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Effect of meteorologic conditions on total suspended particulate (TSP) levels and elemental concentration of aerosols in a semi-arid zone (Beer-Sheva, Israel)

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ABSTRACT

The total suspended particulate (TSP) levels in Beer-Sheva, situated in a semi-arid area with winds bringing in dust from the surrounding deserts, was measured 41 times between June 1977 and May 1978. The TSP levels are correlated with climatic conditions. High TSP levels (890 ± 250 $\mu g\ m^{-3}$ were found during Sharav conditions and sandstorms (hot, dry weather, typical to this region). Low TSP levels (59 ± 28 $\mu g\ m^{-3}$) were found in the winter following rain. Usual TSP levels were found to be 140 ± 20 $\mu g\ m^{-3}$ occurring during normal weather conditions. The elemental composition of the Beer-Sheva aerosols were determined using instrumental neutron activation analysis (INNA) and X-Ray Fluorescence (XRF). The concentrations of the following elements Fe, Na, Br, K, Sm, Au, Sb, Ga, La, Yb, Lu, Se, Hg, Cr, Sc, Rb, Co, Ta and Zn were determined by INNA and Ca, Si, S, Ti, Cl, Pb, Fe, V, Ni and Mn by XRF. Their relative abundances were found to depend on the prevailing TSP level.

The different patterns of elemental distribution as a function of TSP indicate the manifold origins of the TSP. A very high correlation coefficient between elemental concentrations of the following elements Ca, Si, Fe, V, Ti, Mn, Na, Ni, Co, La, K, Sc, Sm and TSP levels (> 0.94) suggest that they originate from natural sources. The very low correlation coefficients < 0.1 between the elemental concentrations of Br, Sb and Hg suggest strongly that the elements come primarily from local industry. The sources of other elements with correlation coefficients of the order of 0.5 (Cl, S) are not clear-cut.

1. Introduction

Beer-Sheva, the capital of the Israeli Negev, is situated in a semi-arid area which is itself surrounded by the vast Syrian–Arabian desert and Sinai Peninsula from north, east and south (see map in Fig. 1). During the early spring, summer and autumn, hot strong winds blow, which raise sandstorms depositing large quantities of fine dust and sand (Joseph *et al.*, 1973). No information regarding the TSP level and the elemental composition of the solid particles in the air was found in the literature for this area. Since it can be expected that TSP levels are high, it is clearly important to determine their levels quantitatively, throughout the year, in order to obtain information on the general ecologic conditions of the area and to set limits on particulate emissions of industry in Beer-Sheva.

2. Methodology

Total suspended particulate levels were measured by passing a known volume of air through a filter. The difference in the weight of the filter before and after filtration divided by the volume of air gives the total suspended particulate level. In this work, air was sampled with a Staplex Air Sampler (TFIA-2) using 11 cm diameter Whatman 41 filters. Whatman 41 filters were chosen for their strength to withstand relatively high air flow rates, for their capacity to trap small particles with high efficiency and for their elemental

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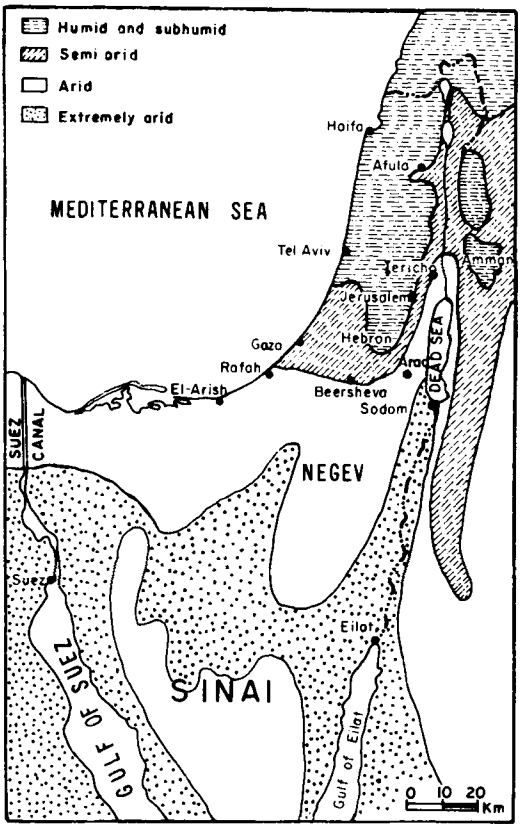

Fig. 1. Map of the investigation area.

purity (Dams *et al.*, 1972). Each sampling lasted for 24 h with the sampler alternatively on 30 min and off for 30 min. The airflow initially was 233 ± 6 l min^{-1}. However, as the filter collected more and more particulate matter, the air flow rate dropped. Consequently, the air flow rate was measured at regular intervals during the sampling, and the total volume of air flowing through the sampler was calculated accordingly.

The weights of the filters were obtained using a semi-micro balance after equilibrating the filter for 24 h in a controlled humidity cell to obtain constant moisture content in the filter. The filters were divided into two main parts. One was sent to the Soreq Nuclear Center for neutron activation analysis and the other one was ground and pelleted for XRF analysis using a Philips X-Ray Fluorescence Spectrometer Model PW-1410. The pellets were thick to simulate an infinite emitting medium. Numerical values were obtained in all cases with reference to standard solutions containing the elements to be analyzed. These standards were applied to clean filters and were simultaneously sent for activation and XRF analysis. In this way, errors due to changes in flux and spectrum were accounted for.

The well-known principles of instrumental activation analysis using a high resolution Ge(Li) detector and a multichannel analyser were followed (Zoller and Gordon, 1970). The spectra were analyzed using the computer program Jane to smoothen the spectra and to integrate the peaks (Schubeger *et al.*, 1975). The following elements were studied: Br, Na, K, Zn, As, La, Sm, Eu, Sb, W, Au, Cr, Co, Fe, Se, Ce, Hg, Th, Hf, Ti, Rb, Mo, Yb, Ba, Cd, Lu, Ir, Cs and Ag. Due to the distance between the Soreq nuclear reactor and the University labs, (80 km) where the samples were counted, short-lived radioisotopes were not analyzed. This prevented the measurement of some elements which produce only short-lived radioisotopes upon reactor neutron activation. This was remedied, to a small extent, by the use of XRF analysis. The following elements were studied by XRF: Pb, Ni, Ca, Si, Cl, S, Ti, Fe, V, and Mn. Fe was measured by both methods and the agreement was within ± 10%. The lower detection limit was of the order of 0.01 ng m^{-3}.

3. Results

41 samples were obtained between June 1977 and May 1978. Information on the date of sampling, wind direction and velocity, relative humidity and TSP in $\mu g\ m^{-3}$ is given in Table 1. The elemental concentrations in ng m^{-3} of the TSP are given in Table 2. Table 3 gives mean, maximum and minimum elemental concentrations according to TSP levels (high, mean, low) in ng m^{-3}. Average concentrations in ng m^{-3} are the following:

During normal meteorological conditions:
Ca 17,000 (12.2%), Si 16,000 (11.5%), S 4300 (3.1%), Ti 300 (0.21%), Cl 3500 (2.5%), Pb 120 (0.08%), Fe 2700 (1.9%), Na 970 (0.7%), Br 275 (0.2%), K 1300 (0.93%).

During or following rainfall (low TSP):
Ca 7300 (12.6%), Si 8500 (14.6%), S 2600 (4.5%), Ti 278 (0.48%), Cl 2100 (3.6%), Pb 90 (0.16%), Fe 1400 (2.4%) Na 350 (0.6%), Br 180 (0.3%).

Table 1. *Meteorological conditions and TSP during sampling*

Sample no.	Date	Relative humidity (%)	Temperature (°C)	Mean wind velocity (ms^{-1})	Wind direction	TSP ($\mu g\ m^{-3}$)	Comments
0	27 June 1977	22–48	21–37	2.06	N-NE-W	104	
1	12 July 1977	13–90	20–40	2.04	W-E	291	
2	18 July 1977	20–75	22–39	1.84	W-E-SE	196	
3	25 July 1977	42–86	20–35	1.93	NW-S-W	169	
4	27 July 1977	43–91	20–31	1.72	NW-W	148	
5	8 Aug. 1977	23–93	22–36	2.0	W-NW	122	
6	30 Aug. 1977	32–91	22–36	2.2	NW-W	315	
7	6 Sept. 1977	38–85	20–34	2.01	NW	243	
8	8 Sept. 1977	37–70	19–32	1.74	W-NW	140	
9	15 Sept. 1977	38–90	19–29	1.67	W-NW-E	121	
10	20 Sept. 1977	30–90	20–35	1.85	NW	160	
11	29 Sept. 1977	28–86	17–36	2.28	W-NW-NE	233	
12	3 Oct. 1977	30–80	16–32	1.95	NW-W-E	103	
13	9 Oct. 1977	30–85	15–53	2.0	NW-NE-E	97	
14	16 Oct. 1977	27–80	18–29	2.0	W-SW	610	Dust storm
15	23 Oct. 1977	14–70	18–27	4.59	NE	581	Dust storm
16	30 Oct. 1977	24–65	10–27	1.96	NW-E-NE	189	
17	7 Dec. 1977	34–94	6–21	1.89	NW-E	149	
18	15 Dec. 1977	53–97	9–14	2.48	W	172	
19	23 Dec. 1977	70–100	7–13	1.67	W-E	36	Rain
20	25 Dec. 1977	40–98	4–16	1.92	E-SW-W	115	
21	1 Jan. 1978	33–71	9–19	1.70	SW-E	154	
22	8 Jan. 1978	37–85	6–15	1.77	E-SE-W	556	Dust storm
23	15 Jan. 1978	49–95	4–15	2.10	NW-E	99	
24	26 Jan. 1978	41–100	8–17	2.24	W-SW-S	767	Dust storm
25	30 Jan. 1978	18–100	9–27	2.14	SE-NW-NE	124	
26	5 Feb. 1978	19–67	13–27	2.48	E-SE-W	544	Dust storm
27	12 Feb. 1978	19–67	10–26	2.28	E-W-E	144	
28	19 Feb. 1978	31–97	11–23	2.29	NW-E	104	Rain
29	26 Feb. 1978	31–100	8–24	1.77	NW-NE	164	
30	7 Mar. 1978	22–65	14–28	2.71	E	90	
31	13 Mar. 1978	24–100	7–18	2.73	W	1600	Dust storm
32	30 Mar. 1978	42–95	10–21	1.83	W-SW	50	Rain
33	4 Apr. 1978	10–16	33–38	3.06	S-SW	680	Dust storm
34	6 Apr. 1978	34–100	11–27	2.02	NW-E	168	
35	11 Apr. 1978	38–97	9–25	1.87	W-NW-E	130	
36	17 Apr. 1978	32–100	13–28	2.00	NW-W	109	
37	30 Apr. 1978	15–36	15–34	2.00	W-NW-E	166	
38	16 May 1978	18–70	22–35	2.25	N-E	613	Sharav
39	27 May 1978	13–20	36–43	2.87	E-SE-E	412	Sharav
40	30 May 1978	12–20	33–36	3.16	W Variable	5080	Sharav

During Sharav conditions (high TSP):
Ca 150,000 (16.8%), Si 160,000 (18%), S 55,000 (0.56%), Ti 2000 (0.22%), Cl 4600 (0.52%), Fe 21,428 (2.4%), Na 3400 (0.38%), Br 250 (0.027%), K 10,000 (1.1%).

The accuracy of the results is of the order of ± 10%.

4. Discussion

Tables 1–3 show the large variations in TSP and elemental concentration. It is convenient to divide the TSP levels into three groups: high, mean and low. High TSP levels are those > 200 $\mu g\ m^{-3}$. They are obtained during dust storms and Sharav

conditions. The prevailing winds during those days were N.E., S.E., E., S.W. and W., which carry dust and solid particles from the surrounding deserts and even from as far as the Sahara as shown by Ganor (1975). Low TSP levels were obtained during rainy days or immediately before or after rain. The levels are < 90 μg m^{-3}. Mean TSP levels were associated with normal days during which the prevailing winds are east and northwest. The mean TSP was found to be 140 μg m^{-3}.

The relative elemental abundances vary significantly between the three groups. Taking the ratio of four elements, S, Fe, Si, Ca as an indicator,

Table 2. *Concentration (ng m^{-3}) of elements in the aerosols of Beer-Sheva*

Sample no.	Ca	Si	S	Ti	Cl	Pb	V	Ni	Mn	Fe	TSP (μg m^{-3})
0	10,500	5,920	3,300	175	570	110	43	—	—	1,930	104
1	29,700	25,100	7,100	740	4,860	76	88	—	—	6,600	291
2	15,900	14,000	3,650	395	2,590	—	18	—	—	3,960	196
3	12,300	11,900	4,470	334	4,800	148	12	—	—	3,590	169
4	9,790	16,300	—	546	2,970	122	42	—	52	2,650	148
5	10,700	9,410	3,950	283	2,050	151	39	—	—	2,890	122
6	39,500	26,100	4,460	759	2,570	241	61	—	—	6,530	315
7	43,300	32,800	5,410	693	2,250	105	75	4	74	4,520	243
8	11,100	8,930	3,960	234	3,250	85	12	—	—	2,570	140
9	12,600	14,300	4,130	483	4,990	77	35	—	25	2,260	121
10	21,900	20,800	6,320	623	2,830	112	63	7	36	2,810	160
11	42,600	29,700	4,850	458	3,430	126	53	5	57	4,060	233
12	9,740	14,300	4,380	276	4,080	67	27	—	31	2,100	103
13	12,500	15,200	5,020	242	2,050	94	25	5	27	2,320	97
14	103,000	108,000	4,110	1,400	5,320	107	152	10	181	14,900	610
15	105,000	122,000	3,940	1,680	2,360	76	175	11	217	15,800	581
16	29,800	35,300	5,010	578	3,260	127	80	11	51	3,910	189
17	29,200	12,400	4,350	117	4,400	151	20	10	25	1,820	149
18	34,100	24,600	2,180	333	5,330	96	27	—	55	3,590	172
19	272	1,820	1,420	—	1,470	80	—	6	10	286	36
20	12,800	11,800	2,950	320	3,480	128	31	19	37	1,990	115
21	27,900	12,300	2,800	—	3,910	131	—	10	32	1,810	154
22	75,000	106,000	4,980	1,000	2,850	174	116	13	156	12,200	556
23	10,300	13,400	4,860	84	2,650	139	16	8	25	1,900	99
24	130,000	139,000	4,680	1,580	7,580	129	174	4	207	14,800	676
25	21,400	20,400	4,610	152	2,740	139	27	7	54	3,140	124
26	111,000	87,000	5,510	960	8,590	120	118	14	176	13,500	541
27	26,900	20,900	4,730	282	2,640	115	45	13	42	2,900	144
28	9,290	11,600	3,300	91	1,970	85	10	—	25	1,820	104
29	21,300	14,900	7,530	103	2,380	215	42	14	31	2,220	164
30	12,000	13,600	3,990	280	1,110	118	34	3	36	2,050	90
31	347,000	277,000	4,560	2,870	2,270	122	344	22	368	32,100	1,600
32	9,740	10,100	2,580	—	3,640	72	—	13	36	1,790	50
33	130,000	130,000	2,990	1,280	4,930	77	122	49	306	18,300	680
34	16,100	16,400	4,150	323	9,140	112	46	5	47	2,130	168
35	13,900	14,000	6,680	176	6,830	121	20	7	39	1,990	130
36	13,100	16,300	2,750	265	2,190	113	25	20	43	2,670	109
37	25,600	32,200	3,090	439	2,360	113	53	15	67	4,910	166
38	91,700	114,000	3,860	1,670	3,550	186	195	31	192	14,700	613
39	68,300	96,800	2,640	1,110	2,860	77	100	4	192	13,400	412
40	816,000	917,000	10,200	12,100	11,300	315	1,340	127	1,710	127,000	5,080*

* Sampling during 3 h of Sharav.

we find that for mean TSP levels, the ratio of these elements is 3.1 : 1.9 : 11.5 : 12.2; for high TSP the ratio is 0.56 : 2.4 : 18 : 16.8; for low TSP the ratio is 4.5 : 2.4 : 14.6 : 12.6. This suggests different sources of the TSP. Further studies are required to identify the exact sources. Partial information regarding the origin of some of the elements in the TSP was obtained by studying the correlations between TSP and elemental concentration (Table 4) and by observing cross correlations between the elements.

4.1 *Correlations*

In analyzing these correlations, the following assumptions were made:

(1) The major part of the TSP in the air is from natural sources. There is a certain contribution

Table 2—*contd.*

Sample no.	Na	Br	K	Sm	Au	Sb	Ga	La	Yb
0	384	237	1,600					5.6	
1	—	—	—					—	
2	880	140	—			0.7		6.9	
3	2,390	59	—		0.049	2.7		11	
4	1,100	180	—					8.8	
5	1,300	100	—		0.030	0.7		—	0.2
6	1,500	370	—			0.7		—	
7	870	174	1,800	0.57				5.9	
8	—	86	—					8.6	
9	1,080	123	—					4.7	
10	660	160	—	0.8				6.6	
11	880	270	—					3.3	
12	1,100	350	—					—	
13	370	250	1,730					1.0	
14	2,300	55	5,600					5.5	
15	—	—	5,200					4.5	
16	480	990	—					—	
17	1,100	800	—			1.2		—	
18	1,300	60	—			1.3		—	
19	160	200	—					—	
20	260	390	—			1.3		—	
21	566	51	1,040		0.032	1.0		3.5	
22	1,440	540	4,600			0.3		19	3.8
23	870	680	—					—	
24	4,300	270	—					—	
25	650	—	—					3	
26	6,500	—	—					5.6	
27	770	550	730					—	
28	580	270	800					—	
29	740	180	1,850	1.7				—	
30	400	310	840					2.5	
31	5,400	300	14,300	8				9.3	
32	490	33	230	0.5		0.74		—	
33	2,200	170	6,300	3.9		0.90	6.5	22	
34	2,200	74	1,100			0.90		3.1	
35	2,200	190	1,400					—	
36	460	31	1,700	1.2				3.8	
37	—	380	1,400					—	
38	2,000	140	4,800					—	
39	1,300	110	3,900					13	
40	1,200	320	47,000	26		17		143	

Table 2—*contd.*

Sample no.	Lu	Se	Hg	Cr	Hf	Cs	Sc	Rb	Co	Tn	Zn
0			10						2.2		
1									1.8		
2			18			0.005	1.2		1.8		
3			2.7		33				1.1		
4									—		
5									—		
6						0.36		8.4	—		
7									1.6		
8									—		
9									1.2		
10									1.3		
11									1.9		
12									1.3		
13			10				0.5		1.8		
14			—				4.5		5.5	0.36	
15			2.4				3.7		5.1		
16			2.7	9			1.1		2.3		
17			—	7.8			0.28		1.5		150
18			8.3	—			0.77		1.3		
19			6.6	—			0.47		0.66		14
20			4.2	6			0.47		1.6		
21						0.006			1.5		
22	2.8		5.6				3.5		4	1.7	
23											
24											
25				6.6	1.4		0.57		1.7		
26											
27				9	2.1		0.75				
28											
29						0.56					250
30											
31		0.8			14	1.7			13	1.1	
32						0.07	0.2				99
33							4.2				2,300
34							0.7		2.1		
35									1.6		
36											
37											
38										0.5	
39											
40						6.8		190	87	9.6	

from industry and motor vehicles, but as the population is relatively small and the industries still not very large, their contribution to the TSP is not significant.

(2) A high correlation between any element and TSP is a sign that the element is part of the natural aerosol and dust concentrations.

(3) If there is very low correlation between TSP and the concentration of the element, i.e. when the TSP levels are very high or low, the concentrations of the element do not follow suit; the source of this element is man-made or from a minor natural source not related to dust carried by the winds.

(4) High cross correlation between elements can either indicate that they are part of a chemical compound or that they both come from the same source.

Table 3. *Percental mean concentrations of main elements of global TSP, low TSP, mean TSP and high TSP*

Element	% of TSP (high TSP)	% of TSP (mean TSP)	% of TSP (low TSP)	% TSP global mean
Ca	16.8	12.2	12.6	16
Si	18	11.5	14.6	17
S	0.56	3.1	4.5	1.1
Ti	0.22	0.21	0.48	0.23
Cl	0.52	2.5	3.6	1
Pb	0.015	0.08	0.16	0.03
Fe	2.4	1.9	2.4	2.3
Na	0.38	0.70	0.60	0.43
Br	0.027	0.20	0.31	0.066
K	1.1	0.93	0.92	1.3
Ca + Si + Fe	36.2	25.6	29.6	35.3

The cross correlation table of 19 elements is shown in Table 4. The elements can be divided into three groups. One group with high correlation with TSP and high cross correlation between its members, consists of Fe, Co, Sc, La, Sm, Mn, Ti, V, Ni, K, Ca, Si and Na. A second group with about 50% correlation between the members of the group and TSP and between each other includes: S, Pb and Cl. A third group includes those elements with very low or negative correlations with TSP and other elements of the table. This group includes Sb, Br and Hg.

Regarding the first group, the very high cross correlation within the group probably indicates that they are primarily crustal in origin; hence all correlate excellently with TSP and consequently with each other. The elements of the second group probably owe their origins to both industrial and crustal sources. This explains the partial correlations with TSP and other crustal elements such as Si and Ti of the first group. The fact that S, Cl and Pb belong to this group is not surprising since S and Cl are used extensively by the local chemical industry as well as being crustal, and Pb undoubtedly comes at least partly from motor vehicle exhausts. Regarding Cl, it is noteworthy that the correlation with Na is only 75% indicating that salt (NaCl) is not the only source of Cl in the air.

The third group includes Hg, Sb and Br. Here the correlation is nearly zero or even negative with TSP and other major crustal elements. The fact that when TSP rises there is no corresponding rise in these elements (in the case of Hg and Sb it tends to decrease), shows that the source is probably not crustal but from local industry emissions of these elements, which are random. A negative correlation can be explained by assuming a local source which is diluted by the weather conditions conducive to high TSP. The correlation fits in very well with the fact that very large quantities of bromine are processed in the Bromine Works in Beer-Sheva, and that large quantities of mercury are used in the electrolytic processes of the production of Cl_2 by the Makhteshim Company. The evidence that bromine in the TSP is industrial in source also comes from comparisons of the Br level in Beer-Sheva and Shivta, which is 30 km to the southwest of Beer-Sheva. Levels two to three times higher are found in Beer-Sheva compared to Shivta. In all cases where the predominant wind was from the direction of the bromine plant, the levels rose dramatically.

4.2. *TSP and meteorological conditions*

It is difficult to predict TSP levels from general meteorological data. There is only a weak correlation between wind and velocity, temperatures and humidity levels and TSP. It has been observed, however, that days of Sharav, during which the winds are very dry and hot, are usually high in TSP; likewise the chances of high TSP are greater when the winds are from the southwest or west, bringing dust from the Sinai or from as far as the Southern Desert.

Days when the wind blows from the northwest or the east are relatively clean days. This is understood, since these directions are opposite to the desert direction and there is no dust source

Table 4. *Correlation factor between the elements and TSP* (×*100*)

Co	Sc	Hg	La	Sb	Sm	K	Br	Na	Fe	Mn	Ni	V	Pb	Cl	Ti	S	Si	Ca	
98	99	−30	95	−24	99	99	4.3	90	99	99	91	99	62	56	99	58	99	99	TSP
96	96	−37	92	−26	99	99	4.8	91	98	98	89	98	58	54	98	55	99		Ca
99	98	−38	96	−26	99	99	4.9	89	99	99	92	99	60	55	99	56			Si
72	18	−16	78	22	69	68	22	61	57	58	51	60	58	46	59				S
99	95	−42	97	—	—	99	0.8	88	99	99	92	99	61	55					Ti
63	11	−29	61	43	84	63	−10	75	56	58	53	55	29						Cl
85	05	−28	86	28	81	74	21	55	60	68	70	62							Pb
99	93	−47	96	—	99	99	3.2	88	99	99	92								V
99	48	—	96	—	93	93	−1.1	77	93	94									Ni
99	94	—	98	—	99	99	0	89	99										Mn
99	98	−32	96	−24	99	99	3.4	89											Fe
94	74	−21	83	4.3	98	97	−1.7												Na
4.5	−14	−44	32	2.9	68	17													Br
99	—	—	96	—	99														K
—	—	—	—	—															Sm
—	—	—	—																Sb
99	—	—																	La
27	—																		Hg
97																			Sc

from these directions. Rain also has a clear effect on the TSP levels. The lowest TSP values were obtained during or after rain. It is interesting to note that the elements Pb, S, Cl which are not related to the TSP are not related to the weather conditions either. These elements, as mentioned, originate from industry and transportation.

4.3 *Enrichment factor analysis*

Complementary information can be obtained by computing the enrichment factor (EF) of the elements found in the aerosols relative to the crust, using some reference material. This was done using the following formula:

$$\text{aerosol crust enrichment factor} = (X/Fe)_{aerosol}/(X/Fe)_{crust}$$

where X and Fe stand for concentrations of elements X and the reference element iron, respectively.

Table 5 gives the EFs calculated from our data for low, normal and high TSPs. In these calculations, average crust values were used (Mason, 1966). Inspection of this table reveals two important groups: one group which comprises 8 elements: Na, Si, Ti, K, Mn, Ni, V and La, has EFs of less than 7. The other group comprising 5 elements: S, Cl, Pb, Br and Hg, has EFs greater than 100. Using the criterion established by Rahn (1976) that elements with EFs less than 7 are crustal in origin and that elements with EFs > 10 are non-crustal in origin, the two groups can be identified as being of crustal and non-crustal origin, respectively.

The same elements were similarly identified by Rahn *et al.* (1979) for Sahara and world aerosols. Applying Rahn's criteria to the two remaining elements in Table 5, Ca and Zn, with $7 < EF < 100$, which do not fall into one of the two groups, it can be seen that at least Zn can be unequivocally assigned to the group of non-crustal aerosols as its EF is significantly greater than 10, whereas Ca with its $7 < EF < 10$, falls in between the limits assigned by Rahn's criteria.

A more detailed examination of Table 5 shows that the elements can also be grouped according to the behavior of their EFs under varying TSP conditions. One group Si, K, Mn, La and Ca has an EF value which does not vary significantly for all TSP conditions. A second group comprising Cl, Pb, Br, Hg, Na, V, Ni shows a decrease in EF values for high TSP conditions. Br, for example, goes from a high EF of 4000 during low TSP conditions to a low EF of 343 for high TSP conditions. Zn and S which make up a third group, on the contrary, show an increase in their EF values during high TSP conditions compared to low TSP conditions. We have no clear explanation for the behavior of the different groups under varying TSP conditions, but we believe that this must be taken into account in future explanations of EF data.

Comparing the information from EF analysis

Table 5. *Enrichment factors* $(X/Fe)_{aerosol}/(X/Fe)_{crust}$

	Enrichment factor		
Element	Low TSP	Normal TSP	High TSP
Si	1.04	1.06	1.34
Ti	1.8	1.26	1.05
K	0.93	0.94	0.915
Mn	0.96	0.72	0.75
Ni	3.12	2.5	0.68
V	8.0	4.07	3.46
La	4.45	5.17	4.75
Ca	7.17	8.67	9.74
Zn	15	28	41
S	177	153	246
Cl	238	205	33
Pb	213	148	20.80
Br	4,000	3,156	343
Hg	470	290	19
Na	0.44	0.63	0.28

and from correlation analysis, it can be seen that the elements Si, Ti, K, V, Mn, and La which have low EF factors are those with high correlation with TSP (>0.95). The elements S, Cl and Pb with EFs of 10–250 have intermediate correlation factors, 0.5–0.6. Hg and Br which have very high enrichment factors (>250) have extremely low correlation factors (in the case of Hg the correlation factors are negative). This comparison shows that information from EF analysis and from correlation analysis is complementary, in that similar basic groupings of elements are obtained by both methods of analysis.

5. Conclusions

In most of the large cities in Europe and the United States, the major sources of suspended particles in the air are from industrial plants, vehicle emission and central heating. The USA primary standard for clean air requires that the TSP level does not exceed 75 $\mu g\ m^{-3}$. In Beer-Sheva, most of the suspended particles are natural dust particles carried by the winds from the arid hills and valleys of the nearby surroundings and distant deserts. The average TSP level is much above the recommended USA standard and is approximately as high as Pittsburgh, 160 $\mu g\ m^{-3}$, and Los Angeles, 169 $\mu g\ m^{-3}$ (Middleton, 1969). During Sharav and sandstorm conditions, the average TSP values are very much higher (890 $\mu g\ m^{-3}$) with extremes reaching values of 1600 $\mu g\ m^{-3}$. Since the major amount of TSP is natural and cannot be avoided, this should be taken into consideration when planning industry in this area.

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