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Mobility of Polycyclic Aromatic Hydrocarbons in Water of the Egyptian Red Sea Coasts

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Polycyclic aromatic hydrocarbons (PAHs) are well known environmental pollutants at low concentrations and are included in the European Union and US Environmental Protection Agency (EPA) priority pollutant list due to their mutagenic and carcinogenic properties (Tsapakisa et al. 2003). They are generated by incomplete combustion of organic materials arising in part from natural combustion such as forest fires and volcanic eruptions (Wang et al. 1999). Petroleum production and import and export of petroleum products also contribute to PAH contamination, especially in the marine samples. Several PAHs are known to be potential human carcinogens these include; benzo[a]anthracene, chrysene, benzo [b]fluoranthene, benzo[k]fluoranthene, benzo[a] pyrene and benzo[ghi]perylene (IARC 1991). The acute toxicity of PAHs to marine organisms increases as the molecular weight of the compounds increases up to 202 molecular weight (e.g., flouranthene and pyrene), (GESAMP 1993).

The rapid growth of industrialization along the Red Sea coast has significantly changed the environment of the region particularly the northern part of the Suez Gulf. That region receives considerable drainage water, about 1.75 X 10^8 m^3 were discharged annually from oil refineries to the Suez Gulf (Awad 2002). On the other hand, the Gulf of Aqaba, is one of the most famous areas of tourism, allover the world. Despite this, the accumulative effects of low-level hydrocarbon presence there are more dangerous than accidental spills, in particular to sea grasses and phytoplankton. El Nemr et al. (2004) recorded an average total concentration of 5452 ng/g; wet weight of 16 PAHs in mussels (*Brachidontes sp.*), collected from the Egyptian Red Sea Coast.

The present investigation is aimed to: 1) assess residual concentrations of dissolved heavy aromatic hydrocarbons that may include carcinogenic PAHs, 2) study the sources and inputs of oil pollutants into the Red Sea in order to estimate the PAH flux into this area due to air–water exchange and 3) study the mobility of PAHs along the Egyptian Red Sea coast.

MATERIALS AND METHODS

Surface water samples (1m depth) were collected from the Egyptian Red Sea coast (Fig. 1) using Nisken bottles from 39 sites during 2003. Water samples were stored at 21°C and transported to the laboratory for PAHs analysis using well established techniques (UNEP/ IOC/ IAEA 1991). Seawater samples were extracted with n-hexane, the sample extracts were concentrated by rotary evaporator to 1 ml and analyzed according to Gogou et al. (1998).

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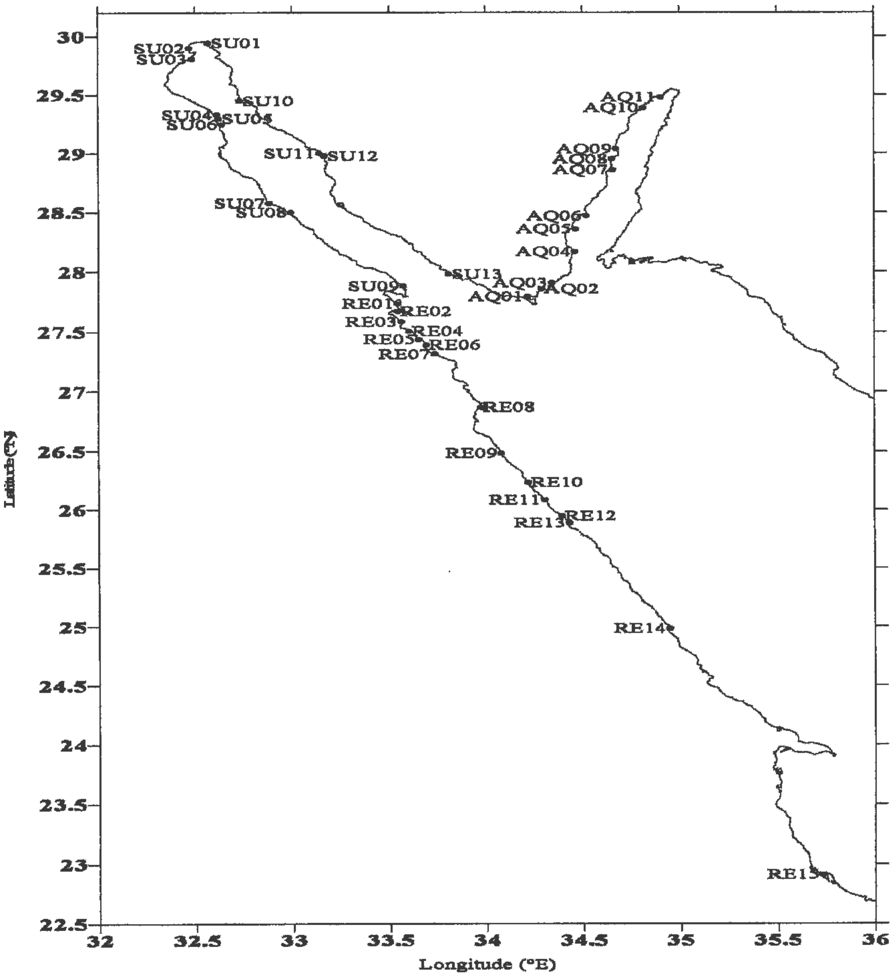

Figure 1. Locations of sampling stations in the area of investigation

Briefly, extracts were fractionated on silica column and eluted with 11ml n-hexane and (9.5/5.5) 15ml n-hexane/dichloromethane. The non polar aliphatic hydrocarbons were collected in the first fraction and PAHs in the second one. Finally, samples were concentrated under a gentle stream of purified nitrogen. To control the analytical reliability and assure recovery efficiency and accuracy of the results, 6 analyses were conducted on PAH reference materials, HS-5 and 2974 (provided by EIMP-IAEA). The laboratory results showed recovery efficiency ranged from 92-111% with coefficient of variation (CV) 8-14% for all studied pollutants. All solvents were pesticide grade purchased from Merck and appropriate blanks (1000 fold concentrates) were analyzed. The gas chromatograph was Hewlett Packard HP-5890 series II with split/splitless injector and a fused silica capillary; HP-1 (30 m length, 0.32 mm i.d, 0.17 µm film thickness); 100% dimethylpolysiloxane, and a flame ionization detector (FID). The temperature was programmed from 60-290°C increased at a rate of 3°C min^{-1} and then maintained at 290°C for 25 min. A 3µL splitless injection was used, and the injection port was maintained at 290°C. The carrier gas was nitrogen flowing at 1.2 ml min^{-1}.

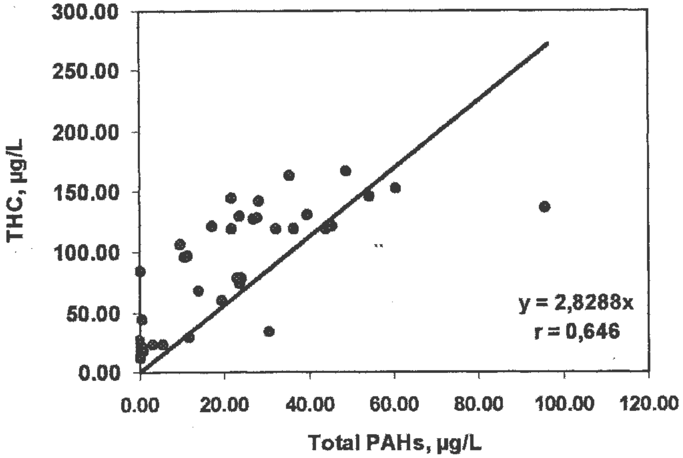

Figure 2. Correlation coefficient between THC and total PAHs for all water samples during winter 2003.

A stock solution containing the following PAHs was used for quantification: naphthalene, acenaphthylene, acenaphthane, fluorene, phenathrene, anthracene, fluoranthene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k) fluoranthene, pyrene, benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(ghi) perylene and indeno(1,2,3-cd)pyrene by dilution to create a series of calibration standards of PAHs at 0.1, 0.25, 0.5, 0.75, 1.0, 2.0, 5.0, and 10 µg ml^{-1}. The detection limit was approximately 0.01 µg ml^{-1} for each PAH.

RESULTS AND DISCUSSION

The residue of 16 PAHs were identified in water (Tables 1-3). Pyrene, chrysene, benzo(a)anthracene and benzo(b)fluoranthene were the most dominant PAHs in most samples. The total ($\sum$16 PAHs) concentrations were varied from 0.40 µg/L to a maximum of 96.45 µg/L with an average of 20.93 µg/L. In addition, total hydrocarbon concentration (THC) ranged from 9.73 µg/L to 164.03 µg/L with an average of 40.26 µg/L. These values were lower than that recorded on the Arabian Gulf; 0.3-455 µg/L with an average of 58.6 µg/L and those recorded on Saudi Arabia coasts ranged from 18.8-412 µg/L with an average of 147.2 µg/L (Awad 1990). The present study suggests that the average THC (i.e. 40.26 µg/L) is to some extent safe and will have weak, but not harmful, effect on marine organisms. This is in accordance with conclusion derived from Mazmanidi et al. (1976) who stated that the THC concentration in seawater which can produce a harmful effect on the aquatic organisms is about 50 µg/L.

PAH concentrations differ depending on the emission sources and several PAH concentration diagnostic ratios have been extensively used in order to identify and quantify the contribution of each source of contamination to the specific compartments (Kavouras et al. 2001). They stated that the general distribution of PAHs in all water samples reflects the high contribution of pyrolytic sources, due to the predominance of parent PAHs over the alkylated derivatives. In general, the most important input of PAHs in the investigated area is from petroleum transportation, offshore exploitation, and/or natural seeps. The detection of perylene may be due to biogenic precursors via short-term digenetic processes.

Table 1. Concentration (µg/L) and ratios of individual PAH compounds determined in water sampels collected from the Gulf of Suez during 2003

Compound	Station												
	SU1	SU2	SU3	SU4	SU5	SU6	SU7	SU8	SU9	SU10	SU11	SU12	SU13
Naphthalene	ND	ND	ND	ND	ND	0.07	0.09	0.09	ND	ND	ND	ND	ND
Acenaphthylene	ND	ND	ND	ND	ND	0.001	ND	ND	ND	ND	ND	ND	0.001
Acenaphthene	0.02	0.03	0.03	0.03	0.01	0.01	0.07	0.03	0.01	0.05	0.03	0.01	0.01
Fluorene	1.08	0.04	0.15	0.34	0.02	0.04	0.11	0.21	0.05	0.28	0.04	0.04	0.04
Phenanthrene	0.53	0.27	1.17	0.92	0.29	0.11	0.14	1.36	0.13	1.25	0.13	0.25	0.11
Anthracene	0.51	0.33	1.85	0.37	0.24	0.31	0.18	2.16	0.40	2.51	0.17	0.24	0.17
Fluoranthene	1.77	6.77	5.99	3.69	1.51	4.32	2.69	5.80	5.30	5.94	10.91	11.34	5.10
Pyrene	4.29	49.69	3.23	6.59	3.18	6.34	4.28	3.97	3.73	7.25	3.30	3.66	1.73
Benzo(a)anthracene	2.35	19.45	7.63	3.36	2.25	8.98	1.91	5.21	1.42	5.28	6.28	3.30	5.23
Chrysene	1.65	10.86	6.22	2.33	6.31	8.61	1.55	6.47	5.79	5.34	2.45	4.69	4.91
Benzo(b)flouranthene	2.70	7.54	9.97	7.49	6.76	1.11	1.17	1.53	5.41	1.52	3.87	13.82	5.12
Benzo(k)fluoranthene	1.85	0.20	7.99	5.88	0.17	0.75	0.46	12.18	0.78	1.69	1.06	0.64	1.06
Benzo(a)pyrene	0.08	0.20	2.33	0.64	0.13	0.09	0.17	2.93	0.10	1.33	0.13	0.32	0.10
Dibenzo(a,h)anthracene	0.61	0.40	4.37	2.69	0.94	0.19	1.07	8.26	0.90	7.12	0.14	1.06	0.69
Benzo(ghi)perylene	0.13	0.06	1.83	0.74	0.25	0.07	0.20	5.58	0.17	4.24	0.19	0.35	0.16
Indeno(1,2,3-cd)pyrene	0.24	0.61	2.20	1.06	0.33	0.41	0.59	5.50	0.43	5.89	0.36	0.61	0.29

Table 1., continued

PHE/ANT	1.02	0.81	0.63	2.51	1.21	0.37	0.77	0.63	0.32	0.50	0.76	1.01	0.64
FLTH/PYR	0.41	0.14	1.85	0.56	0.48	0.68	0.63	1.46	1.42	0.82	3.31	3.10	2.95
BaA/CHR	1.43	1.79	1.23	1.44	0.36	1.04	1.23	0.81	0.25	0.99	2.57	0.70	1.07
T PAHs	17.80	96.45	54.95	36.12	22.38	31.39	14.67	61.17	24.59	49.69	29.08	40.32	24.71
THC	118.8	134.4	143.2	160.4	141.9	31.4	65.8	150.4	127.3	164.0	139.5	128.3	75.8
TCOM	16.70	96.38	54.77	35.74	22.35	31.28	14.39	60.93	24.53	49.36	29.00	40.27	24.67
TF-PAHs	1.10	0.07	0.18	0.37	0.03	0.11	0.27	0.32	0.06	0.34	0.08	0.05	0.05
TF-PAH/TCOM	0.07	0.001	0.003	0.01	0.001	0.004	0.02	0.01	0.002	0.01	0.003	0.001	0.002
% TF-PAHs/TPAHs	6.20	0.07	0.33	1.03	0.13	0.35	1.85	0.53	0.24	0.68	0.26	0.11	0.19
%TPAHs/THC	14.98	71.75	38.38	22.51	15.77	99.88	22.29	40.67	19.32	30.30	20.84	31.42	32.59
T Carc PAHs	5.98	28.20	26.49	15.24	10.40	10.78	4.90	23.44	8.25	21.15	10.78	19.11	11.43
% T Carc PAH/T PAHs	33.59	29.24	48.21	42.19	46.46	34.33	33.40	38.31	33.54	42.55	37.06	47.40	46.25

TCOM: sum of PAHs come from combustion/pyrolysis processes (MW>178); TF-PAHs: sum of PAHs come from fossil fuel (MW<178); THC: total hydrocarbns; TPAHs:= total polycyclic aromatic hydrocarbons; TCarc: (IARC probable and possible human carcinogens) total carcinogenic hydrocarbons; Benzo(a) anthracene, Benzo(b)fluoranthene, Benzo(a)Pyrene, Dibenzo(a,h)anthracene and Indeno(1,2,3-cd)pyrene, SU1:Suez North, SU2: Suez Midlle, SU3: Suez South, SU4: Ain Sukhna Offshore, SU5: Ain Sukhna North, SU6: Ain Sukhna South, SU7: Ras Gharib City, SU8: Ras Gharib Harbour, SU9: Ras Shukeir, SU10: Ras Sudr,SU11: Abu Zenima, SU12: Ras Budran and SU13: El Tur.

Table 2. Concentration (µg/L) and ratios of individual PAH compounds determined in water sampels collected from the Red Sea proper during 2003

Compound	Station														
	Re 1	Re 2	Re 3	Re 4	Re 5	Re 6	Re 7	Re 8	Re 9	Re 10	Re 11	Re 12	Re 13	Re 14	Re 15
Naphthalene	0.019	ND	ND	0.02	0.016	0.016	0.017	0.011	0.014	ND	ND	0.03	0.002	ND	0.029
Acenaphthylene	0.0004	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.006
Acenaphthene	0.01	ND	ND	0.01	0.012	0.007	0.014	0.012	ND	ND	ND	0.056	0.057	0.038	0.05
Fluorene	0.01	ND	ND	0.04	0.046	0.040	0.055	0.013	0.028	0.02	ND	0.147	0.133	0.056	0.079
Phenanthrene	0.056	0.052	0.053	0.052	0.067	0.056	0.059	0.082	0.074	0.049	0.035	0.292	0.278	0.266	0.398
Anthracene	0.056	0.034	0.024	0.039	0.049	0.046	0.046	0.039	0.045	0.04	0.028	0.104	0.094	0.07	0.069
Fluoranthene	0.216	ND	ND	0.161	0.264	ND	0.135	0.538	0.278	ND	ND	5.544	6.060	5.867	7.01
Pyrene	0.389	ND	ND	0.274	0.315	0.346	0.252	0.498	ND	ND	ND	1.374	1.719	1.905	1.776
Benzo(a)anthracene	0.120	ND	ND	0.086	0.177	0.148	0.076	0.179	ND	ND	ND	0.599	2.196	1.62	0.646
Chrysene	0.074	0.070	0.117	0.139	0.109	0.111	0.081	2.864	ND	ND	ND	1.658	0.237	1.826	1.928
Benzo(b)flouranthene	ND	ND	0.598	0.392	0.088	ND	0.032	1.084	ND	ND	ND	0.222	0.284	0.189	0.215
Benzo(k)fluoranthene	0.020	0.014	2.834	0.314	0.060	0.080	0.023	0.34	ND	0.076	0.343	0.109	0.115	0.07	0.036
Benzo(a)pyrene	0.006	0.007	0.102	0.008	0.007	0.011	0.005	0.015	0.005	0.008	0.010	0.018	0.017	0.009	0.009
Dibenzo(a,h)anthracene	0.020	ND	0.074	0.092	0.018	0.023	0.033	0.155	0.318	ND	0.186	0.358	0.041	0.016	0.112
Benzo(ghi)perylene	0.007	0.080	ND	0.014	0.009	ND	0.009	0.27	0.008	ND	ND	0.035	0.040	0.113	0.051
Indeno(1,2,3-cd)pyrene	0.024	0.268	0.024	0.056	0.173	0.293	0.027	0.052	0.072	0.203	0.045	0.065	0.049	0.062	0.055

Table 2., continued

PHE/ANT	1.00	1.53	2.21	1.33	1.37	1.22	1.28	2.10	1.64	1.23	1.25	2.81	2.96	3.80	5.77
FLTH/PYR	0.56	NC	NC	0.59	0.84	NC	0.54	1.08	NC	NC	NC	4.03	3.53	3.08	3.95
BaA/CHR	1.622	NC	NC	0.619	1.624	1.333	0.938	0.063	NC	NC	NC	0.361	9.266	0.887	0.335
T PAHs	1.01	0.53	3.83	1.70	1.41	1.16	0.86	6.15	0.83	0.40	0.65	10.58	11.32	12.11	12.43
THC	11.83	21.70	20.50	14.93	18.43	41.29	9.73	21.27	82.13	19.72	24.20	104.2	93.28	94.59	26.16
TCOM	0.99	0.53	3.83	1.63	1.34	1.11	0.78	6.12	0.80	0.38	0.65	10.38	11.13	12.01	12.31
TF-PAHs	0.04	ND	ND	0.07	0.07	0.06	0.09	0.04	0.04	0.02	ND	0.23	0.19	0.09	0.16
TF-PAH/TCOM	0.04	NC	NC	0.04	0.06	0.06	0.11	0.01	0.05	0.05	NC	0.02	0.02	0.01	0.01
% TF-PAHs/TPAHs	3.91	NC	NC	4.12	5.25	5.43	9.95	0.59	5.07	5.05	NC	2.20	1.70	0.78	1.32
%TPAHs/THC	8.52	2.42	18.66	11.36	7.65	2.81	8.88	28.93	1.01	2.01	2.67	10.16	12.14	12.80	47.54
T Carc PAHs	0.17	0.28	0.80	0.63	0.46	0.48	0.17	1.49	0.40	0.21	0.24	1.26	2.59	1.90	1.04
% T Carc PAH/T PAHs	16.86	52.38	20.86	37.36	32.84	40.91	20.02	24.14	47.71	53.28	37.25	11.93	22.85	15.66	8.34

RE1:Abu Shar, RE2: Hurghada-NIOF, RE3: Hurghada-Public Beach, RE4: Hurghada-Hotel Sheraton, RE5: Coral reef-Island Gezr. Gift., RE6: Sahl Hashish, RE7: Safaga North, RE8: Safaga Middle, RE9: Safaga South, RE10: El Hamarawein, RE11: Quseir North, RE12: Quseir Middle, RE13: Quseir South, RE14: Marsa Alam and RE15: Bir Shalatin NC: not calculated due the two concentrations being below the detection limit.

Table 3. Concentration (µg/L) and ratios of individual PAHs determined in water of the Gulf of Aqaba during 2003

Compound	AQ1	AQ2	AQ3	AQ4	AQ5	AQ6	AQ7	AQ8	AQ9	AQ10	AQ11
Naphthalene	ND	0.072	ND	0.075	0.075	ND	0.063	0.072	ND	ND	ND
Acenaphthylene	0.001	ND	ND	ND	ND	ND	ND	ND	ND	0.001	ND
Acenaphthene	0.008	0.023	0.026	0.025	0.016	0.022	0.041	0.013	0.009	0.007	0.028
Fluorene	0.033	0.243	0.132	0.283	0.173	0.242	0.274	0.167	0.037	0.040	0.204
Phenanthrene	0.077	0.234	1.266	1.265	1.399	1.429	0.126	1.259	0.135	0.232	1.317
Anthracene	0.239	0.150	1.525	2.22	1.815	2.249	0.249	2.068	0.268	0.136	1.567
Fluoranthene	4.140	3.557	3.734	4.796	4.562	3.375	1.525	4.497	1.143	4.339	3.640
Pyrene	4.547	3.204	1.894	3.140	3.052	2.578	5.767	2.169	1.308	3.787	3.314
Benzo(a)anthracene	5.987	6.502	2.426	6.214	1.824	1.763	1.100	2.268	9.388	1.321	5.796
Chrysene	3.637	3.195	1.899	3.566	2.278	2.485	6.907	2.949	7.532	5.263	3.166
Benzo(b)flouranthene	3.950	5.544	3.934	1.527	1.091	1.042	5.891	5.116	1.749	2.611	9.446
Benzo(k)fluoranthene	0.931	0.950	1.218	1.524	8.903	5.201	0.776	1.942	0.100	0.933	8.213
Benzo(a)pyrene	0.067	0.140	1.073	2.305	2.198	1.067	0.143	0.968	0.193	0.106	1.236
Dibenzo(a,h)anthracene	0.381	0.273	4.501	8.033	5.515	2.405	0.307	5.096	0.161	0.952	4.738
Benzo(ghi)perylene	0.255	0.186	1.759	4.69	1.536	1.984	0.192	1.236	0.537	0.146	1.078
Indeno(1,2,3-cd)pyrene	0.282	0.031	2.235	5.002	2.644	2.741	0.403	3.169	ND	0.263	2.660
PHE/ANT	0.32	1.56	0.83	0.57	0.77	0.64	0.51	0.61	0.50	1.71	0.84
FLTH/PYR	0.91	1.11	1.97	1.53	1.49	1.31	0.26	2.07	0.87	1.15	1.10
BaA/CHR	1.646	2.035	1.277	1.742	0.801	0.709	0.159	0.769	1.246	0.251	1.831
T PAHs	24.54	24.30	27.62	44.66	37.08	28.58	23.76	32.99	22.56	20.14	46.40
THC	71.50	76.32	125.0	116.4	117.0	125.7	76.6	116.3	116.5	58.0	119.3
TCOM	24.49	23.97	27.46	44.28	36.82	28.32	23.39	32.74	22.51	20.09	46.17
TF-PAHs	0.04	0.34	0.16	0.38	0.26	0.26	0.38	0.25	0.05	0.05	0.23
TF-PAH/TCOM	0.002	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.002	0.002	0.01
% TF-PAHs/TPAHs	0.17	1.39	0.57	0.86	0.71	0.92	1.59	0.76	0.20	0.24	0.50
%TPAHs/THC	34.31	31.84	22.10	38.38	31.70	22.73	31.04	28.37	19.36	34.72	38.90
T Carc PAHs	10.67	12.49	14.17	23.08	13.27	9.02	7.84	16.62	11.49	5.25	23.88
% T Carc PAH/T PAHs	43.48	51.39	51.30	51.68	35.79	31.55	33.01	50.37	50.94	26.09	51.45

AQ1: Ras Mohammed, AQ2: Sharm El Sheikh Harbour, AQ3: Nema Bay, AQ4:Nahlat El Tel, AQ5:Dahab, AQ6: Ras Mamlah, AQ7: Hibeq, AQ8: Nuweiba Harbour, AQ9: Nuweiba El-Siadin, AQ10: Mersa Muqibila and AQ11: Taba.

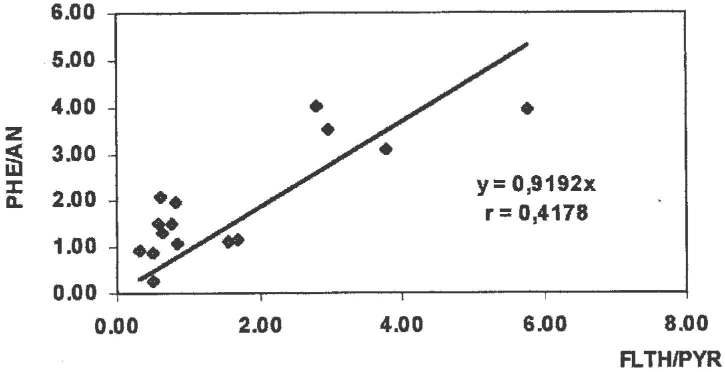

Figure 3. Plot of isomeric ratios PHE/ANT vs.FLTH/PYR for water samples of the area of study during, 2003

A maximum concentration of perylene (5.58 μg/L) was recorded at station SU8; Gulf of Suez. The origin of perylene is quite controversial. Perylene could also be derived from aquatic material or diatoms. Ratio values such as phenanthrene/anthracene (PHE/ANT) and fluoranthene /pyrene (FLU/PYR) had been used by different workers to identify the origin of hydrocarbons (El Nemr et al. 2004). Petroleum often contains more phenanthrene relative to anthracene as phenanthrene is the most thermodynamically stable tricyclic aromatic isomer. A low PHE/ANT ratio (<10) indicated that the major PAH input was from combustion of fossil fuels while a high PHE/ANT ratio (>10) suggested primarily petrogenic inputs. In addition, a FLU/PYR ratio less than 1 suggested PAH presence was attributed to petrogenic inputs and values greater than 1 were related to a pyrolytic origin (Bentahcen et al. 1997). In the present study, the simultaneous occurrence of isomer ratios of PHE/ANT <10 for all stations indicated that the major PAH input was from combustion of fossil fuels (pyrolytic source) with an average ratio of 1.321 for all samples.

Also, FLU/PYR was <1 with an average value of 1.46. Figure (2) shows a positive correlation (r = 0.646) between the ratio of fluoranthene/pyrene (FLTH/PYR) and PHE/ANT, confirming also that the PAHs of the investigated areas were released from pyrolytic resources (Readman et al. 2002). This is in accordance with El-Sikaily et al. (2003) who stated that PAHs recorded in coral reef samples of the Red Sea coasts is of pyrolytic origin. In addition, the TCOMB (sum of PAHs come from combustion/pyrolysis; MW>178) concentrations displayed values from 0.53 to 96.38 μg/L representing an average of 95% of total PAHs. While TF-PAHs (sum of PAHs come from fossil fuels; MW<178) displayed values from 0.02 to 1.10 μg/L representing an average of 5% of total anthropogenic PAHs. The benzo(a)anthracene/chrysene (BaA/CHR) ratio has also been suggested to identify PAH sources, and this ratio tended to increase as the petrogenic contribution decreased. The ratio for crude and fuel oil ranged from 0.24 to 0.4 (Colombo et al. 1989). The BaA/CHR ratio in this study ranged between 0.06-9.27 suggesting a pyrolytic source. On the other hand, a good correlation was found between the THC and TPAHs with r = 0.42 (Fig. 3), which is greater than the significant value; r = 0.329 at P = 0.05 for 38 pairs of water samples. This clearly indicates that the two classes of compounds (alkanes and PAHs) may come from the same source (i.e. pyrolytic).

In addition, the present data shows that the group of PAHs from fossil fuels (MW<178); naphthalene, acenaphthylene, acenaphthene and fluorene posed the lowest dominant compounds in all water samples. Pyrene was the most dominant fraction of total combustion oil (MW>178) observed clearly in both of the Gulf of Suez and the Red Sea proper more than that recorded in the Gulf of Aqaba. The carcinogen BaP was the lowest fraction among the TCARC compounds (sum of BaA+BbF+BaP+InP+DBA) in all water samples.

The mobility of PAHs and THC are presented in Tables (1-3). It is clear that the order of concentration of both of THC and TPAHs was: Gulf of Suez > Gulf of Aqaba > Red Sea proper. It can be concluded that water of the Red Sea does not interfere with the identity of water of the Gulf of Suez even with the most northern wind prevailing all the year (Morcos 1970). This is also evident by low concentration in the Red Sea. The counter clockwise circulation of water in the northern part of the Gulf of Suez caused transport of hydrocarbons toward Ain Sukhna (SU6). Otherwise, we can divide the Gulf of Suez water into two sectors; Sector a: (SU1-SU6) as industrial activity source from oil refineries and Sector b: (SU7-SU13) as oil field activity. Going toward the Red Sea proper, the activities occurred at Safaga harbour (RE 9) and at Quseir (RE 12) were the highest source of pollution. Also, the PAHs were the lowest in the Red Sea proper. In the Gulf of Aqaba another trend was observed, where the main source of pollution was oil fields with distribution along the Saudi Arabian coast via atmospheric deposition.

The sum of six carcinogenic PAHs ($TPAH_{CARC}$) as recommended by IARC (1991), were highest at stations; SU2, RE13, AQ11 showing a concentration of 28.20, 2.59 and 23.88 µg/L, respectively (Tables 1-3). Benzo[a]pyrene has been chosen as a general indicator of total PAHs in a given sample. The Joint FAO/WHO Expert Committee on Food Additives has adopted a specification which requires that the concentration of benzo[a]pyrene should not exceed a limit of 10 µg/kg. This value is much below the average of 5.59, 0.02 and 0.86 µg/L obtained in water of the Gulf of Suez, Red Sea proper and Gulf of Aqaba respectively indicating low level contamination. According to studies done in the USA, in four major cities, the total PAHs in drinking water ranged between 4.7 µg/L and 600 µg/L (ATSDR 1995) as against average total concentrations of 4.33, 30.24 and 38.717 µg/L recorded in water collected from the Red Sea proper, Gulf of Aqaba and Gulf of Suez, respectively obtained in this study.

REFERENCES

Awad H (1990) Survey of some persistent polyaromatic hydrocarbons in Saudi Arabia Red Sea coastal waters. Bull Nat Inst Oceangr Fish Egypt 16: 41-50

Awad F K (2002) Characterization and determination of the environmental wastes of Suez province. PhD Thesis, Faculty of Science, Mansoura University, 157pp

ATSDR (1995) Toxicological profile for polycyclic aromatic hydrocarbons. US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, GA

Bentachen K T, Chaoui A, Budzinski H, Belloca J, Garrigues P (1997) Distribution and sources of polycyclic aromatic hydrocarbons in some Mediterranean Coastal sediment. Mar Pollut Bull 34: 298-305

Colombo J C, Pelletier E, Brochu C, Khalil M (1989) Determination of hydrocarbon sources using n-alkane and polycyclic aromatic hydrocarbons distribution indexes. Case study: Rio de La Plata Estuary, Argentina, Environ Sci Technol 23: 888-894

El Nemr A, El Sikaily A, Khaled A, Said T O, Abd-Alla A M A (2004) Determination of hydrocarbons in mussels from the Egyptian Red Sea Coast. Environ Monitor Assess 96: 251-261

El-Sikaily A, Khaled A, El Nemr A, Saíd T O, Abd-Alla A M A (2003) Polycyclic aromatic hydrocarbons and aliphatics in the coral reef skeleton of the Egyptian Red Sea Coast. Bull Environ Contamin Toxicol 71: 1252-1259

GESAMP (1993) Impacts of oil and released chemicals and wastes on the marine environment. (Joint Group Experts on the Scientific Aspects of Marine Pollution). Reports and studies 50, International Maritime Organization, London

Gogou A I, Apostolaki M, Stephanou E G (1998) Determination of organic molecular markers in marine aerosols and sediments: one step flash chromatography compound class fractionation and capillary gas chromatographic analysis. J Chromatog 799: 215–231

IARC. (1991). Monographs on evaluation of polynuclear aromatic compounds, Part 1, Chemical, environmental, and experimental data (Internal Agency for Research on Cancer), Lyon, France.

Kavouras I G, Koutrakis P, Tsapakis M, Lagoudaki E, Stephanou E G, Baer D, Oyola P (2001) Source apportionment of urban aliphatic and polyaromatic aromatic hydrocarbons (PAHs) using multivariate methods. Environ Sci Technol 35: 2288 – 2294

Mazmanidi N D, Kovaleka G I, Kotov A M, Bazhashvili T R, Diasamadizi N M, Zambakhidzi N P (1976) On the effect of petroleum products on the Black Sea hydrobiology. Mar Pollut Bull 6: 201- 208

Morcos S A (1970) The tidal currents in the southern part of Suez Canal. Gen Assoc Helsinki Finland 51: 307–316

Readman J W, Fillmann G, Tolosa I, Bartocci J, Villeneuve J P, Catinni C, Mee L D (2002) Petroleum and PAH contamination of the Black Sea. Mar Pollut Bull 44: 48-62

Tsapakisa M, Stephanoua E G, Karakassisb I (2003) Evaluation of atmospheric transport as a nonpoint source of polycyclic aromatic hydrocarbons in marine sediments of the Eastern Mediterranean. Mar Chem 80: 283 – 298

UNEP/IOC/IAEA (1991) Sampling of selected marine organisms and sample preparation for the analysis of chlorinated hydrocarbons. Reference methods for marine pollution studies no. 12, revision 2. (United Nation Environment Program/International Oceanographic Comitte/International Atomic Energy Agency) Nairobi: United Nations Environment Program 17

Wang Z, Fingas M, Shu Y Y, Sigouin L, Landriault M, Lambert P, Turpin R, Campagna P, Mullin J (1999) Quantitative characterization of PAHs in burn residue and soot samples and differentiation of pyrogenic PAHs from petrogenic PAHs—the 1994 mobile burn study. Environ Sci Technol 33: 3100 – 3109