20	24.7	1.8	**11.06**	1	**19.91**	1	**19.91**	20	1.00	24.74	0.80
Ag	4.12	2.60	7.8	0.07	**58.92**	0.09	**45.82**	0.06	**68.74**			4.13	0.99
Hg	1.72	1.10	2.3	0.02	**86.06**	0.03	**57.37**	0.09	**19.12**	1–1.5	**1.72**	2.05	0.83
Mo	27.00	20.00	63	1.5	**18.00**	0.2	**135.00**	0.3	**90.00**	10	**2.70**	25.96	**1.04**
Sb	5.67	5.10	6.7	0.2	**28.35**	0.09	**63.00**	0.1	**56.70**			5.95	0.95
Sn	7.83	6.80	8.9	2.5	**3.13**	0.9	**8.70**	0.5	**15.67**	20	0.39	8.17	0.95
V	38.12	21.50	55.4	110	0.35	20	**1.91**	40	0.95			63.3	0.60
W	6.58	5.50	8	1.2	**5.48**	1.6	**4.11**	0.77	**8.54**			7.61	0.86

Bold characters are anomaly value

Sediment (mg/kg, $n = 40$); Valid N (listwise) 40; *Min* minimum; *Max* maximum

Table 3 Coefficient correlation between the elements on dune sediments in the Susanoglu shoreline (marked correlations are significant at ** the 0.01 level and * at the 0.05 level; $N = 33$)

	S	Cl	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Cr	Cu	Ni	Co
S	1														
Cl	**0.551****	1													
SiO_2	−0.675**	−0.057	1												
Al_2O_3	−0.419*	0.098	**0.793****	1											
Fe_2O_3	**0.480****	0.358*	−0.476**	−0.199	1										
CaO	0.**632****	0.192	−0.635**	−0.231	0.277	1									
MgO	0.**552****	0.324	−0.482**	0.058	**0.565****	**0.839****	1								
Na_2O	−0.422*	−0.001	**0.719****	**0.729****	−0.369*	−0.347*	−0.210	1							
K_2O	−0.659**	−0.042	**0.945****	**0.810****	−0.394*	−0.678**	−0.461**	**0.625****	1						
TiO_2	−0.068	0.265	0.427*	**0.636****	−0.075	0.172	0.265	0.170	**0.476****	1					
MnO	0.**448****	0.287	−0.309	0.005	0.171	**0.807****	0.**701****	−0.118	−0.384*	0.272	1				
Cr	−0.317	0.136	**0.622****	**0.710****	−,289	−0.018	0.034	0.441*	**0.593****	**0.661****	0.164	1			
Cu	−0.293	−0.149	**0.478****	**0.513****	−0.256	−0.053	−0.050	0.331	**0.476****	0.358*	0.063	**0.597****	1		
Ni	−0.237	0.139	**0.534****	**0.632****	−0.167	−0.022	0.103	0.264	**0.574****	**0.514****	0.365*	**0.672****	**0.548****	1	
Co	0.046	−0.012	0.110	0.224	0.031	0.139	0.123	0.038	0.111	0.270	0.163	0.202	0.238	0.249	1
Pb	0.**450****	0.292	−0.156	0.142	0.299	**0.503****	**0.582****	0.086	−0.217	0.031	**0.468****	0.086	0.189	0.161	0.041
Zn	0.337	0.426*	0.063	0.216	0.412*	0.217	0.396*	0.012	0.031	0.222	0.438*	0.073	0.210	0.332	0.303
Cd	−0.032	−0.213	−0.118	−0.206	0.032	−0.172	−0.131	0.222	−0.201	−0.718**	−0.255	−0.454**	−0.207	−0.449**	−0.175
As	0.**490****	0.237	−0.464**	−0.026	**0.539****	**0.467****	**0.654****	−0.309	−0.316	0.049	0.339	−0.254	−0.165	0.077	0.120
Ag	0.135	−0.046	−0.069	−0.153	0.233	−0.001	0.022	−0.053	−0.087	−0.162	−0.095	−0.042	−0.007	−0.022	−0.240
Hg	0.280	−0.119	−0.363*	−0.328	−0.040	**0.484****	0.233	−0.367*	−0.446**	0.077	**0.454****	−0.016	−0.146	−0.025	−0.067
Mo	−0.320	−0.037	**0.567****	0.**470****	−0.343	−0.121	−0.134	0.375*	**0.469****	0.325	0.314	**0.479****	0.414*	**0.767****	0.115
Sb	0.059	−0.152	−0.123	0.175	−0.110	0.285	0.303	0.320	−0.146	−0.084	0.073	−0.043	0.088	−0.230	0.047
Sn	−0.014	−0.188	−0.086	0.053	−0.180	0.282	0.261	−0.086	−0.106	−0.093	0.212	0.168	0.389*	0.206	0.268
V	0.**585****	0.199	−0.**448****	−0.327	**0.514****	0.167	0.215	−0.266	−0.414*	−0.342	0.006	−0.445**	−0.187	−0.376*	0.125
W	0.057	0.209	0.223	**0.532****	−0.104	**0.489****	**0.517****	0.212	0.207	**0.560****	**0.716****	0.**601****	**0.465****	**0.820****	0.304

	Pb	Zn	Cd	As	Ag	Hg	Mo	Sb	Sn	V	W
S											
Cl											
SiO_2											
Al_2O_3											
Fe_2O_3											
CaO											
MgO											
Na_2O											
K_2O											
TiO_2											
MnO											

Table 3 continued

Cr																								
Cu																								
Ni																								
Co																								
Pb	1																							
Zn	**0.466****	1																						
Cd	0.234	−0.117	1																					
As	0.249	0.299	−0.164	1																				
Ag	0.267	0.065	−0.059	0.101	1																			
Hg	−0.004	−0.033	−0.240	0.049	0.019	1																		
Mo	−0.060	0.157	−0.317	−0.226	−0.074	0.181	1																	
Sb	**0.485****	−0.188	0.400*	0.174	−0.095	−0.077	−0.316	1																
Sn	0.343	0.160	0.263	−0.046	−0.308	0.020	0.044	0.316	1															
V	0.196	0.286	0.407*	0.399*	0.040	−0.110	−0.466**	0.019	0.008	1														
W	0.441*	0.395*	−0.390*	0.232	−0.053	0.137	**0.585****	0.064	0.346*	−0.27	1													

Bold characters are similar sources

Table 4 Results of factor analysis for dune sediments in the Susanoglu shoreline

	Component matrix		
	1	2	3
S	−0.709	0.464	−0.048
Cl	−0.123	0.431	−0.107
SiO_2	**0.939**	−0.124	0.103
Al_2O_3	**0.803**	0.318	0.277
Fe_2O_3	−0.557	0.295	−0.012
CaO	−0.503	**0.737**	−0.016
MgO	−0.409	**0.805**	0.135
Na_2O	**0.656**	−0.049	0.471
K_2O	**0.919**	−0.126	0.065
TiO_2	**0.522**	**0.539**	−0.291
MnO	−0.175	**0.835**	−0.113
Cr	**0.746**	0.401	−0.043
Cu	**0.597**	0.301	0.244
Ni	**0.677**	**0.560**	−0.128
Co	0.159	0.337	0.125
Pb	−0.199	0.**604**	0.**544**
Zn	−0.017	**0.598**	0.104
Cd	−0.296	−0.410	**0.728**
As	−0.445	0.493	0.016
Ag	−0.141	−0.014	−0.092
Hg	−0.264	0.266	−0.471
Mo	**0.667**	0.293	−0.256
Sb	−0.123	0.111	**0.736**
Sn	0.029	0.297	0.491
V	−0.607	0.036	0.286
W	0.397	**0.848**	0.019

Extraction method: principal component analysis

Bold characters are similar sources in factors

[a] Three components extracted

Table 5 Explanation of total variance of dune sediments with eigen values

Component	Initial eigenvalues (extraction method: principal component analysis)		
	Total	Variance (%)	Cumulative %
1	7,151	27,502	27,502
2	5,591	21,505	49,008
3	2,534	9,748	58,755

Discussion

The abundances of elements in the Susanoglu sand beaches are from highest to the lowest are Ca, Si, Mg, Fe, Al, K, Na, Cl, Ti, S, Cr, Mn, Ni, V, Mo, Co, As, Zn, Cu, Sn, W, Sb, Pb, Cd, Ag and Hg (Table 1). Based on this, the elements that are toxic to the region are ranked in the order of

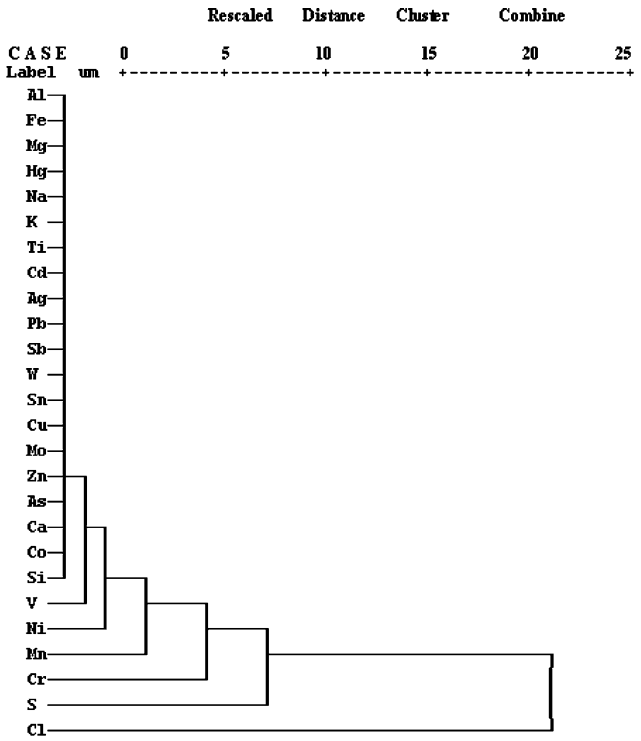


Fig. 2 Hierarchical cluster analysis dendogram by dendrogram using average linkage (within group) of dune sediments in the Susanoglu shoreline

significance as Fe, Al, Ti, Cr, Mn, Ni, V, Mo, Co, As, Zn, Cu, Sn, W, Sb, Pb, Cd, Ag and Hg.

The basement of sand beach sediments in the study area comprised carbonate and clastic rocks of the Bolkar dağı unit. Tuff, basic and ultrabasic rocks (Mersin ophiolite) and serpantinites are also observed in the vicinity of area.

Heavy metal contents of the Susanoglu sands in which the average SiO_2 content was found as <50% show anomaly for Ti, Cr, Ni, Co, Cd, As, Ag, Hg, Mo, Sb, Sn and W with respect to earth crust (Krauskopf 1979) and for Cr, Ni, Co, Cd, Hg and Mo with respect to Turkish acceptable limit values. Heavy metals with anomalous values have toxic effects on the region.

Concentrations of Al, Cu, Pb, Cd, Mo, Si, Na and K in the Susanoglu sands are about 1.44, 1.26, 1.21, 1.02, 1.04, 1.63, 1.07 and 4.41 times greater than those in the Kızkalesi sands. High concentrations of heavy metals are attributed to anthropogenic effects and particularly closeness of the Mersin–Antalya road to the study area may also result in metal contents to increase. The close association of Al_2O_3, K_2O and Na_2O clearly indicates the presence of K-feldspar in the beach sediments. Results of chemical analysis also support the efficiency of K-feldspar in the Susanoglu area where agricultural activities are intense (Yalcin and Ilhan 2008). Terra rossa soils characteristically observed in southern parts of the Bolkardagları Mountains comprise the source of Al_2O_3. The positive relationship of $Al_2O_3$with Na_2O, K_2O, TiO_2 indicates the deposition of sediments from the basement rocks that were formed in various facies and environments.

Results of correlation analysis (CA) are conformable with of heavy metal concentrations with toxic effects. In this respect, strong positive correlations were found between *Cr* and Cu, Ni, Mo, W, between *Cu* and Ni, W; between *Ni* and Mo, W; between *Pb* and Zn; between *Mo* and W. However, strong negative correlations are observed between *Cr* and Cd, V; between *Ni* and Cd; between *Mo* and V (Table 3). Metals with strong positive correlations are thought to have the same origin while those with strong negative correlations are believed to have different sources.

According to results of principal component analysis (PCA), three factors were determined; *natural process factor* (Factor 1), *anthropogenic factor* (Factor 2) and *intermediate factor* (Factor 3) (Table 4). Natural process factor represents for processes related to sand formation.

Factor 1 (27.502% of the total variance with a high eigenvalue of 7.151) is composed of Cr, Ni, Cu and Mo heavy metals and it was probably derived from ophiolites. To determine anthropogenic effects among the factors, contaminant sources were examined and similar works in nearby areas were reviewed. Soils along the highways are

Table 6 Model summary and anova tables of regression data from dune sediments from the Susanoglu shoreline

Model summary						
Model	*R*	*R* square		Adjusted *R* square		Std. error of the estimate
1	0.992[a]	0.984		0.934		0.03752
ANOVA[b]						
Model		Sum of squares	*df*	Mean square	*F*	Sig.
1	Regression	0.693	25	0.028	19.678	0.000[a]
	Residual	0.011	8	0.001		
	Total	0.704	33			

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

[b] Dependent variable: Al

subjected to traffic-based pollution (Yalcin and Battaloglu 2007). Sediments in natural areas are negatively affected by agricultural and industrial wastes (Yalcin et al. 2007). Factor 2 (21.505% of the total variance with a eigenvalue of 5.591) composed of Pb, Zn, Ni and W metals and it is anthropogenic. Factor 3 (9.748% of total variance with an eigenvalue of 2.534) composed of Pb, Cd and Sb metals shows similarities to the first two factors and thought to be affected by anthropogenic sources. The high correlations between Cr and Cu, Ni, Mo, W were revealed as Cr, Ni, Cu and Mo in the PCA (Factor 1). Results of factors 1, 2, and 3 are found to be suitable for investigation of heavy metal contents of sands in the Susanoglu area.

Dendogram was drawn with cluster analysis (CA) based on Bray–Curtis approximation criteria with simple arithmetical average. CA is the most suitable method for determination of correlation between the variables (Le Maitre 1982). Although it is not significantly different from PCA, CA is an alternative method used for justification of results (Facchinelli et al. 2001; Yalcin et al. 2007). Q-type cluster at a random approximation level of 50% was performed and two groups were identified. The first group includes Al, Fe, Mg, Hg, Na, K, Ti, Cd, Ag, Pb, Sb, W, Sn, Cu, Mo, Zn, As, Ca, Co and Si elements and the second group contains V, Ni, Mn, Cr, S and Cl elements. Cr–Ni association within the factor analysis supports each other with correlation analysis and PCA (Fig. 2).

Conclusions

Fe, Al, Ti, Cr, Mn, Ni, V, Mo, Co, As, Zn, Cu, Sn, W, Sb, Pb, Cd, Ag and Hg metals detected in the sand and coastal sediments of the Susanoglu beach overlying the carbonate/clastic rocks of the Bolkardağı unit show anomalous concentrations to be an indicator. Heavy metal contents of Cr, Ni, Co, Cd, Hg and Mo of the sands in which the average SiO_2 content was found as <50% exceed Turkish acceptable limits and show toxic effects.

Heavy metal concentrations such as Al (1.44-fold), Cu (1.26-fold), Pb (1.21-fold), Cd (1.02-fold), Mo (1.04-fold), Si (1.63-fold), Na (1.07-fold) and K (4.41-fold) in the Susanoglu beach sands are greater than those of the Kizkalesi beach sands. However, all other metal contents are at low levels.

According to correlation analysis, there are strong positive correlations between *Cr* and Cu, Ni, Mo, W, between *Cu* and Ni, W; between *Ni* and Mo, W; between *Pb* and Zn; between *Mo* and W and these metals are thought to have the same origin.

Results of PCA reveals three factors. The first factor represented by *Natural process factor* explains 27.502% of the total variance with a high eigenvalue of 7.151 (Table 5). Regarding heavy metal contamination of coastal sands, SiO_2, Al_2O_3, Na_2O, K_2O and TiO_2 and Cr, Ni, Cu and Mo metals behave as indicator elements. In a regional sense, the Bozkır unit is composed of tuff, basic, ultrabasic rocks (Mersin ophiolite) and serpantinites. Heavy metals under investigation are thought to be derived from similar natural sources such as ophiolitic rocks. The second factor represented by *Anthropogenic factor* explains 21.505% of the total variance with a eigenvalue of 5.591 (Table 5). Ni, Pb, Zn and W heavy metals associated with CaO, MgO, TiO_2 and MnO of the first factor behave as indicator elements. However, they believed to be associated with Ca and Mg-bearing carbonate rocks. Anthropogenic pollutants in the region include ship wastes, uncontrolled municipal wastes, wastes of oil stations along the coast, Mersin–Antalya road in the vicinity of beach, fertilizers, summer resorts along the coast and wastes of touristic hotels. The third factor represented by *Intermediate factor* explains 9.748% of total variance with an eigenvalue of 2.534. Regarding heavy metal contamination, Pb, Cd and Sb metals behave as indicator elements. Although it has similarities with previous factors, the third factor is thought to be affected by anthropogenic sources. Factor analysis was successfully applied for investigation of heavy metal contents. Similar results were obtained from both correlation analysis and PCA.

According to cluster analysis based on Bray–Curtis approximation criteria with simple arithmetical average, two groups were identified at a random approximation level of 50% of Q-type cluster. The first group composed of Al, Fe, Mg, Hg, Na, K, Ti, Cd, Ag, Pb, Sb, W, Sn, Cu, Mo, Zn, As, Ca, Co and Si elements and the second one is made up by V, Ni, Mn, Cr, S and Cl. The first group is represented by heavy metals with anthropogenic source. The second group explains natural processes responsible for beach sands that can also be expressed as the effect of modern coastal erosion. Metals of the third factor in PCA are heavy metals of anthropogenic origin. This indicates that results of PCA and CA are conformable. In addition, Cr–Ni association determined by the CA is also supported by the correlation analysis and PCA.

To protect ecologic balance in the Susanoglu beach which is one of the clearest beaches on the Mediterranean coast of Turkey, immediate measures should be taken and protection sites are needed to be proposed on the basis of new projects. Priority should be given to prevent heavy metal input. In this respect, the highway in the vicinity of coastal area should be removed, no new licenses should given to structures in the protection sites, new residential sites must be planned in areas in distal parts of the coast, infrastructure facilities of the region are needed to be renewed and expanded, refinery facility should be efficiently operated, waste storage sites along the coast must

be removed, wastes from the sea should be controlled, no motor vehicle must be allowed into the sand beach and all inspections should be made by international organizations.

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