ISSN 1110-0354
Bull. Nat, Inst. Of Oceanogr. & Fish., A.R.E., 2003. Vol, (29): 355 - 376

PAHS AND FAECAL STEROLS IN SEWAGE POLLUTED MARINE ENVIRONMENT ALONG THE EASTERN RED SEA COAST, SOUTH OF JEDDAH, SAUDI ARABIA

BY

*GUL R. NIAZ AND MOHAMED A. El SAYED**
**Faculty of Marine Science, King Abdulaziz University, PO Box 80207, Jeddah 21589 Saudi Arabia.*

Key words: PAHs, Faecal sterols, tracer, Sewage, Coastal area, Red Sea

ABSTRACT

Sediments and water samples, taken near a sewage discharge point on the Eastern Red Sea coast south of Jeddah, were analyzed for faecal sterols cholesterol, coprostanol and cholestanol content and PAHs. PAHs ranged from 0.7 to 18.7 $\mu g\ l^{-1}$ in water and 0.5 to 11.5 $\mu g\ g^{-1}$ in sediments. The concentration of coprostanol in water showed a minimum of 3.6 $\mu g\ l^{-1}$ and a maximum of 27.6 $\mu g\ l^{-1}$, while in sediments it was significantly high reaching 1200 $\mu g\ g^{-1}$ at the discharge point. Cholesterol and cholestanol were also found in appreciable concentrations particularly close to the discharge point. The behavior of sterols in water was found to be conservative and the ratios of coprostanol and cholestanol to cholesterol were constant in water and sediments. Results indicate that the complete mineralization of cholesterol is very low. The value of r^* ($5\beta/5\beta + 5\alpha$) was always higher than 0.7 indicating a definite and positive sewage contamination infecting almost the whole study area.

INTRODUCTION

The elevated population density and the rapid rate of population growth are behind the increase of anthropogenically driven changes in the coastal area where most of the land based pollution sources are situated. An estimated 0.7 billion tons of sewage sludge is generated annually in the sewage treatment plants worldwide, where 12-16 million tons per annum are dumped on to the surface water at the ocean dump sites every year (Takada et al-1994). The detection of sewage pollution in the environment is therefore of considerable importance for health, aesthetic and ecological reasons.

Coprostanol (5β-cholestan-3β-ol, (Fig. 1), a mammalian metabolite of cholesterol, is a faecal sterol that has been shown to be a reliable marker of sewage pollution (Marvin et al., 2001). Concentrations in excess of 0.1 μg g^{-1} in sediments indicate sewage pollution (Hatcher and McGillivary, 1979). It is a remnant contaminant; its concentration is unaffected by high temperature, by various treatments as chlorination or aeration of overlying waters and persist in anoxic sediments (Venkastesan and Kaplan-1990). It is a specific indicator and its presence in wastewater uniquely confirms sewage contamination; the human waste contains mainly coprostanol as the major sterol (Leeming et al-1996). Concentration of coprostanol in treated sewage ranges between 30 and 50 μg $^{l-1}$ and from 1400 to 7900 μg g^{-1} in sewage sludge (Walker et al., 1982). The human excretion of coprostanol ranges between 82 and 1272 mg per day per capita (Mitchel and Diver, 1969).

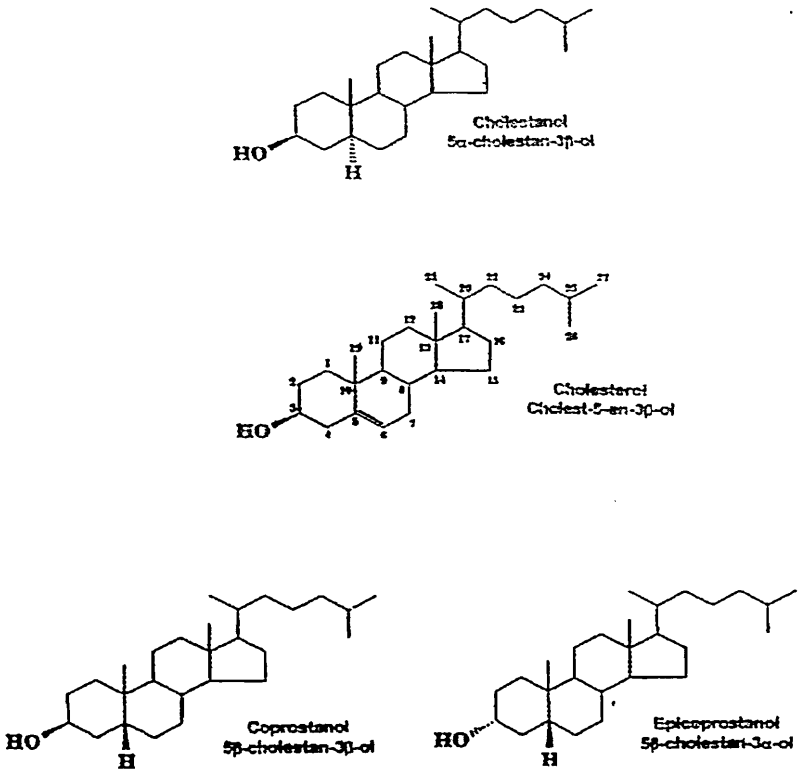

Fig.1: Structure of cholesterol and related sterol compounds

Coprostanol is produced by microbial reduction of cholesterol in the gut of humans (Kirchmer, 1971; Midtvedt and Midtvedt, 1993). Samples of bird guano from seagull rookeries in Hamilton Harbour contained minute values of coprostanol (27 ng g^{-1}, c.f Marvin *et al.*, 2001) which are approximately 1 millionth of the level found in human execretion (Murtaugh and Bunch, 1967). Related compounds such as cholesterol (cholestan 5-en-3β-ol) and dihydrocholesterol or cholestanol (5α-cholestan-3β-ol) are also used as tracer accessories (Marvin *et al.*, 2001). However, the low water solubility of these sterols and their great affinity for sediment particles make them more useful as tracers for sediments contaminated with sewage.

Beside transporting nutrients and organic matter, sewage contains offensive and potentially dangerous substances such as toxic trace elements and organic pollutants including petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAHs), particularly when municipal sewage is mixed with industrial wastes. According to the American Academy of Science the quantity of petroleum hydrocarbons (PHs) that reaches the ocean every year via sewage discharge is estimated as $3x10^5$ tons, which represents 5% of the total petroleum hydrocarbons that reaches the ocean every year (NAS, 1975). PAHs are ubiquitous in nature and are also another parameter to study the marine pollution. These PAHs may have a short and long term toxic effects on marine organization (Kennicut and Sweet-1992) and some of them are known to be active carcinogens (Grover, 1973). Therefore the study of the PAHs has also been a point of interest for the marine environmentalists. The anthropogenic origin of PAHs has led to interest in their distribution and fate in the environment.

The City of Jeddah has a vast network to collect urban wastes. The collected sewage is treated in several Sewage Treatment Stations (STS), however, due to the rapid expansion of the city and its population, the treatment capacity of the STS is insufficient and great part of the raw sewage is dumped in the coastal area, creating a dramatic environmental situations as observed in the Southern Corniche area (El Sayed, 2002&2003a), in Al Arbaeen Lagoon (El Rayis, et al., 1982, Basaham, 1998) and in Al Shabab Lagoon (El Sayed 2003b).

The present study aims at determining the levels of PAHs and faecal sterols in water and sediments of the coastal area south of Jeddah and detecting the extent of dispersion of the sewage dumped to appreciate the geographic extension of the problem and to provide a basis on which future monitoring of the pollutants or assessment of the state of environment in this area can be based.

STUDY AREA

The coastal area under investigation lies between 21° 16' and 21° 22' N and extends approximately 10 km south of Jeddah (Fig. 2 a&b). The area is divided into two zones: (i) a coastal narrow strip extending along the entire length of the area and lies between the fringing reef and the coastline, the width and depth of the area are variable but are rarely greater than 500 and 1-2 m respectively; (ii) a lagoon type basin in which evacuation and dilution of the effluent water take

place. The lagoon receives the effluent of a sewage treatment station which discharges more than 100,000 m^3 of treated and raw sewage (detailed composition of the effluent is given in El Sayed, 2002 & 2003a). The lagoon is bordered by natural and artificial barriers that limit water circulation and exchange with the open sea.

MATERIALS AND METHODS

Two field visits were organized for sample collection from the area where dilution and dispersion of the effluent were expected to take place. The first sampling was undertaken along the coastal strip where ten sediment and water samples were collected from 10 stations selected at almost regular intervals to represent the area including one sample from the effluent (Fig. 2a). During the second sampling trip 17 stations were selected in the basin in which the effluent is discharged[1] (Fig. 2b). Water samples for the EOM were collected in 2.5 liter amber glass bottles. Glass vials were prepared according to the recommendations given by Aminot and Chaussepied (1983). Sediment samples were manually collected from shallow water (< 1.5m) using a plastic scope and in deeper water samples were collected using a Petersen grab sampler. Sediment samples were placed in wide neck glass containers and stored in iceboxes until taken to the main laboratory where water samples were preserved in refrigerator until further processing and separate portions of sediment (~ 50 g) were freeze-dried for chemical analysis.

[1] Only 12 samples were analyzed for their sterol content

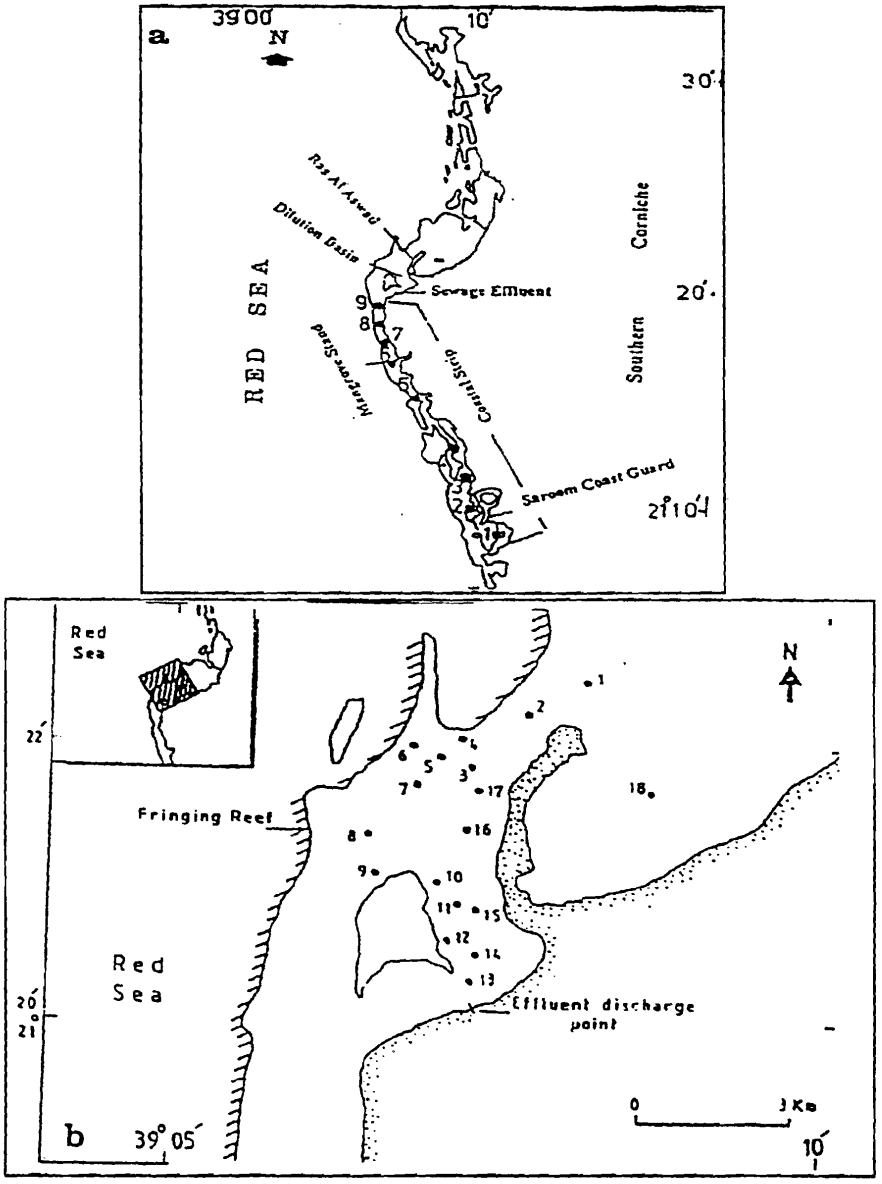

Fig. 2: Study area and sampling stations:

a- Coastal strip ; b- Dilution basin

Extractable organic matter EOM, polyaromatic hydrocarbons PAHs and sterols.

Freeze-dried sediment samples (ca. 35 g) were soxhlet extracted for 6 hours using a chloroform/methanol mixture (2:1 v/v). Solvent was then evaporated under vacuum on a rotary evaporator and the residue further dried under a stream of nitrogen. The extractable organic matter (EOM) was weighed on a microbalance and termed as total extractable organic matter (Guzzella and Poalis, 1994). The dry extract was then dissolved in minimal quantity of chloroform and elemental sulfur was removed from the extracts using activated copper. The extractwas saponified with 0.5 N methanolic KOH, the non-saponifiable fraction was isolated by extraction with hexane four times. The hexane extract was dried (Jeng & Han, 1994) and subjected to column chromatography on silica (top) and alumina (bottom) so as to separate the hydrocarbons from the sterols. The column was eluted with gradual increase in polarity of the eluent. The following four eluents were used; (i) hexane; (ii) 10% hexane - 90% chloroform; (iii) 50% hexane - 50% chloroform; (iv) chloroform. The first fraction contained aliphatic hydrocarbons, the second fraction contained polyaromatic hydrocarbons (PAHs), the third fraction carried some of the derivatives of PAHs while the forth fraction contained the sterols. All the fractions were evaporated on a rotary evaporator and dried in a stream of nitrogen. After reconstitution of the second fraction in 50 ml of hexane the PAHs were determined measuring their fluorescence intensity (excitation 310 nm and emission 360 nm) (Law and Winnet, 1992) using a UV-spectrofluorometer (Schimadzu RF-5000). Standardization and quantification were done with respect to chrysene.

The last fractions from the chromatography column containing the sterols were also evaporated to dryness and converted to their corresponding trimethylsilyl ethers by treatment with bis-trimethylsilyl trifluoroacetamide BSTFA at 80 °C for 60 min. (Green and Nichols, 1995). The trimethylsilyl derivative was repeatedly evaporated with dichloromethane until free of BSTFA. Samples were analyzed with an internal standard to aid quantification. The final product was analyzed by gas chromatography using GC-Shimadzu 17A using a capillary column 25 m long and 0.3 mm i.d. (Chromatopac CR 7A). The temperature programme was designed in two steps; initially 40 °C to 250 °C at 25 °C min^{-1} and then 250 °C to 300 °C at 5 °C min^{-1}. All the solvents used were HPLC grade. Identification of components was made by co-injection of the samples with authentic standard (SIGMA).

Water extractable organic matter was determined by extracting exactly 2 l of the unfiltered water with 2x50 ml dichloromethane. The organic extract was reduced to few milliliters in a rotary evaporator. The concentrated extract was transferred to a pre-weighed vial and evaporated to dryness using a stream of nitrogen. The vial was reweighed and the weight of the EOM was calculated. For the determination of PAHs and sterols, water

samples, ~2 l, were extracted with 2x50 ml of 50/50 n-hexane and chloroform. The extract was dried over anhydrous sodium sulfate and the solvent was evaporated using a rotary evaporator at ~40 °C. The residue was further dried under a stream of nitrogen and weighed exactly. The analytical protocol for the separation and quantification of PAHs and sterols was identical to that used for sediments.

RESULTS

In the coastal strip area, EOM in the sediments ranged from 6.4 to 18.5 mg g^{-1} whereas in the water range was found to vary between 1.1 and 12.5 mg l^{-1} (Table 1). The average concentration was found to be 10.6 mg g^{-1} in the sediments and 3.3 mg l^{-1} in water. In the sediments, EOM was highest at stations 1C and 3C (18.5 and 22.3 mg g^{-1} respectively). The high concentration at station 1C is most likely due to the organic rich solid load of the effluent while the high concentration recorded at station 3C is seemingly the result of enhanced primary productivity in the area as indicated by the massive development of algae. Amongst the water samples the highest concentration of EOM was observed at station 5C (12.5 mg l^{-1}) that may be attributed to the high participation of natural organic production due to the enhancement of primary productivity by the excess of nitrogen and phosphorus discharge.

Table 1 : Concentrations of EOM and PAHs in sediments and water of the coastal strip.

Station №.	Sediment		Water	
	EOM mg g^{-1}	PAHs µg g^{-1}	EOM mg l^{-1}	PAHs µg l^{-1}
1C*	18.5	11.5	9.3	18.7
2C	8.0	0.5	--	--
3C	22.3	0.6	--	--
4C	9.3	3.5	3.7	3.6
5C	9.6	0.6	12.6	4.2
6C	8.4	3.0	2.3	5.2
7C	9.7	2.6	2.1	4.6
8C	--	--	--	--
9C	8.4	2.5	2.4	3.7
10C	6.4	2.6	1.2	4.2

*** Discharge point (not considered in average calculation given in the text)**

In the sediments of the dilution basin, EOM ranged between 4.8 and 16.0 mg g^{-1} averaging 7.3 mg g^{-1} whereas in water this range was found to be distinctly lower, 1.0 to 3.2 mg l^{-1} with an average of 2.0 mg l^{-1} (Table 2). The gist of an overall picture of the sediment samples indicated in general a greater content of EOM in coastal strip area as compared to the dilution basin area. The water samples also followed a somewhat similar pattern. It has been shown (El Sayed, 2002) that the potential organic production due to complete assimilation of the phosphorus and nitrogen load of the sewage effluent is about 21 tons representing three times its actual organic load. About one third of potential organic matter is formed in the dilution basin while 12 tons are exported to the adjacent coastal area. It is, therefore not surprising that the coastal strip area is richer in organic matter than the dilution basin. Moreover, due to its hydrophobic nature, most of the EOM in water is associated with the suspended particulate matter; therefore its concentration will depend on the concentration of particles in suspension and their nature. In sediments, particle nature and size are the determining factors in the control of sedimentary organic carbon. Generally, muddy sediments contain higher concentration of organic matter.

Along the coastal strip concentration of PAHs in sediments ranged from 0.5 to 11.5 ug g^{-1} whereas in water it was found to be from 3.6 to 18.7 μg l^{-1} (Table 1). The highest concentration was found at station 1C, at the sewage out-fall, both in water and sediment. Concentration declined rapidly away from the effluent. In the sediments of the dilution basin, highest concentration was found at station 11D and the lowest at station 14D (Table 2). The geographic distribution does not seem to have a particular pattern. In water, concentrations of PAHs ranged from 1.1 to 9.0 μg g^{-1}. PAHs were not detectable in samples ID, 2D and 4D as these sampling stations were farthest from the source point.

Although an amount of PAHs in excess of few micro grams is considered as pollution, the average concentration in water and sediments was found to be, slightly higher than the standard set for the pollution but still not exorbitantly high. Very high concentrations of PAHs in the surface water have been reported by various groups of workers, while investigating the intensity of pollution due to oil spill or leakage (Gundlach et al., 1983). Sediments near the Severn Estuary were found to contain about 6000 μg g^{-1} of PAH (Thompson and Eglington, 1976), while the sediments along the coast of Arthur Harbor contained PAHs with a range of 9273 – 50900μg g^{-1} (Kennicutt and Sweet, 1996). PAHs concentration in our study area is so small that it can be attributed to the natural decay or the biodegradation of constituents of the sewage effluent. The results suggest that the degree of pollution by PAH was not of severe intensity.

Table 2 : Concentrations of EOM and PAHs in sediments and water of the dilution basin.

Station №.	Sediment		Water	
	EOM mg g^{-1}	PAHs μg g^{-1}	EOM mg l^{-1}	PAHs μg l^{-1}
1D	4.8	3.5	1.7	5.2
2D	5.8	2.1	1.2	7.2
3D	4.4	7.6	1.1	6.0
4D	5.1	5.2	1.1	0.7
5D	4.3	6.3	1.2	4.5
6D	6.3	2.2	1.0	2.0
7D	3.3	4.1	1.6	3.7
8D	16.1	4.0	1.5	6.2
9D	4.2	7.7	1.2	8.0
10D	6.6	2.2	2.2	8.1
11D	6.9	8.3	3.1	9.0
12D	5.7	--	2.8	8.7
13D	8.5	6.8	--	--
14D	7.6	1.3	2.8	5.0
15D	7.0	4.6	3.2	1.1
16D	7.6	9.0	2.9	--
17D	4.1	3.9	--	--

Sterols

Along the coastal strip area, the range of the faecal sterol coprostanol in water was found to vary between 2.6 and 27.3 $\mu g\ l^{-1}$ with an average of 9.6 $\mu g\ l^{-1}$ (Table 3) while cholesterol varied between 2.8 to 21.56 $\mu g\ l^{-1}$. Surprisingly, the highest concentration was recorded at station 5C. Cholestanol had generally lower concentrations averaging 1.6 $\mu g\ l^{-1}$ with a maximum concentration (6.7 $\mu g\ l^{-1}$) measured at station 1C. Sediment showed much higher concentration compared to water. Coprostanol was found to range between 67 and 1200 $\mu g\ g^{-1}$ with an average of 484 $\mu g\ g^{-1}$. Cholesterol was generally found in lower concentration compared to coprostanol. Concentrations varied between 37 and 1050 $\mu g\ g^{-1}$ with the highest concentration measured at the effluent. Cholestanol also showed a wide range of concentrations. Is minimum concentration (33 $\mu g\ g^{-1}$) was measured at station 2C, while the highest concentration was recorded at station 5C (185 $\mu g\ g^{-1}$); the average concentration in the sediments was 125 $\mu g\ g^{-1}$.

In the dilution basin the sterols were not detected or found in comparatively low concentration. Faecal sterols were not detected in five out of twelve stations (Table 4). These stations are located far to the north of the discharge point and over the general surface current direction (N-S) with respect to the location of the discharge point. These stations have been shown to be almost free from the influence of the effluent discharge (El Sayed, 2002). In water, coprostanol ranged from 7.5 to 37.5 ug l^{-1} with an average of 15.9 ug l^{-1}; whereas cholestanol ranged from 2 to 13.2 ug l^{-1} (Table 4). It has been found that 85-95% of coprostanol in sewage effluents is associated with particulate matter (Venkatesan and Kaplan, 1990). The sediment samples contained much higher concentrations than water. Coprostanol varied between a minimum of 67 $\mu g\ g^{-1}$ at station 6D and maximum of 827 $\mu g\ g^{-1}$ at station 13D. These values are similar to the concentrations measured in coastal areas suffering sewage dumping in big cities of the world; for example in Cheasepeak Bay, Norfolk, coprostanol was found to be 1600 $\mu g\ g^{-1}$ from the sewage source (Brown and Wade, 1984), whereas in Hamilton Harbour in Canada and Sanagawa river in Japan, the faecal sterol was estimated to be 934 and 867 $\mu g\ g^{-1}$ respectively indicating a high sewage contamination into the sea (Bachtiar et al. 1996, Takada and Eagenhouse, 1997). The delineation of coprostanol indicates that the concentration decreases as one moves away from the source. Cholesterol and cholestanol were also found in higher concentrations in sediments but are generally lower than coprostanol (Table 4).

Table 3 : Concentrations of cholesterol, coprostanol and cholestanol and the r* value in sediments and water of the coastal strip.

Station №	Sediments			r*	Water			r*
	Cholesterol	Coprostanol	Cholestanol		Cholesterol	Coprostanol	Cholestanol	
	$\mu g\ g^{-1}$				$\mu g\ l^{-1}$			
1C+	1050	1200	110	0.91	19.54	22.4	6.7	0.78
2C	97	138	33	0.80	n.d.	n.d.	n.d.	--
3C	320	396	116	0.77	n.d.	n.d.	n.d.	--
4C	870	960	172	0.93	4.80	5.52	1.06	0.83
5C	204	470	185	0.71	21.56	27.32	4.16	0.86
6C	366	410	150	0.73	10.63	10.65	0.67	0.68
7C	37	67	43	0.60	2.80	2.60	0.59	0.81
8C	n.d.	n.d.	n.d.	--	n.d.	n.d.	n.d.	--
9C	355	476	132	0.78	5.98	4.27	1.13	0.79
10C	664	732	183	0.80	6.40	4.47	1.91	0.73

+ Discharge point n.d.not detected $r^* = 5\beta / 5\beta + 5\alpha$

Cholesterol= Cholest-5-en-3-β-ol, Coprostanol = 5- β- cholestan-3- β-ol, Cholestanol = 5- α - cholestan-3- β-o

Table 4 : Concentrations of cholesterol, coprostanol and cholestanol and the r* value in sediments and water of the dilution basin..

Station №	Sediments			r*	Water			r*
	Cholesterol	Coprostanol	Cholestanol		Cholesterol	Coprostanol	Cholestanol	
	$\mu g\ g^{-1}$				$\mu g\ l^{-1}$			
1D	n.d.	n.d.	n.d.	--	n.d.	n.d.	n.d.	--
2D	n.d.	n.d.	n.d.	--	n.d.	n.d.	n.d.	--
4D	n.d.	n.d.	n.d.	--	n.d.	n.d.	n.d.	--
6D	71	67	31	0.68	26.3	27.6	13.2	0.67
8D	185	196	43	0.82	16.0	18.5	5.8	0.75
10D	208	306	69	0.81	22.1	20.5	6.8	0.75
11D	n.d.	n.d.	n.d.	--	25	24.1	9.6	0.71
12D	n.d.	n.d.	n.d.	--	n.d.	n.d.	n.d.	--
13D	460	827	143	0.85	27.3	37.5	10.2	0.81
14D	236	373	115	0.76	21.8	23.7	10.1	0.7
15D	196	208	69	0.75	6.9	7.5	2.0	0.78
16D	150	168	48	0.9	n.d.	n.d.	n.d.	--

n.d. not detected $r^* = 5\beta / 5\beta + 5\alpha$

Cholesterol= Cholest-5-en-3-β-ol, Coprostanol = 5- β- cholestan-3- β-ol, Cholestanol = 5- α - cholestan-3- β-o

DISCUSSTION

Sediment in general contained more PAHs and sterols compared to water samples in the whole study area. These hydrophobic nonpolar organic molecules have very low water solubility and tend to accumulate on the surface of sediment particles and, therefore, are expected to be mainly present in sediments.

The distribution between water and sediment of a particular compound or ion is represented by the partition coefficient K_p which is the ratio between the concentration in the sediment ($\mu g\ kg^{-1}$) and in water ($\mu g\ l^{-1}$). In the dilution basin the average K_p for PAHs was found to be 2×10^3 while in the coastal strip it was $\sim 0.6 \times 10^3$ (Table 4). This difference may result from the sediment composition which is lower in carbonate and higher in organic matter in the dilution basin and/or the nature of the organic matter itself. Table 5 shows the contribution of PAHs and sterols to the extractable organic matter in sediments and water in the dilution basin and the coastal strip. It appears that while contribution of PAHs is higher in sediments and water of the dilution basin than the other area, the participation of cholesterol, coprostanol and cholestanol to the sedimentary EOM pool is invariably lower in the DB than in the coastal strip area. This trend is reversed in water. This situation appears to agree with the distribution of these sterols between sediments and water (K_p) which is generally higher in the coastal strip area than in the area of the dilution basin; the latter has fairly stable values for the three sterols (Table 4).

Sterols in the surface water appear not to suffer any significant bacterial degradation during their transit in the dilution basin as indicated by the linear relationship of cholesterol, coprostanol and cholestanol with salinity (Fig. 3). This property indicates a conservative behavior and supports the use of faecal sterols as sewage tracers particularly coprostanol due to its presence in relatively higher concentrations. The anaerobic microbial transformation of cholesterol into 5α- and 5β-cholestan-3β-ol has been studied in a number of different sedimentary environments. Gaskell and Eglinton (1975) incubated labeled cholesterol in contemporary aquatic sediments and anaerobic sludge and found 5α- and 5α-[^{14}C]cholestan-3β-ol in both environments with the 5α- isomer predominating in sediments and the 5β-isomer predominating in the sludge. Toste (1976) studied the diagenesis of sterols in Mono Lake (California) and reported that cholesterol is transformed primarily into the 5β-isomer by sediment microorganisms. Using the microbial enrichment approach, Taylor et al. (1981) studied the anaerobic degradation of cholesterol and found that the transformation products represented only 25-30% of the initial incubated cholesterol and that 5α- and 5β-cholestan-3β-ol were detected in nearly equal proportions. The process appeared as nitrate limited. The conservative behavior of the three sterols indicates the

absence of significant microbial transformations in the area. The conclusion is supported by the inter-relation between the cholesterol and the 5α- and 5β-cholestan-3β-ol in both sediments and water (Fig. 4). The linear relationships indicate a constant ratio between the different components. It is also probable that transformation is taking place but at a constant rate throughout the entire area. However, it seems that if bacterial transformation was active, it is more vigorous in sediments than in water. Coprostanol to cholesterol and cholestanol ratios in sediments are twice their values in water (Table 6). When coprostanol and cholestanol were summed and correlated to cholesterol (Fig 5) a highly significant linear correlation is obtained indicating that complete mineralization of cholesterol to CO_2 is either absent or inefficient. This agrees with the observations of Taylor et al. (1981) who found in their degradation experiment that only 2-5 % of the added cholesterol was recovered as CO_2. The cholestanol and coprostanol to cholesterol ratios found in the sediments of our study area are comparable to values found in the sediments of Kaohsiung harbour and the Tan-Shui estuary (Jeng and Han, 1994).

To evaluate the contribution of coprostanol as an indicator of sewage pollution, Grimalt et al (1990) introduced the index r* (where $r^* = (5\beta/5\beta + 5\alpha)$; values higher than 0.7 are indicative of sewage pollution. In all the water and sediment samples of the coastal strip area (excepting stations 6 water ; 7 sediments) the value of r* was found to be greater than 0.7 (Table 3). Fourteen out of 16 samples have values between 0.71 and 0.93 (Table 3).

In the DB, twelve out of fourteen values of r* were found to be higher than 0.7 (Table 4). These results provide a definite and positive evidence of sewage pollution in the coastal area.

Table 5 : Average ratios of PAHs and sterols to the EOM in sediments and water ($x10^3$).

	Sediments				Water			
Area of study	PAHs	Cholesterol	Coprostanol	Cholestanol	PAHs	Cholesterol	Coprostanol	Cholestanol
Coastal Strip	0.22	42	52	14.2	2.1	2.9	2.6	0.6
Dilution Basin	0.89	27	38	9.5	3.3	10.7	11.6	4.4

Table 6 : Average distribution coefficient K_p of PAHs and sterols.

Area of study	PAHs x 10^5	Cholesterol x 10^5	Coprostanol x 10^5	Cholestanol x 10^5
Coastal Strip	0.60	0.60	0.73	1.24
Dilution Basin	2.21	0.13	0.14	0.13

Table 7 : Regression equations fitting the relationships between the three sterols.

Regression equations Sediments	r	Regression equations Water	r
Coprostanol = - 131 + 2.05 x cholesterol	0.986 $p < 0.01$	Coprostanol = - 131 x 1.12 cholesterol	0.913 $p < 0.01$
Cholestanol = 7.75 + 0.31 x cholesterol	0.908 $p < 0.01$	Cholestanol = - 1.33 x 0.47 cholesterol	0.913 $p < 0.01$
Coprostanol = - 112 + 5.55 x cholestanol	0.925 $p < 0.01$	Coprostanol = 5.89 + 2.05 x cholestanol	0.823 $p < 0.01$

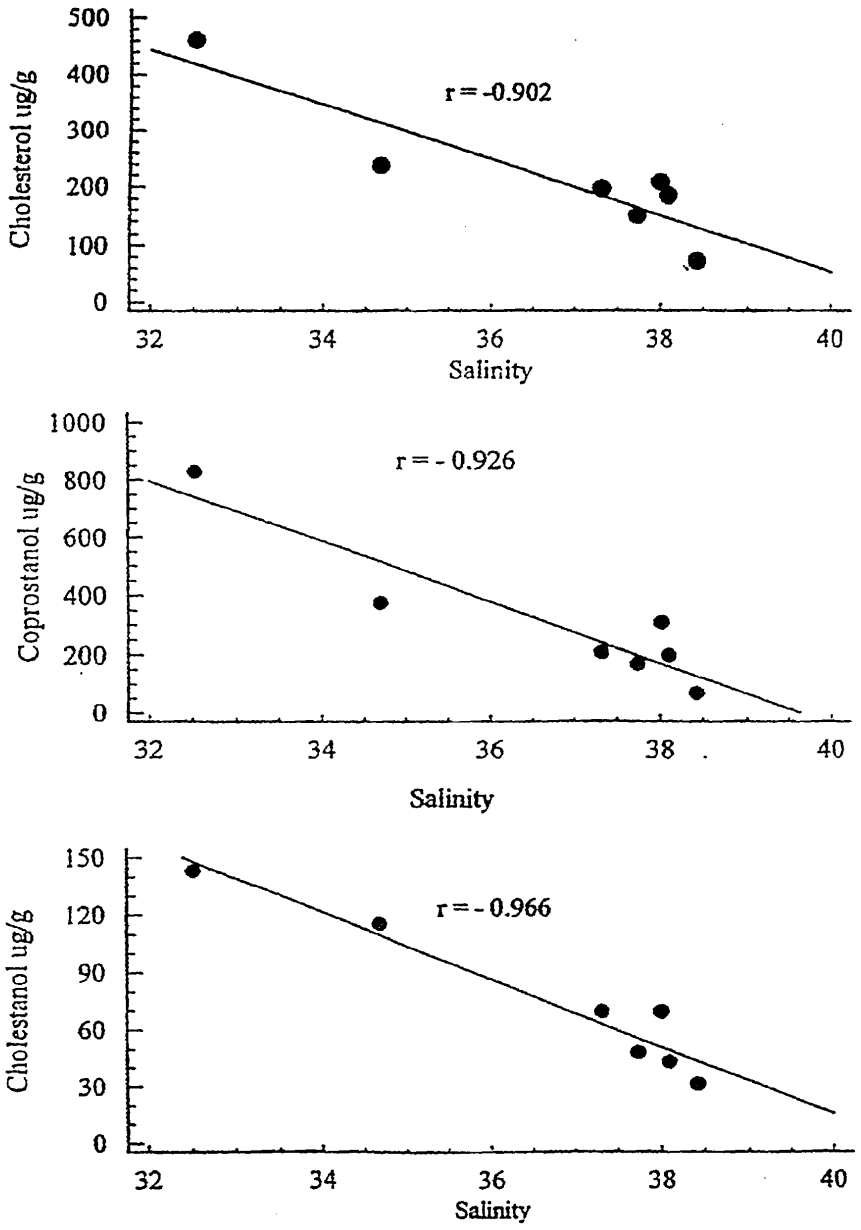

Fig. 3 : Relationship between cholesterol, coprostanol and cholestanol and salinity in the dilution basin.

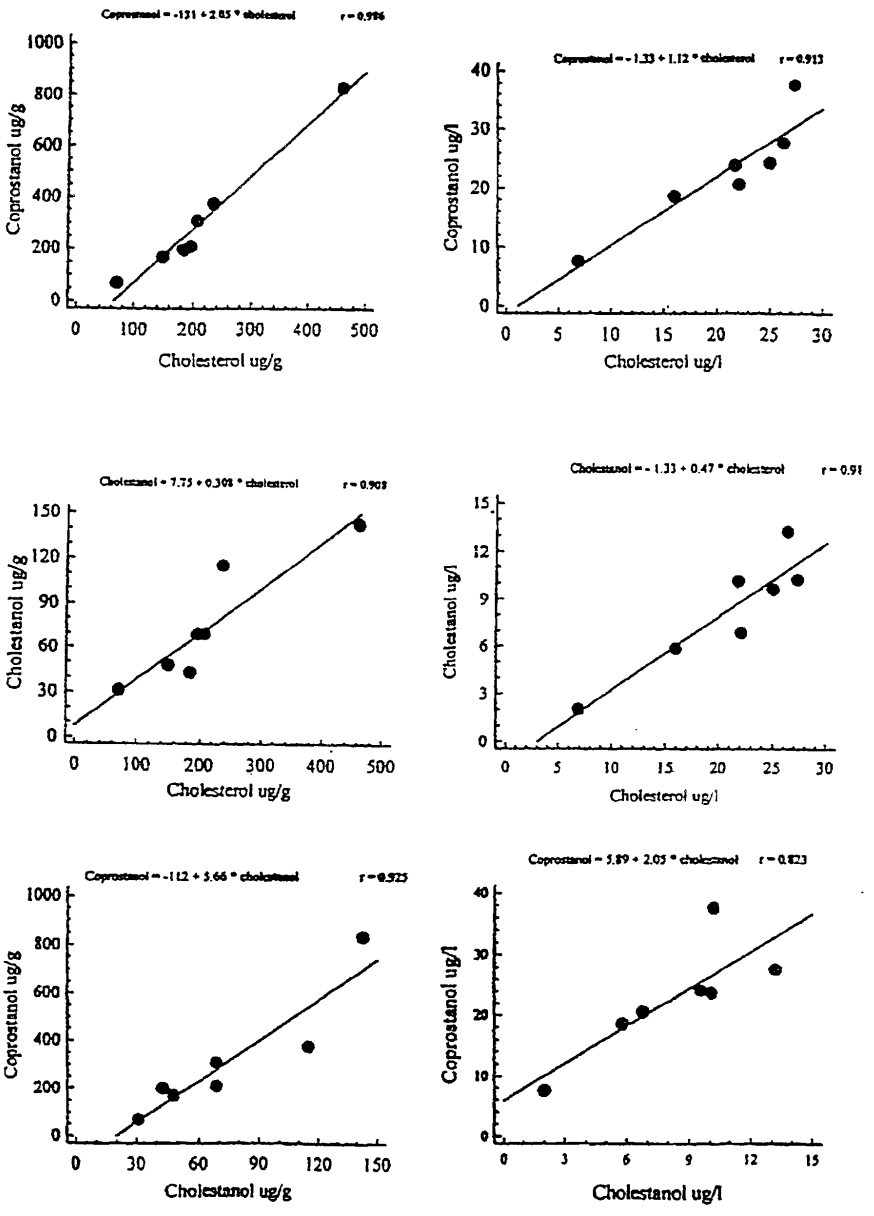

Fig.4 : Interrelationship between the sterol components in sediments and water of the dilution basin

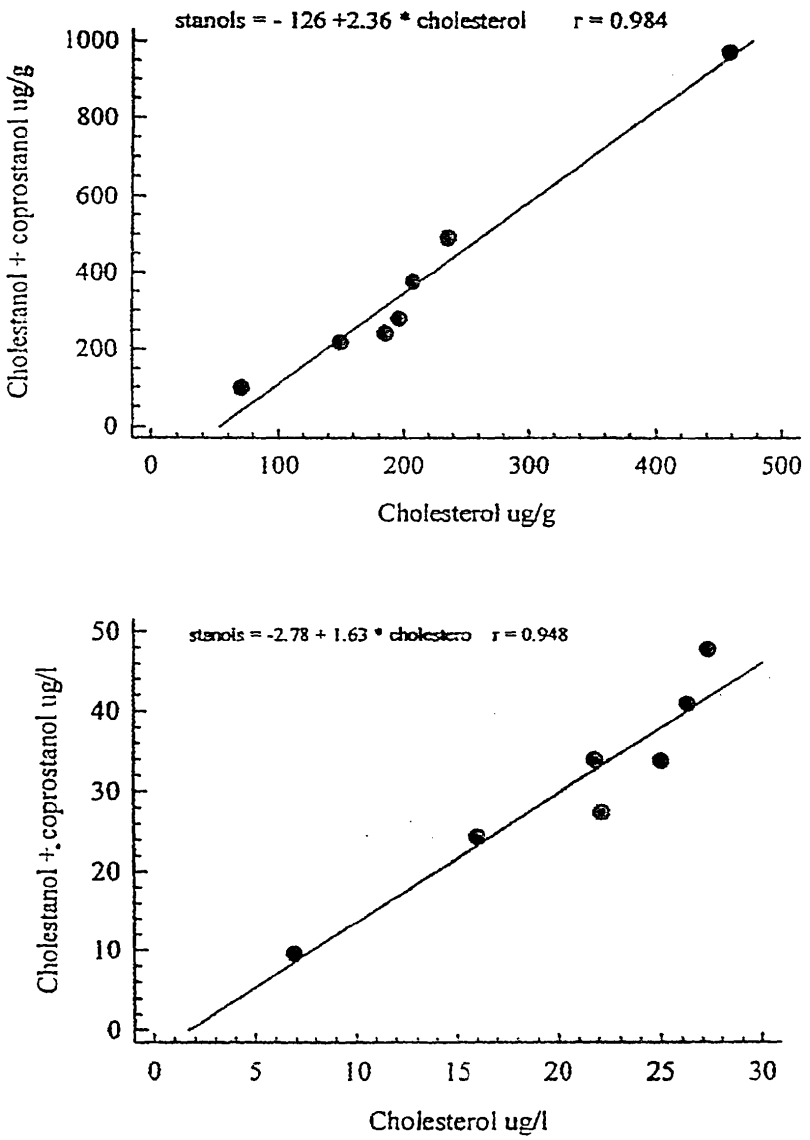

Fig. 5 : Relationship of the sum coprostanol and cholesterol on cholesterol in sediments and water of the dilution basin

CONCLUSIONS

The impact of sewage discharge on the coastal area south of Jeddah, Eastern Red Sea, was traced using PAHs and faecal sterols cholesterol, coprostanol and cholestanol. Results indicate that the impact of the effluent is detectable several kilometers south of the discharge due to the prevailing N-S surface water current. Concentrations of PAHs were relatively low but faecal sterols, particularly coprostanol, were found in appreciable concentrations. Highest concentrations were found near the discharge point and concentrations were generally higher in sediments than in water. According to the index proposed by Grimalt et al (1990), all the samples indicated positive and heavy sewage pollution, as the values of r* were generally greater than 0.7.

The faecal sterols were linearly and negatively correlated to salinity indicating that the sewage effluent was the main source of the sterols and that they behave conservatively. In the sediments and water the ratios of coprostanol and cholestanol to cholesterol were constant over the whole area indicating either a conservative behaviour or a constant transformation rate.

Acknowledgement

This research was supported by the Scientific Research Council, King Abdulaziz University, Grant No. 12/17/S.S.

REFERENCES

Aminot, A. and Chaussepied, M. 1983. Manuel des analyses chimiques en Mlieu Marin. CNEXO- Brest, pp. 203-210.

Bachtiar, T., Coakley, J.B., and Risk, M. J., 1996. Tracing sewage contaminated sediments in sewage in Hamilton Harbour, using selected geochemical indicator, Sci. of Total Environ., 179: 3-16.

Basaham, A. S. 1998. Distribution and behaviour of some heavy metals in the surface sediments of Al-Arbaeen lagoon, Jeddah, Red Sea coast. J.K.A.U., Earth Sci. 10: 59-71

Brown, R.C., and Wade, T.L., 1984. Sedimentary coprostanol and hydrocarbon distribution adjacent to sewage outfall, Water Res., 18: 621-622.

El Rayis, O. A. 1990. Distribution of some heavy metals in sediments, water and different trophic levels from Jeddah coast, Red Sea. J. K. A. U., Earth Sci. 3: 33-45.

El Sayed, M. A. 2002. Nitrogen and phosphorus in the effluent of a sewage treatment station on the eastern Red Sea coast: daily cycle, flux and impact on the coastal area. Internat. J. Environm. Stud., 59: 73-94.

El Sayed, M. A. 2003a. Factors controlling the geochemistry of organic carbon and trace elements in a heavily sewage polluted coastal environment. JKAU, Mar. Sci. (in press).

El Sayed, M. A. 2003b. Distribution and behavior of the dissolved species of nitrogen and phosphorus in two coastal Red Sea lagoons receiving domestic sewage. JKAU, Mar. Sci. (in press).

Gaskell, S. J. and Eglinton, G. 1975. Rapid hydrogenation of sterols in a contemporary lacustrine sediment. Nature, 254: 209-211.

Green, G. and Nichols, P. D., 1995. Hydrocarbons and sterols in marine sediments and soil at Davis station, Antarctica, a survey for human derived contaminants. Antarctic Sci. 7: 137-144.

Grimalt, J.O., Fernandez, P., Bayonna, J.M., and Albaiges, J. 1990. Assessment of faecal sterols and ketones as indicator of of urban sewage inputs to coastal waters. Environ. Sci. Technol. 24: 357-363.

Gundlach, E. R.; Boehm, P. D.; Marchand, M.; Atlas, R. M.; Ward, D. M. and Wolfe, D. A. 1983. The fate of Amoco Cadiz oil. Science, 221: 122-129.

Guzzella, L. and Poalis, A., 1994. Polycyclic aromatic hydrocarbons in the sediments of the Adriatic Sea, Mar. Poll: Bull. , 28: 159-165.

Hatcher, J. P. and McGillivary, P. A. 1979. Sewage contamination in the New York Bight: Coprostanol as indicator. Envirn. Sci. Technol. 13: 1225-1229.

Jeng, W-L. and Han, B-C. 1994. Sedimentary coprostanol in Kaohsiung harbour and the Tan-Shui estuary, Taiwan. Mar. Pollut. Bull. 28: 494-499.

Kennicutt, M.C., McDonald, T.J., Denoux, G.J., and McDonald, S.J., 1992. Hydrocarbon Contamination of Arctic Peninsula, Mar. Poll. Bull., 24: 499-506.

Kennicutt, M.C., and Sweet,S.T., 1992. Hydrocarbon contamination on the Antarctic Peninsula, the Bahia Paraiso, two years after the spill, Mar. Poll. Bull., 25, 303-306.

Law, J. B. and Whinnet, J. A. 1992. Polycyclic aromatic hydrocarbons in muscle tissues of Harbour Porpoise from UK waters. Mar. Poll. Bul. 11: 550-553.

Leeming, R., Baal. A, Ashbolt, N., and Nichols, P., 1996. Using faecal sterols from human and animals to distinguish faecal pollution in receiving waters, Water Res., 30: 2893-2900.

Marvin, C.; Coakley, J.; Mayer, T.; Brown, M. and Thiessen, L., 2001. Application of faecal sterol ratios in sediments and effluents as source tracers. Water Qual. Res. J. Canada, 36: 781-792.

Midtvedt, A. and Midtvedt, T. 1993. Conversion of cholesterol to coprostanol by the intestinal microflora during first two years of human life. J. Paediat. Gastroenter. Nutr. 17: 161-168.

Murtaugh, J. J. and Bunch, R. L. 1967. Sterols as a measure of faecal pollution. J. Water Pollut. Control Fed. 39: 404-409.

NAS, 1975. Petroleum hydrocarbons in the marine environment. National Academy of Science. Washington D.C.

Nishimura, M., 1982. 5β-isomers of stanols and stanones as potential markers of sedimentary organic quality and depositional paleoenvironments. Geochim. Cosmochim. Acta., 46: 423-432.

Sherwin, M.R., Van-Vleet, E.S., Fossato, U.V., and Dolci, F., 1993: Coprostanol in lagoonal sediments and mussels of Venice, Italy, Mar. Poll. Bull., 26: 501-507.

Takada, H., Farrington, J.W., Bothner. M., Johnson, C.G., and Tripps. B.W., 1994: Transprot of sludge derived organic pollutants to deep sea sediments at deep water dump sites, Environ. Sci. andTechnol. 28: 1062-1072.

Takada, H. and Eagenhouse, R., 1997: Molecular markers of anthropogenic wastes, their use in determining the source transport pathways and fate of waste in aquatic environments. Encuclopedia of Environm. And Analysis remediation, pp. 13-212.

Taylor, C. D.; Smith, S. O. and Gagosian, R. B. 1981. Use of microbial enrichments for the study of the anaerobic degradation of cholesterol. Geochim. Cosmochim. Acta, 45: 2161-2168.

Thompson, S., and Eglinton, G., (1976), The presence of polluted hydrocarbons in estuarian epipelic diatom. Populations., Eust. Coastal Mar. Sci., 4: 417-425.

Toste, A. T. 1976. The sterol molecule: Its analysis and utility as a chemotaxonomic marker and a fine geochemical probe into the Earth's past. Ph.D. Thesis, University of California, Berkeley.

Venkatesan, M.J. and Kaplan, M., (1990), Sedimentary coprostanol as an index of sewage addition in Santa Monical Basin, Southern California. Environ. Sci. and Technol. 24: 208-214.

Walker, R. W.; Wun, C. and Litsky, P. 1982. Coprostanol as an indicator of fecal pollution. CRC, Critical Reviews in Environment Control, 10: 91-112.