



R-mode factor analysis applied to the distribution of elements in soils from the Aydın basin, Turkey

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Abstract

Soil samples collected at approximately 4-km intervals within the Aydın basin, Turkey, were analysed by Energy Dispersive X-ray Fluorescence Spectroscopy, Gamma Spectroscopy and Alfa Spectroscopy for the elements Ba, Ce, Cr, Fe, Mn, Ni, Rb, Sr, Ti, Zn, Zr; K (radioactive potassium), ²³²Th (equivalent thorium, eTh), ²³⁸U (equivalent uranium, eU) and Ra. R-mode factor analysis was used to describe the relationship among 15 remotely sensed and geochemical and industrial variables for the basin. Principal component and varimax factor rotation were applied to the data. Because varimax factor loading values show the best results, these were used in interpreting. Four factors were extracted in topsoil data and account for 78% of the total data variance. These are named as an industrial, a mineral/an agricultural, igneous and radioactive factors.

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1. Introduction

Rivers carry sediments characteristic for the area and they drain. Alluvial soils are the most favourable sinks for heavy metals in a polluted mining environment (Förstner and Wittmann, 1979). The Aydın basin soil, which locates in the middle part of the Büyük Menderes River and which is about 160 km long along the river, is a mixture of natural erosion detritus, tailings from a milling plant and hydrogenous precipitates. Besides detrital carbonates, derived

from a dolomitic litho-logical unit, a significant amount of carbonate is likely to precipitate on the river bed due to the influx of mine waters from the catchment basin.

Floods and deposition of sediment cause the river to change its course in the basin. The Büyük Menderes River is located in the Menderes Massif, which covers a large area starting from the Aegean Sea in the south of İzmir, West Anatolia, Turkey, to Muğla in the south, to Afyon in the east, to Susurluk in the north and to Kütahya via Demirci in the northeast. The river originates in the vicinity of Dinar near Afyon, flows through the mountains of Ortadağ, Çubuk, Babadağ, Cevizli and Beşparmak and reaches the Aegean Sea near the Söke plain. It is about 500 km long and the bedrock structure of the river is composed mainly of metamorphic rocks

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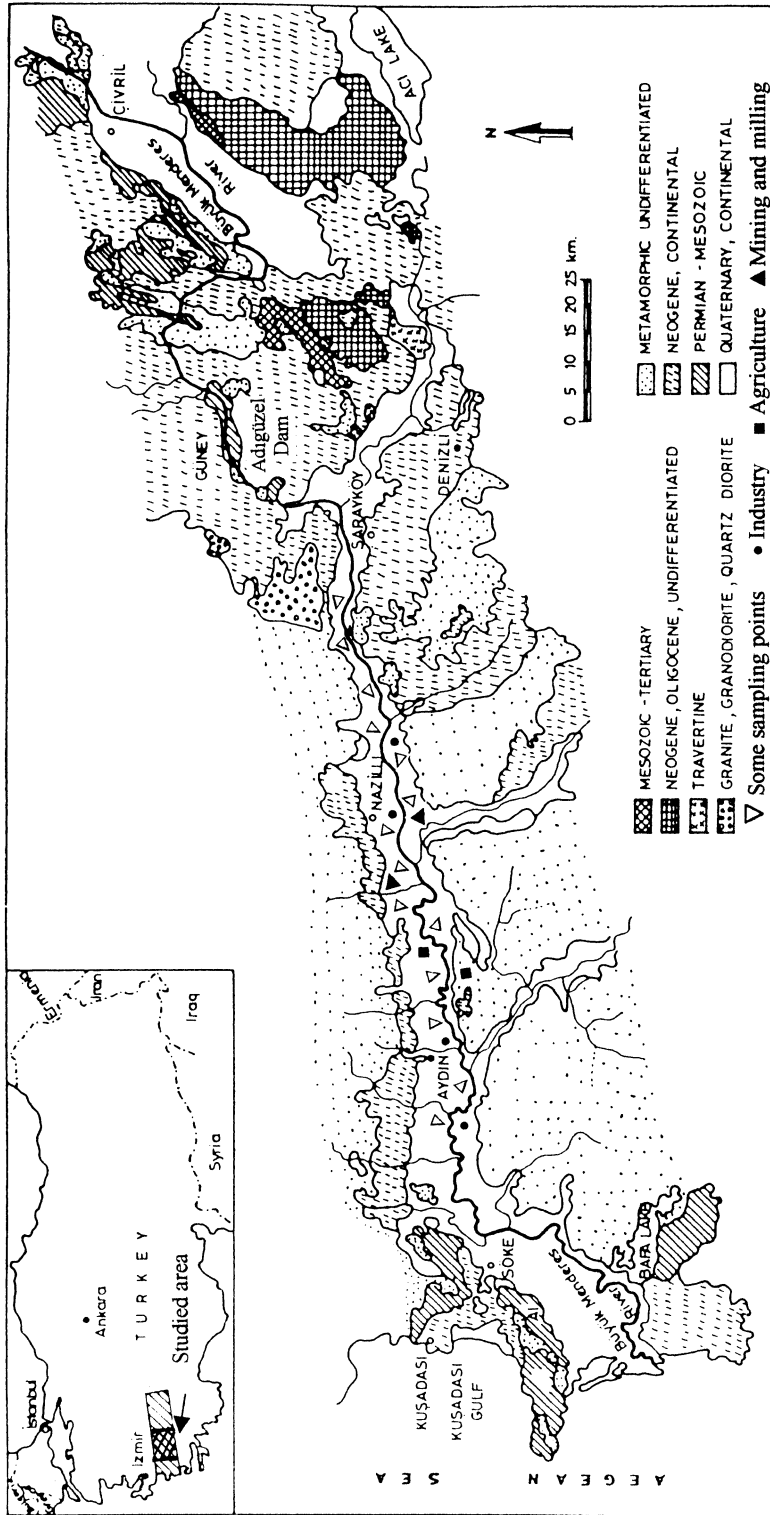


Fig. 1. Geochemical map of the studied area and some sampling points.

of the Palaeozoic, Mesozoic, Permian and Neogene ages. A geological map of the study area and some sampling locations are indicated in Fig. 1. Three different tectonic belts are present in western Anatolia. The eastern most of these is the Menderes Massif, which consists of very thick mica schist and platform-type marbic successions in ascending stratigraphic order. The crystalline Menderes Massif has the core series. The core series consists of Precambrian to Cambrian high-grade schists, leptite-gneisses, metagabbros, augen gneisses (orto gneisses), granitic gneisses and migmatites. The metagranites and augen gneisses are 550 Ma old, dated on the basis of magmatic zircons (Akkök, 1983; Dora et al., 1995).

Multivariate analyses in statistical studies are especially useful because combinations of chemical and physical variables and their relative importance can be evaluated. Factor analysis, one of the possible multivariate analyses has been widely used for the interpretation of geochemical, radiochemical and hydrochemical data on sediment, soil and water. The technique was first used in geological evaluation by Krumbein (1957). A number of geochemical and hydrogeochemical investigations have been performed on the Büyük Menderes River (Kumru, 1994, 1995; Kumru and Başsarı, 1994). In these studies, water, sediment and soil samples collected from the Büyük Menderes River were analysed for radioactive elements (uranium, thorium, potassium and radium). However, no multivariate statistical analyses were performed on these data. The technique was used in geochemical uranium exploration by Bolivar et al. (1983); Maassen and Bolivar (1987); Balakrishnan and Bhaumik (1994); in environmental radioactivity studies by Bakaç et al. (1999); in hydrogeochemical studies by Ruiz et al. (1990), Jayakumar and Siraz (1997) and Simeonov et al. (2000) and in pollution explorations by Ramanathan et al. (1996); Gupta (1998); Bakaç (2000); Bityukova et al. (2000); Heemken et al. (2000).

The present study is the first study to use factor analysis on the geochemical data of soil samples from the Aydın basin and is important in view of the relationship between the various components (elements). That is, it is an application of well-established statistical methods to derive novel information about the study area.

2. Materials and methods

2.1. Sampling

A total of 40 soil samples were collected at approximately 4-km intervals along the middle part of the river during the summer season (July and August) at an average distance of 100 m from the river edge and at a depth of 10 cm to the surface. About 2 kg of soil was taken so that sufficient radioactivity measurements and chemical analyses could be performed. Topsoil cover, plants and stones were removed. All the samples were air-dried in the laboratory and thoroughly homogenised and ground to pass through a 270-mesh sieve in order to obtain the fraction for analyses.

2.2. Analytical methods

There are several direct and indirect methods for ^{238}U measurements in geological samples. Among these, the most widely used one is scintillation gamma spectrometry, based on the detection of high energy gamma rays of ^{214}Bi (Killeen, 1979). However, there is always an important problem due to the ^{238}U and ^{226}Ra disequilibrium in geological materials. That is why the concentration determined through product activities relies on the assumption that the ^{238}U decay series is in equilibrium and is called the equivalent uranium (eU) concentration. This method was used for the determination of eU, eTh and K in the present study. The concentrations of equivalent uranium (eU), equivalent thorium (eTh) and radioactive potassium (K) were determined by gamma spectroscopy employing a NaI(Tl) detector. For this, the sediment samples were dried for 12 h at 85 °C and sieved at 270 mesh. The particles (100 g) were sealed in a cylindrical plastic container of 6-cm diameter and 5-cm height. To attain radioactive equilibrium, these were stored for at least 43 days before counting ^{226}Ra and ^{224}Ra . Equilibrium between ^{226}Ra and its daughters is necessary for accurate analysis for ^{226}Ra in environmental studies when gamma ray is used. Therefore, two radioactive daughters of ^{226}Ra (^{214}Pb and ^{214}Bi) are used for quantitative and qualitative analysis when equilibrium has been established. In this study, the 1.76-MeV peak of ^{214}Bi was used for quantitative determination of uranium, the 2.62-MeV peak of ^{208}Tl was used for the quantitative determination of thorium and the 1.46-

Table 1
Elemental concentrations and summary statistics for soil data (values in mg kg⁻¹)

Sample station	Distance from estuary (km)	K	U	U (Bq kg ⁻¹)	Th	Ra (Bq kg ⁻¹)	Ti	Cr	Mn
1	160	12,700	12.63	159	2.69	425	1700	452	309
2	164	25,900	13.53	170	3.54	49	1900	473	380
3	168	12,900	12.75	160	3.94	16	2900	226	229
4	172	15,700	8.43	106	5.31	33	2800	325	324
5	176	29,400	15.10	190	1.28	16	nd	nd	nd
6	180	9500	13.73	173	2.95	33	2400	902	574
7	184	16,400	11.96	151	5.51	212	5300	435	495
8	188	25,700	6.47	81	1.97	245	nd	nd	nd
9	192	3500	2.55	32	3.84	196	4700	185	480
10	196	22,700	10.39	131	2.76	229	5800	258	517
11	200	13,600	8.63	109	2.26	278	6200	246	511
12	204	7200	20.79	262	0.59	196	5200	288	489
13	208	4900	3.92	49	6.20	82	5600	239	350
14	212	44,100	1.57	20	6.79	180	4200	304	392
15	216	7600	15.69	197	1.48	82	5100	296	406
16	220	15,500	22.75	286	4.72	392	5600	300	532
17	224	30,300	0.39	5	7.19	409	5400	287	410
18	228	28,400	11.18	141	7.48	180	6200	409	419
19	232	26,600	1.57	20	6.59	49	4300	517	439
20	236	23,100	3.92	49	3.35	65	3900	243	358
21	240	44,400	10.98	138	2.76	16	3700	288	376
22	244	31,000	15.88	200	2.36	16	4100	420	382
23	248	47,600	6.08	77	3.05	131	4000	368	400
24	252	32,300	29.02	365	1.38	49	nd	nd	nd
25	256	36,300	9.80	123	6.10	65	nd	nd	nd
26	260	42,700	11.37	143	3.54	98	4500	374	314
27	264	30,500	13.73	173	7.48	621	4700	370	444
28	268	30,700	11.37	143	6.89	654	nd	nd	nd
29	272	59,600	2.55	32	10.53	229	5000	256	386
30	276	31,500	12.16	153	7.68	33	4500	250	390
31	280	36,000	2.35	30	3.25	49	4800	290	392
32	284	28,900	14.90	187	8.96	33	nd	nd	nd
33	288	34,000	10.20	128	0.98	114	nd	nd	nd
34	292	40,700	2.75	35	7.97	65	4600	314	410
35	296	11,800	18.24	229	0.98	82	4600	302	390
36	300	33,000	9.80	123	4.04	82	4300	286	412
37	304	35,800	4.12	52	0.10	147	3800	270	400
38	308	22,400	15.49	195	3.74	65	nd	nd	nd
39	312	8800	18.04	227	0.69	229	4000	310	342
40	316	22,700	11.96	150	4.63	65	4100	308	366
<i>n</i>		40	40	40	40	40	32	32	32
Min		3500	0.39	5	0.10	16	1700	185	229
Max		59,600	29.02	365	10.53	654	6200	902	574
Mean		25,900	10.72	135	4.19	160	4400	337	407
Standard deviation		13,000	6.35	80	2.59	160	1100	129	72
Sample station	Distance from estuary (km)	Fe	Ni	Zn	Sr	Zr	Rb	Ba	Ce
1	160	30,000	279	59	200	87	179	254	47
2	164	28,000	18	67	225	120	37	266	34

Table 1 (continued)

Sample station	Distance from estuary (km)	Fe	Ni	Zn	Sr	Zr	Rb	Ba	Ce
3	168	25,000	47	73	109	325	161	503	89
4	172	31,000	168	69	169	214	108	338	29
5	176	nd	nd	nd	nd	nd	nd	nd	nd
6	180	25,000	305	64	160	171	nd	182	46
7	184	36,000	45	68	131	422	nd	488	64
8	188	36,000	nd	nd	166	294	nd	220	52
9	192	35,000	39	69	103	343	72	400	47
10	196	40,000	40	85	120	348	89	483	62
11	200	37,000	42	78	130	445	119	422	83
12	204	34,000	74	78	197	365	94	411	71
13	208	39,000	42	59	145	332	140	502	95
14	212	35,000	39	68	145	305	125	444	97
15	216	32,000	66	63	144	373	nd	363	65
16	220	39,000	61	87	247	346	210	454	102
17	224	37,000	41	79	170	316	110	365	55
18	228	30,000	43	57	156	579	114	332	88
19	232	34,000	91	51	251	314	98	303	76
20	236	29,000	47	124	175	256	119	427	49
21	240	28,000	68	98	119	545	58	422	67
22	244	27,000	74	104	217	407	84	350	59
23	248	27,000	70	100	230	429	123	288	92
24	252	26,000	nd	nd	359	321	73	294	68
25	256	nd	nd	nd	315	310	78	352	73
26	260	30,000	66	94	380	285	92	307	51
27	264	29,000	72	88	337	172	56	279	36
28	268	28,000	68	68	199	218	79	351	49
29	272	nd	nd	nd	nd	nd	nd	nd	nd
30	276	32,000	56	76	527	166	71	56	nd
31	280	nd	nd	nd	445	345	nd	225	nd
32	284	nd	nd	nd	628	147	nd	242	nd
33	288	nd	nd	nd	761	164	94	249	nd
34	292	34,000	58	73	407	158	64	284	53
35	296	32,000	74	85	678	185	49	263	44
36	300	29,000	70	80	617	243	90	326	84
37	304	30,000	62	76	325	334	83	291	56
38	308	nd	nd	nd	462	102	56	246	nd
39	312	nd	nd	nd	372	178	64	175	nd
40	316	29,000	58	79	253	380	80	267	43
<i>n</i>		32	30	30	38	38	32	38	32
Min		25,000	18	51	103	87	37	56	29
Max		40,000	305	124	761	579	210	503	102
Mean		32,000	76	77	284	291	96	327	63
Standard deviation		4000	64	16	174	117	38	100	20

nd: Not determined.

MeV peak of radioactive potassium was used for the quantitative determination of potassium. Standards used in this study have concentration of 118 mg kg^{-1} U_3O_8 , 600 mg kg^{-1} ^{232}Th and 52.4% ^{40}K for uranium, thorium and potassium, respectively. The sensitivity

factors and stripping ratios of the detector were determined using the indicated standards. The sensitivity factors (K_1 , K_2 , K_3) and the stripping ratios (α , β , γ) were $K_1 = 1.41 \times 10^{-3}$, $K_2 = 7.86 \times 10^{-3}$, $K_3 = 81.18 \times 10^{-3}$ and $\alpha = 0.47$, $\beta = 0.94$, $\gamma = 1.61$.

In order to determine the level of radium in soil, the collector-chamber method was used (Kumru and Kınacı, 1989; Kumru and Öznur, 1994). Kumru (1992) gives details of this method. The study reported here is based on the measurement of alpha particles emitted by radon daughters. The emanation procedure used in the study is specific for soluble ^{226}Ra (Bq) and can be used to analyse waters, soils, rocks and sediments. Soil samples were dried for 12 h at 500 °C and sieved at 270 mesh. Sample aliquots weighing 10 g were transferred into radon bubblers with 10 ml of 1 M HCl and 90 ml of distilled water. They were flooded with pressurised aged-air for about 20 min, and stored for at least 43 days. Within this period, the equilibrium ratio between ^{226}Ra ($t_{1/2} = 1622$ years) and ^{222}Rn ($t_{1/2} = 3.825$ days) becomes about 99.9%. Then, their alpha disintegration was directly measured by alpha scintillation counter system (Eberline Model SAC-4) and a detector (Zn(S)) employing a counting time of 20 min. The radium content was calculated from the radon that was generated during the storage time. For this, the line graphic depicted for the ^{226}Ra test solutions was used. The collector chamber was calibrated with radium standards obtained from NIST. For samples, most of our tests were carried out with solutions containing several picocuries of ^{226}Ra . Test solutions, each of 100 ml volume, were made by adding distilled water and HCl to 10 ml of a standard ^{226}Ra solutions, containing an activity of 0.185, 0.370, 0.555, 0.740 and 0.925 Bq, respectively. The accuracy of the estimation for radium was about 12%. The accuracy and precision of ^{226}Ra analyses for soil samples obtained with collector chamber were within the acceptable statistical limits (1 S.D.).

Soil samples were oven-dried for 24 h at about 85 °C and sieved at 270 mesh. Energy dispersive X-ray fluorescence analyses were undertaken by adding 50 mg cellulose to a 100 mg aliquot of soil sample and mixing for 15 min. An annular ^{238}Pu (10 mCi) source (Ni, Cu, and Zn standards in the energy range 4–9 keV) was used to ionise the K shells from Ti to Zn for 80,000 s and a Si(Li) detector with a resolution of 185 eV (FWHM) at 5.89 keV was used with an ADCAM Digital 350 counting system. The different standards (Mo, Pd, and Cd in the energy range 13–45 keV) and the same samples were also excited using an ^{241}Am (30 mCi) annular source for 80,000 s and an HPGe detector with a resolution of approximately 350 eV

(FWHM) at 5.89 keV. MCA Emulation Software program was used to analyse the samples. Samples were palletised and stored in a desiccator until analysis for Cu, Cr, Ti, Mn, Zn, Rb, Sr, Zr, Ba and Ce. This method was checked using IAEA (Soil-5 and SL-1) standards. The accuracy of the estimation is approximately 18%. The elements, for which accuracy of the measured values was not in good agreement with true values, were omitted from the geochemical database.

2.3. Statistics

It was considered by the authors that the large amount of geochemical data and the complex character of the relation between the chemical data and the numerous sources of pollution, required the application of statistical methods for the interpretation of these data. Factor analysis, a well-known statistical technique, offers a powerful tool to study the interrelationship among the various components. It compresses the total information content of the multivariate data in terms of a few factors. In our present study, with data from diverse sources, our aim is to explore the relationships among the variables and so it is considered that R-mode analysis is appropriate. The statistical analysis of the geochemical data, correlation, principal and R-mode factor analysis and interpretation of obtained results for every data set were performed using SPSS for WINDOWS software. For more detailed description of the mathematical principles and flow diagram for factor analysis, see Krumbein and Graybill (1965), Johnson and Wichern (1988) and Bakaç (2000).

3. Data analysis

Table 1 summarises the range, mean and standard deviation of the elements in topsoil of the Aydın region. Range, mean and standard deviation were calculated using standard methods (Norusis, 1988). The present study, performed on 15 data sets at 40 sampling points in the basin, was undertaken in an effort to evaluate R-mode factor analysis with respect to geological and industrial features. The initial step in the analysis is to calculate a correlation matrix for the different elements. This matrix of simple correlation coefficients was first computed from the standardised variables (Krumbein and Graybill, 1965). Standardisa-

Table 2

Correlation coefficients for elements in soil samples

Ba	Ce	Cr	Fe	K	Mn	Ni	Ra	Rb	Sr	Th	Ti	U	Zn	Zr
Ba	0.53*	-0.81*	0.26	-0.24	0.07	-0.72*	-0.54*	-0.15	0.71*	-0.14	0.38	-0.14	0.29	0.29
	Ce	-0.15	0.08	-0.08	-0.01	-0.51*	-0.17	0.29	-0.40	0.20	0.52	0.23	-0.28	0.65*
		Cr	-0.30	0.37	-0.24	0.71*	0.42	0.45	0.74*	0.21	-0.31	0.51*	-0.41	-0.17
			Fe	-0.07	0.74*	-0.32	0.36	-0.50*	-0.21	0.03	0.67*	-0.46	-0.09	0.19
				K	0.14	-0.16	0.26	-0.15	0.38	0.37	0.26	0.01	0.34	0.27
					Mn	-0.43	0.38	-0.75*	-0.34	-0.16	0.76*	-0.28	0.11	0.50*
						Ni	0.31	0.54*	0.66*	-0.24	-0.77*	0.42	-0.31	-0.74*
							Ra	0.07	0.34	-0.08	0.11	0.07	-0.20	-0.14
								Rb	0.43	-0.11	-0.57*	0.50*	-0.23	-0.42
									Sr	0.20	-0.39	-0.01	0.07	-0.49
										Th	0.31	-0.34	-0.36	0.38
											Ti	-0.34	0.01	0.83*
												U	-0.32	0.01
													Zn	-0.14
														Zr

* Significance of correlation is 0.50 at 5% level of significance.

tion of the data result in new values for all variables that not only have zero mean but are measured in units of standard deviations. This is done by subtracting the mean of the distribution from each observation and dividing by the standard deviation of the distribution. The new variables have a standard normal form. The results are given in Table 2. In a second step, statistically significant principal components were extracted from the correlation matrix. The method of principal component analysis provides a unique solution, so that the original data can be reconstructed from the results. The principal component analysis extracted four fac-

tors (Table 3) accounting for a 78% variance. In a third step, the varimax rotated R-mode factor loading matrix was calculated and preferred, as geochemical processes evolve through very dynamic and highly inter-related mechanisms. The factor extraction was done with a minimum acceptable eigenvalue greater than 1 (Kaiser, 1958). The varimax factor matrix is given in Table 4. All factor loadings in the matrix were considered to be significant and the elements were accord-

Table 3

Principal component matrix

Factor	Factor 1	Factor 2	Factor 3	Factor 4
Ba	0.70	-0.61	-0.02	0.04
Ce	0.44	-0.29	0.75	-0.12
Cr	-0.74	0.48	0.42	-0.02
Fe	0.58	0.45	-0.21	-0.44
K	0.00	0.57	0.18	0.63
Mn	0.65	0.56	-0.21	-0.35
Ni	-0.94	0.10	-0.11	-0.28
Ra	-0.21	0.72	-0.05	-0.40
Rb	-0.68	-0.36	0.38	-0.07
Sr	-0.73	0.45	-0.04	0.31
Th	0.12	0.35	0.52	0.48
Ti	0.86	0.40	0.27	-0.04
U	-0.44	-0.28	0.48	-0.28
Zn	0.19	-0.11	-0.61	0.56
Zr	0.72	0.17	0.58	0.09

Table 4

Varimax factor matrix

Factor	Factor 1	Factor 2	Factor 3	Factor 4	Communality
Ba	0.92	0.06	-0.08	-0.09	0.863
Ce	0.59	0.01	0.34	0.62	0.855
Cr	0.81	-0.24	0.26	0.41	0.947
Fe	-0.07	0.87	-0.08	-0.00	0.766
K	0.31	0.04	0.75	-0.28	0.746
Mn	-0.06	0.94	0.04	-0.08	0.902
Ni	0.79	-0.38	-0.42	0.20	0.977
Ra	0.67	0.49	-0.03	0.17	0.730
Rb	0.21	0.69	-0.13	0.46	0.746
Sr	0.82	-0.31	0.21	-0.15	0.833
Th	0.05	-0.02	0.79	0.07	0.629
Ti	-0.39	0.75	0.49	0.09	0.962
U	0.10	-0.41	-0.13	0.62	0.579
Zn	-0.18	-0.08	0.00	0.83	0.734
Zr	-0.49	0.40	0.63	0.29	0.886
Eigenvalue	5.38	2.80	2.30	1.68	
% Var. expl.	36	18	15	11	
Cum. % var.	-36	54	69	80	

ingly grouped under the respective factors for the floodplain soils.

The communality is the proportion of the variance of an element that is common to other elements in the set. It is the sum of the squares of the common factor loadings. Initially, these values are unknown and must be estimated from the data. Estimates of communalities are inserted as diagonal elements in the table of correlation before proceeding with the factor analytic solution. Communality estimates may be inserted in the diagonal, then a factor analytic procedure applied, and the sum of squares of common factor loadings used a new estimate of the communalities. The communality of each element and eigenvalues are seen on the last column and row of Table 4.

4. Discussion

The R-mode factor analysis highlights four groupings among the variables and they are: Factor 1—more than 36% of the variance is explained through this factor. Ba, Sr, Cr, Ni, Ra and Ce are grouped under this factor. Factor 2, describing 18% of the variance, has high factor loadings for the elements Mn, Fe, Ti and Rb. Factor 3 includes the elements Th, K, and Zr and explains 15% of the total variance. Finally, Factor 4 explains 11% of the variance and groups Zn, Ce and U. The factor scores of all the sample stations were calculated and illustrated in Figs. 2–5.

The first factor (factor 1), loaded for Ba (0.92), Sr (0.82), Cr (0.81), Ni (0.79), Ra (0.67) and Ce (0.59),

shows the highest scores at km 160, 180 and between 264 and 296 along the river (sample nos.: 1, 6 and 27–35, respectively). Cr, Ni, Ba and Sr are grouped under this factor as these are derived from the anthropogenic activities (textile, leather and dyeing) in the region. No Cr, Ni and Ba mines in neither of these zones are referred nor does the soil contain these elements in significant contents. In particular, the elements Cr, Ba and Ni in this group show that smaller streams, which join the river, have a significant role in the pollution of the Büyük Menderes River sediments and consequently, in the Aydın basin soils. There are factories discharging these elements in the streams in Aydın. Chromium especially points out that wastewaters from the leather trade in the Aydın and Denizli basin located up stream are dumped into the river. Most small and large leather plants are located in the centre of Denizli in the middle part of the river's course. This is named, therefore, as an industrial factor.

The second factor (factor 2), loaded for Mn (0.94), Fe (0.87), Ti (0.75) and Rb (0.69), shows its highest loadings between km 192 and 200 along the river (sample nos.: 9–11). As seen, this factor is significant along the middle part of the basin. Therefore, the source of this factor is wide and it may result from two reasons. First, Fe and Mn are grouped under this factor as these metals are derived from the weathering of the drainage area as well as from mining activity in the stream region. The contamination of the soils for these elements is partly caused by flooding and dust fallout from mining and milling activities. Simple statistics for soil samples suggests that the heavy metal

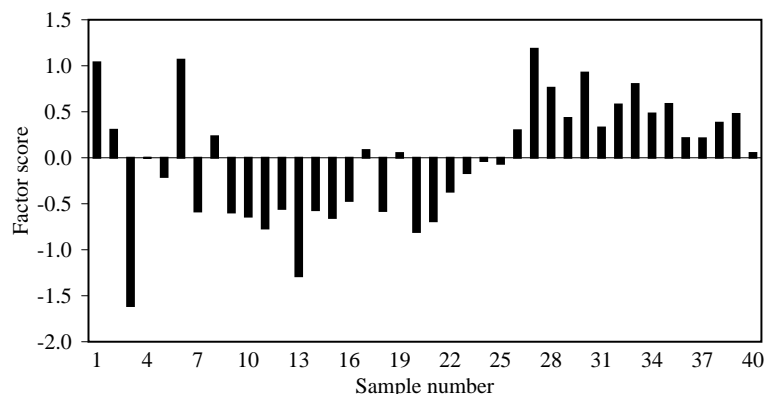


Fig. 2. Factor-1 score of soil data.

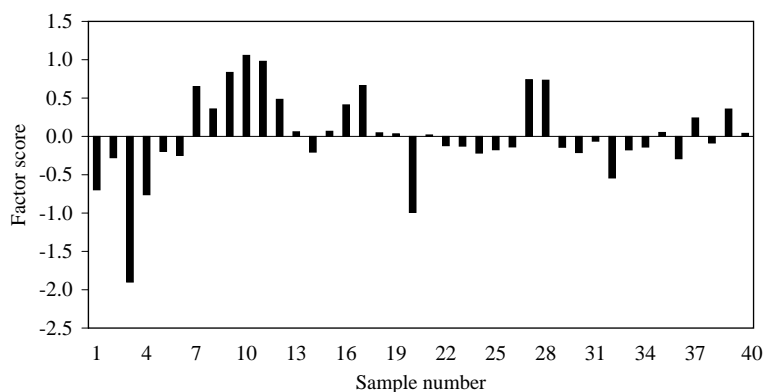


Fig. 3. Factor-2 score of soil data.

contamination of the soil is highest near the milling complex (between km 192 and 200) and decreases with distance from the mill. It is obvious that higher concentrations of heavy metals in soil samples are found around a mineral-processing site (Mineral Resource and Exploration Institute Authority (MREIA), 1980). Because the river flows by washing these beds, the basin soils may have been rich in manganese. So, this factor is naturally named as a mineral factor. Second, the presence of manganese and iron may be related to the agricultural activities in these areas since it is well known that manganese salt is used as an ingredient of fertiliser. So, it has been wide-spread along the river for soils. Consequently, agricultural activities can constitute the reason for this factor. This factor is also designated as an agricultural factor.

The third factor (factor 3), which consists of Th (0.79), K (0.75) and Zr (0.63), has the highest factor scores at km 228 and 272 along the river (sample nos.: 18, 29). This factor may be explained by the metamorphic rocks and basalt of Middle Gediz and its surroundings. The province of Sarayköy in the south and the environs of Nazilli and Güney in the north of the river consist of basalts. Alkaline basaltic volcanism took place in three different phases during Quaternary in western Anatolia around Güney (Denizli). These volcanics were possibly derived from a hot spot over the mantle rising through a plume where graben type tectonics were active (Ercan et al., 1985). This factor is thus called an igneous factor reflecting the volcanic features besides being economically relevant as is shown by the geochemistry of the region of the Adi-

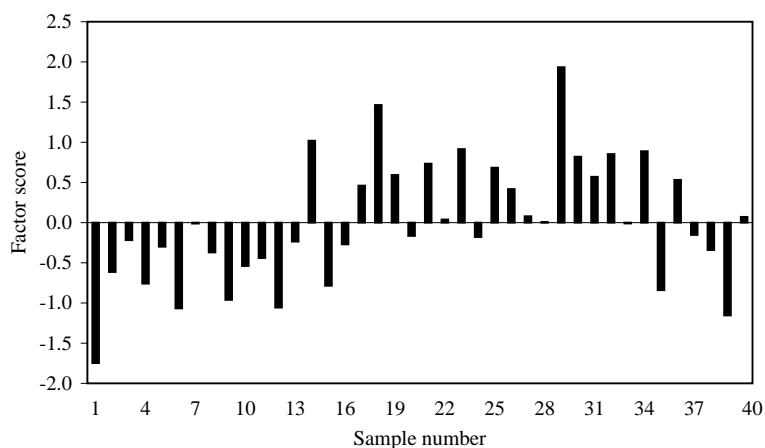


Fig. 4. Factor-3 score of soil data.

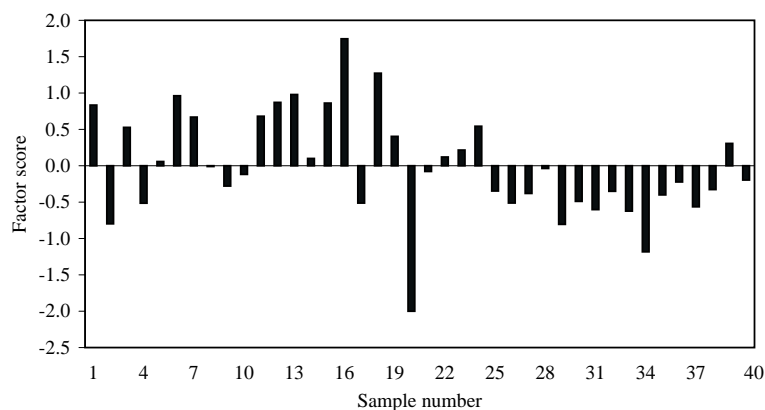


Fig. 5. Factor-4 score of soil data.

güzel Dam. The anomaly in radium concentrations at some points may be explained by the uranium (U_3O_8) found in Uşak, and Afyon. Furthermore, U_3O_8 and thorium mines have also been found in Dinar (Afyon) at the foot of Murat Mountain (MREI Authority, 1980).

The last factor (factor 4), which is loaded for Zn (0.83), U (0.62) and Ce (0.62), shows the highest values between km 200 and 228 along the river (sample nos.: 11–18). The elements U and Ce represent granite-type rocks. Consequently, this factor is designated as a radioactive factor. It was also encountered in a previous study (Bakaç, 2000). The general rise of trace element concentrations for U, Ce in the western and middle part of the study area must be related to the occurrence of uranium deposits in that area, thus showing that the occurrence of these elements as ore is also reflected in the surficial material. The uranium deposits in the sedimentary rocks of Turkey occur in the upper fluvial unit as pore fillings, as coatings on grains or pebbles, and along cracks in mudstone and siltstone. The Killik, Yardere and Karaelmacık uranium deposits in the lower and middle conglomerate beds of the upper fluvial unit are yellow to greenish yellow and are characterised by irregularly shaped discontinuous lenses of uranium ore (King et al., 1976). The reasons for this coincidence of trace elements are closely connected with the mechanisms of ore formation, which still only partly understood. Additionally, in a recent study (Karamenderesi and Helvacı, 2001), it is found that groundwater that leaks from geothermal water sources in the basin is effective in the polluting Aydın basin soil.

5. Conclusions

The application of geochemical and analytical methods and their responses to typical geological and environmental influences within the western portion of the Superior Industrial and Geological Province of the southwestern Aegean have been demonstrated in this study.

The application of multivariate statistical analysis for the assessment of geochemical data has led to the determination and classification of different sources of contaminants. This study based on R-mode factor analysis on geochemical data from soil samples collected in a large area indicates that R-mode factor analysis offers a reliable method and helps us to understand the causative mechanism underlying the factor model and brings out a significant factor for elements which provide an identifier of the pollution in the basin soil. In the Aydın basin, the influence of different types of contamination is obvious. The most intensive soil contamination is caused by leather and dyeing industries and the natural geological formations along the river. Besides the natural weathering input of metals, it is possible that multiple sources or depositional activities exist, which influence the metal distribution in the Aydın basin.

In addition, as seen from Table 1, in several sampling points (e.g. 1, 7, 8, 9, 18, 27, 29, 37) in our study, the reason that the specific activity of ^{226}Ra is greater than that of ^{238}U is that the deposition of radium is greater than that of uranium. Therefore, these areas should be surveyed in more detail.

References

- Akkök, R., 1983. Structural and metamorphic evolution of the northern part of the Menderes Massif: new data from the Derbent area, and their implication for the tectonics of the massif. *J. Geol.* 91, 342–350.
- Bakaç, M., 2000. Factor analysis applied to a geochemical study of suspended sediments from the Gediz River, western Turkey. *Environ. Geochem. Health* 22, 93–111.
- Bakaç, M., Kumru, M.N., Başsarı, A., 1999. R-mode factor analysis applied to the exploration of radioactivity in the Gediz River. *J. Radioanal. Nucl. Chem.* 242, 457–465.
- Balakrishnan, S.P., Bhaumik, B.K., 1994. Factor analysis of geochemical data of Precambrian granitoids of South India: implication in uranium exploration. *Explor. Res. At. Miner.* 7, 109–124.
- Bityükova, L., Shogenova, A., Birke, M., 2000. Urban Geochemistry: a study of element distributions in the soils of Tallinn (Estonia). *Environ. Geochem. Health* 22, 173–193.
- Bolivar, S.L., Campbell, K., Wecksung, G.W., 1983. R-mode factor analysis applied to uranium exploration in the Montrose Quadrangle, Colorado. *J. Geochem. Explor.* 19, 723–743.
- Dora, O.Ö., Candan, O., Dürr, St., Oberhansli, R., 1995. New evidence on the geotectonic evolution of the Menderes Massif. *International Earth Sciences Colloquium on the Aegean Region, İzmir/Güllük-Turkey, İzmir Proceedings, İzmir, Turkey*, pp. 53–69.
- Ercan, T., Satır, M., Kreuzer, H., Türkecan, A., Günay, E., Çevikbaş, A., Ateş, M., Can, B., 1985. Batı Anadolu Senozoyik volkanitlerine ait yeni kimyasal, izotopik ve radyometrik verilerin yorumu. *Bull. Geol. Soc. Turk.* 28, 121–136 (in Turkish).
- Förstner, U., Wittmann, G.T.W., 1979. *Metal Pollution in Aquatic Environment*. Springer, Berlin, p. 486.
- Gupta, V.S., 1998. Geochemical factors controlling the chemical nature of water and sediments in the Gomti River, India. *Environ. Geol.* 36 (1/2), 102–108.
- Heemken, O.P., Stachel, B., Theobald, N., Wenclawiak, B.W., 2000. Temporal variability of organic micropollutants in suspended particulate matter of the River Elbe at Hamburg and the River Mulde at Dessau, Germany. *Arch. Environ. Contam. Toxicol.* 38, 11–31.
- Jayakumar, R., Siraz, L., 1997. Factor analysis in hydrogeochemistry of coastal aquifers—a preliminary study. *Environ. Geol.* 31 (3/4), 174–177.
- Johnson, A.R., Wichern, W.D., 1988. *Applied Multivariate Statistical Analysis*, 2nd ed. Prentice-Hall, Englewood Cliffs, NJ, p. 607.
- Kaiser, H.F., 1958. The varimax criteria for analytical rotation in factor analysis. *Psychometrika* 23, 187–200.
- Karamenderesi, İ.H., Helvacı, C., 2001. Büyük Menderes Vadisindeki jeotermal kaynakların yeraltısularına etkisi. *Proceedings of the 1st Symposium on Environmental and Geology, İzmir-Turkey, İzmir Foundation of Environment, İzmir, Turkey*, pp. 339–350. In Turkish.
- Killeen, P.G., 1979. Gamma-ray spectrometric methods in uranium exploration—application and interpretation. *Geol. Surv. Can. Econ. Geol. Rep.* 31, 163–299.
- King, J., Tauchid, M., Frey, D., Basset, M., Çetintürk, I., Aydonoz, F., Keçeli, B., 1976. *Exploration for Uranium in Southwestern Anatolia*. IAEA Publications, Vienna, Austria, p. 529.
- Krumbein, W.C., 1957. Comparison of percentage and ratio data in facies mapping. *J. Sediment. Petrol.* 27, 293–297.
- Krumbein, W.C., Graybill, F.A., 1965. *An Introduction to Statistical Models in Geology*. McGraw-Hill, New York, p. 317.
- Kumru, M.N., 1992. Determination of Radium-226 in environmental samples by the collector chamber method. *Appl. Radiat. Isotopes* 43 (8), 1031–1034.
- Kumru, M.N., 1994. Radium, soil gas radon and field measurement in the Büyük Menderes River. *Turk. J. Eng. Environ. Sci.* 18, 391–396.
- Kumru, M.N., 1995. Distribution of radionuclides in sediments and soils along the Büyük Menderes River. *Proc. Pak. Acad. Sci.* 32 (1–4), 51–56.
- Kumru, M.N., Başsarı, A., 1994. Quantitative analysis of some elements of Aydın basin soils by X-ray fluorescence spectrometry. *X-ray Spectrom.* 23, 151–154.
- Kumru, M.N., Kınacı, S.R., 1989. Aşağı Büyük Menderes akıntılarında ve sedimentlerinde radyoaktivite ölçümleri. *Proc. of 3rd Natl. Nucl. Sci. Conf.* 1, 122–129 (in Turkish).
- Kumru, M.N., Öznur, Ö., 1994. Investigational of some parameters of the collector chamber method for the determination of radium-226. *Appl. Radiat. Isotopes* 45 (11), 1113–1114.
- Maassen, L.W., Bolivar, S.L., 1987. A geochemical survey of St. Lucia, West Indies. *J. Geochem. Explor.* 28, 451–466. Mineral Resource and Exploration Institute Authority (MREIA), 1980. *Türkiye maden envanteri*. Ankara-Turkey, Publications of M.T.A. No.: 179, pp. 571 (in Turkish).
- Norusis, J.M., 1988. *SPSS/PC+ Advanced Statistics V 2.0*. SPSS International, The Netherlands, pp. B40–B69.
- Ramanathan, A.L., Subramanian, V., Das, B.K., 1996. Sediment and heavy metal accumulation in the Cauvery basin. *Environ. Geol.* 27, 155–163.
- Ruiz, F., Gomis, V., Blasco, P., 1990. Application of factor analysis to the hydrogeochemical study of a coastal aquifer. *J. Hydrol.* 119, 169–177.
- Simeonov, V., Stefanov, S., Tsakovski, S., 2000. Environmental treatment of water quality survey data from Yantra River, Bulgaria. *Mikrochim. Acta* 134 (1/2), 15–21.