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Re-Evaluation of the Impact of Sewage Disposal on Coastal Sediments of the Southern Corniche, Jeddah, Saudi Arabia

A.S. Basaham, A.E. Rifaat, M.H. El-Mamoney and **M.A. El Sayed**

Faculty of Marine Sciences, King Abdulaziz University
P.O. Box 80207, Jeddah 21589 Saudi Arabia

Abstract. The southern corniche area of Jeddah receives through Al-Kumra effluent the equivalent of 300,000 m^3 of semi-treated sewage. Before 2001, the sewage was directly dumped from an outlet situated at about 1 m above the sea surface. Since 2001, the same volume of municipal wastewater is disposed from underwater diffuser situated at about 3 km south of the old effluent.

In order to study the environmental consequences of the dumping site transfer from a sheltered to an open sea area, the region was revisited and sediment samples were collected from the same stations sampled prior to the transfer of the effluent. Samples were analysed for their grain size distribution and their content of organic carbon, Al, Fe, Mn, Cu, Zn, Cr, Cd and Pb. Results were compared to those obtained in a previous study carried out in 1999.

The study showed that despite the very pronounced dilution effect, the impact of the effluent is measurable and extends, in situ, north and south directions along the entire study area. The impact is very pronounced in the coastal area as shown by the excessive development of algal production which extends further southward and by the destruction of the mangrove stand. Sediments are becoming enriched in heavy metals where concentrations of Al, Fe, Mn, Cu, Zn and Cr are almost doubled. The present study is the first of its kind to be carried out after the effluent transfer. The authors therefore believe that the system did not yet reach a steady state and will continue to change and develop for several years.

Introduction

The eastern coast of the Red Sea is about 1900 km long; 90% of which belongs to the Kingdom of Saudi Arabia. Since the beginning of the seventies of the twentieth Century, the Kingdom is seeing an unprecedented economic expansion that lead to a massive expansion of the urban areas of the Kingdom.

The City of Jeddah is one of the biggest Red Sea coastal agglomerations. Jeddah has grown from a small seaport town of 30,000 inhabitants and occupying just over one square kilometer in 1947; its population in the beginning of the seventies of the twentieth Century reached about 300,000 inhabitants. At present, the area of the City is more than 1200 km^2 and its population is about 2.5 millions, and is continuously expanding.

The economic expansion of the City was accompanied by growing industrial activities. More than 450 factories are implemented in the industrial area lying at the southern part of the City. These factories cover a wide variety of industrial activities, the most important of which are refineries, petrochemicals, food processing, paper mill, canning, car repair and painting, tanning, chemical and pharmaceutical, soap and cleaning products.

As a trade centre, the City is connected to the other parts of the world through a highly developed maritime transport network and its port is one of the greatest ports on the Red Sea.

However, due to rapid expansion of the City and its growing population the capacity of the sewage treatment plants is largely insufficient and great part of the raw sewage is dumped into the coastal area creating dramatic environmental situations as has been shown in the Southern Corniche area (El Sayed and Niaz, 1999), Al-Arbaeen Lagoon (El-Rayis, 1990; Basaham, 1998) and Al Shabab lagoon (El Sayed, 2002b; Turki *et al*., 2002).

An equivalent volume (~ 200,000 m^3) of entirely raw sewage is transported and dumped in a huge sewage lake at the east of the City. This sewage, may be considered as a contamination source for the underground water, before reaching the marine environment.

Al Khumra Plant is the most important sewage treatment plant in Jeddah. Its nominal treatment capacity is approximately 100,000 m^3 day^{-1}. However, it is believed that the wastewater the plant received daily is largely greater than nominal capacity and is estimated to be 200,000-300,000 m^3. It is evident that the plant dumps partially treated sewage that does not meet the environmental requirements; a fact revealed in a previous study (El Sayed and Niaz, 1999).

In the year 2000, the partially treated sewage was dumped into the coastal water south of Jeddah (Southern Corniche). Wastewater outlet was placed on the shore at about 1 m above seawater level. Sewage was dumped into a semi-enclosed coastal lagoon with an area of about 2.3 km^2 (Fig. 1 and 2). The lagoon was artificially formed by constructing a sand barrier to prevent sewage dispersion southwards forced by the prevailing wind induced surface water current. Practically, this configuration created an additional decantation tank for the almost untreated sewage dumped into the area and could be considered as part of the treatment operation. Measurements undertaken in the lagoon and along the coastal area up to 10 km south of the dumping site (El Sayed and Niaz, 1999; El Sayed, 2002a and El Sayed, 2002b) revealed that, most of the solid charge of the effluent with its associated organic and metallic pollutants was retained within the lagoon. Further, about half of the nutrients load was assimilated by the primary productivity. However, the presence of traces of sewage out of the lagoon and up to the most southern limits of the area was detected by the presence of coprostanol, a fecal sterol indicator of sewage pollution (El Sayed and Niaz, 1999). The study of El Sayed and Niaz, (1999) shed the light on important information about the composition of the effluent, the behaviour of its constituents in the receiving environment and their fate.

In the year 2001, sewage dumping pipeline was moved farther about 3 km south from the old dumping site. The new effluent is situated about 500 m from the shoreline just on the edge of the fringing reef at about 10m below the mean sea level. The new effluent is no more visible; the threat has however been increased for both the environment and the public health for the following reasons:

1. Direct dumping in open unsheltered area results in wider dispersion of the effluent and increases its threat to the reef ecosystem, mangrove and benthic communities;

2. Preliminary analyses revealed the presence of relatively high concentrations of heavy metals in the fish catch from the area, which may represent a real threat to the public health, and

3. Emanation of bad odours resulting from the degradation of the organic matter.

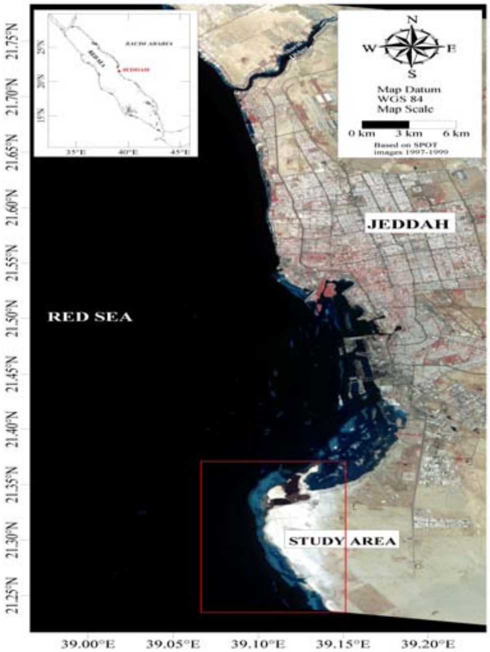

Fig. 1. Area of study.

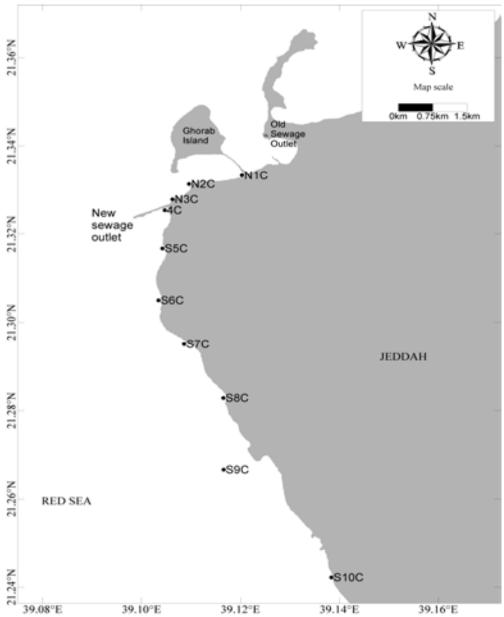

Fig. 2. Location of sediment samples.

A recent visit to the study area has shown that the threat is true and the area is experiencing a real modification evidenced by the following visual indications:

- Increasing algal development in the area between the edge of the reef and the coast particularly south of the new effluent;
- Witnessed by the dramatic degradation of the nearby mangrove stands;
- Sediments became sludgy and dark coloured indicating more reducing conditions.

The major objective of this study is to re-evaluate environmentally the impact of the new constructed effluent on the ecosystem at the vicinity of the study area. To achieve the goal, some chemical properties of the tidal flat sediments were determined and compared with data previously obtained before the transfer of the effluent.

Area of Study

The area of study (Fig. 1) lies about 25 km south of Jeddah. It extends for about 12 km between Latitudes 21.3207° N and 21.3483° N.

The study area is located at the central part of the Red Sea which is characterized by a tropical to subtropical climate. The wind is mostly north to north-northwest throughout the year round (Patzert, 1974). Waves are generated by winds and tidal action. Water temperature ranges between 25.5 and 31.0°C, but higher temperatures could be reached in the very shallow and isolated coastal areas (Edwards, 1987). The same fact applies to salinity which has an average of 39.2 but may exceed 40 psu. The horizontal water movement is the result of the combination of the wind and tidal stream actions. It has a general north-south direction in the coastal area but local conditions like bottom topography may largely influence surface water movement.

The nearshore zone, extending between the shoreline and the fringing reef, is a shallow water area of small but variable depth and width. The bottom is rocky and is composed of hard reefal limestone structures covered by a more or less thin layer of unconsolidated reefal sediments. Some land-derived materials could also be detected. In accordance with the northerly surface current, the longshore sediment transport takes place from north to south (Durgaprasada, *et al.*, 1982).

Materials and Methods

Sampling

Sediments from the coastal area were manually sampled at ten locations (Fig. 2) using a plastic scoop. Samples were placed in plastic bags and preserved in ice box until brought to the home laboratory. Subsamples were taken and air dried for grain size analysis. Subsamples for chemical and mineralogical analysis were freeze-dried. All grains greater than 2 mm (mainly shell fragments) were mechanically removed before any chemical analysis were carried.

Grain Size Analysis

Representative subsamples were analyzed for grain size analysis to determine the three major fractions, gravel, sand and mud using the standard wet sieving method (Folk, 1980).

Carbonate Determination

Carbonate content in the powdered sediments was estimated by treating a known weight of the air-dried sediment with 0.2 M HCl (1/25 W/V). Carbon dioxide evolved was measured using a calcimeter. Carbonate concentration in the sample was calculated using standard pure $CaCO_3$ (Basaham and El Sayed, 1998).

Organic Carbon Determination

Organic carbon (OC) was measured using the sulfo-chromic wet oxidation method (le Core, 1983). Powdered sediment was first treated with phosphoric acid at 110^{o}C to remove carbonate and chloride ions then organic matter was oxidized with a mixture of potassium dichromate and sulfuric acid. The excess dichromate was then back titrated with sodium thiosulfate. The quantity of the thiosulfate corresponds to a definite quantity of total organic carbon, which is then attributed to the weight of the sediment sample.

Heavy Metals in Sediments

For the determination of total heavy metals, powdered freeze-dried subsamples were digested using a nitric-hydrofluoric acid mixture in the ratio 1:1 (v/v) (Basaham and El Sayed, 1998). Digestion was carried out using a microwave digestion unit (Anton Paar Multiwave 3000). The acid was evaporated to near dryness and the residue was taken in 0.1 M HCl. Concentrations of major elements were determined using Flame Atomic Absorption Spectrophotometer AAS (Perkin Elmer Analyst 800, equipped with Zeman background correction). Cu, Pb and Cd were measured using graphite tube technique GFAA. The accuracy and precision of the results were tested by the analysis of the Canadian certified reference materials project (LKSD-4). Accuracies were within 10% of the certified values for the elements and 15% for Fe and Cr. The five replicates precisions were within 10%.

Results and Discussion

General Observations

The shore zone at the study area is relatively narrow and is bordered from the east by the Corniche Road (Fig. 1). It is covered by sand sediments. It trends E-W at its northern extremity and truncated at the location of the new sewage outlet having more or less N-S trend. The litter cover is dense and includes, remnants of construction operations, cemented blocks, flint, glass stuff, plastic, foam, wood, metal and paper cans, rubber, tires, food-stuff, metal barrels, and other anthropogenic wastes. Algal remains cover the entire front-beach zone along the study area from north to south.

The intertidal-zone is rocky and covered by a relatively thin layer of sediment and algal residues. Ghorab island (Fig. 2) is located offshore and forms a semi-enclosed lagoon. This lagoon receives the disposed sewage from the effluent before its transfer. It was considered as part of the treatment system where processes such as decantation, dispersion and dilution, oxidation of organic matter, and biochemical transformation of certain constituents took place.

However, the lagoon suffered from massive algal development and algal mats used to cover the entire lagoon (Fig. 3). According to Thukair (2003), there were 24 species of algae recorded in Ghorab lagoon during the period from January to October 2000, of which *Oscillatoria sp.* showed to be the abundant species while *Chroococcus sp.* and *Microcystis sp.* were recorded frequently. In the period from January to April 2001, 17 species were recorded and again *Oscillatoria sp.* were the most abundant species.

The blooming of algae is the result of nutrient enrichment due to sewage discharge. The drastic effect of algal blooming is the depletion of dissolved oxygen necessary to support the marine life. Figure 3 shows the SPOT images of 1997 and 1999 for the study area. In 1997 image a red patch reflecting the presence of the surface algal mats layer covering the entire Ghorab lagoon is observed. Furthermore, the shore is a dwelling area for many birds that are frequently observed on the beach.

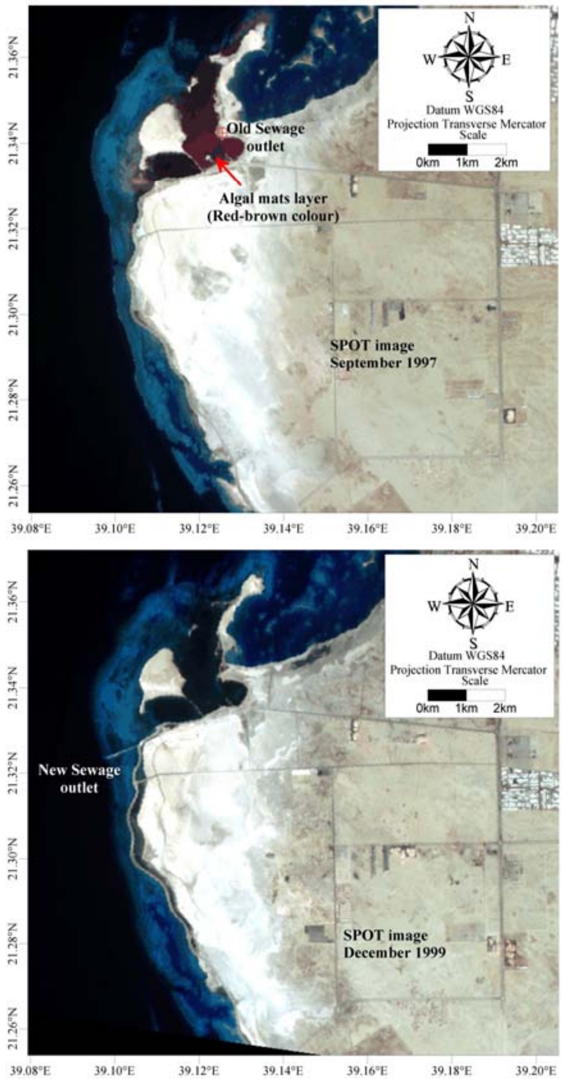

Fig. 3. Growth of algal mats in 1999 due to dumping sewage into the sea.

The sewage discharged from the effluent outlet is carried by the currents to the southern parts of the area and reached the intertidal and beach zones. The effect of sewage effluent is very remarkable on the *aviccenia marina* mangrove stand located ~10 km south of the outlet position. The mangrove stand was healthy in 2000 (Photo 1). After the start of sewage dumping through the new outlet in late 2001, the mangrove trees dramatically deteriorated most probably due to the environmental degradation that followed the transfer of the effluent (Photo 2).

Photo 1. The mangrove stand *Avicennia marina* in healthy conditions in 1998.

Photo 2. The same mangrove stand of Photo 1 after the relocated sewage outlet started dumping its effluents to the sea.

Chemical Composition of Sediments

Figures 4 to 10 show the organic carbon content and concentrations of Al, Fe, Mn, Cu, Zn and Cr in the tidal sediments sampled in 1999 and 2003. For more obvious comparison the study area is divided into two regions; the northern region that is represented by the sampling area north of the new sewage outlet and the southern region that is represented by the sampling area south of the sewage outlet (Fig. 2). The concentrations of the analyzed elements in the tidal sediment collected during 2003 are divided by the corresponding concentration in the sediments collected during 1999 at the same stations and the results are given in Table (1). In 2003, organic carbon and Zn concentrations are higher in sediments of the northern region than in the sediments of the southern region (Fig. 4). Copper shows nearly similar values in the sediments of the two regions, while the other elements show an opposite mode (Fig. 5 to 10), where they are higher in the southern region than in the northern one. The ratios calculations (Table 1) show that in the northern region (area of the old sewage discharge) the organic carbon in sediment of 2003 is significantly higher than that of 1999. The 2003/1999 ratios for Al, Fe, Mn, Cu, Zn and Cr indicate a significant lowering of the concentration of these elements since the transfer of the effluent in the year 2000.

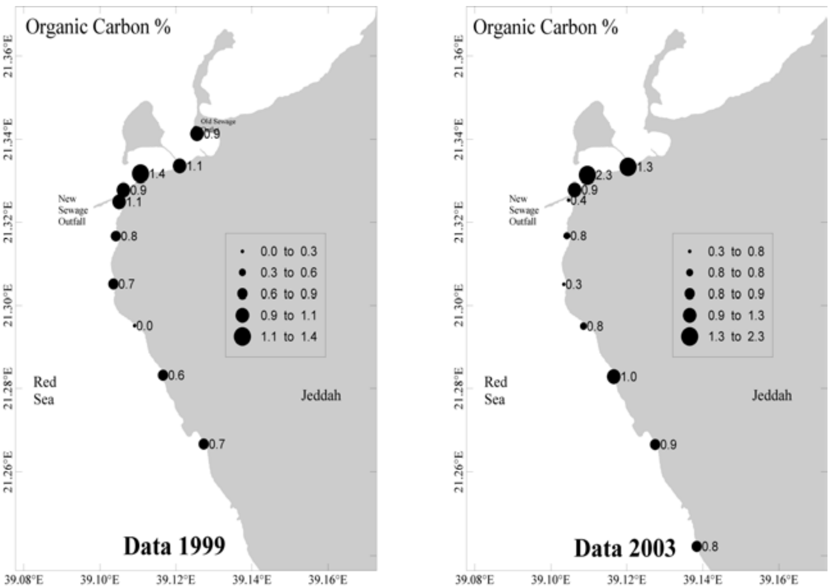

Fig. 4. Comparison of organic matter concentrations in sediment samples between the years 1999 and 2003.

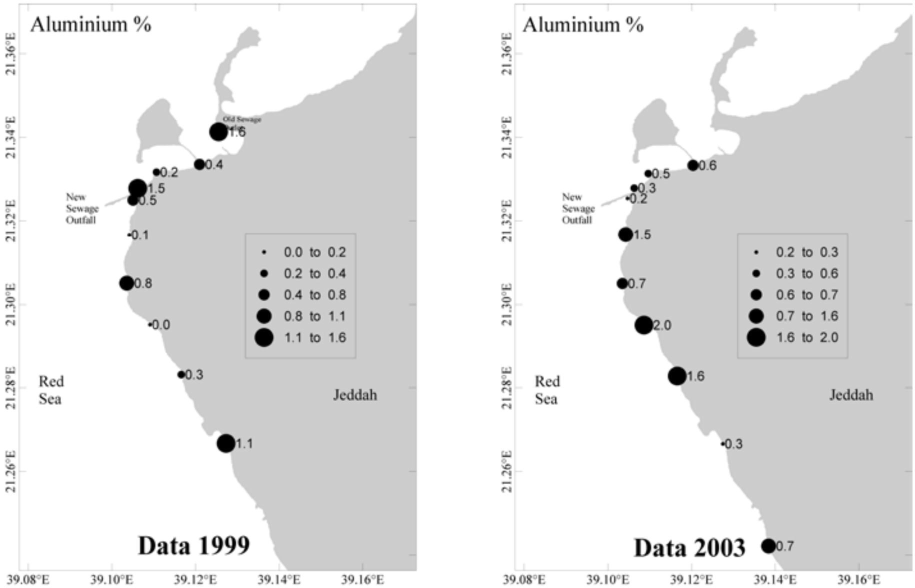

Fig. 5. Comparison of aluminium concentrations (%) in sediment samples between the years 1999 and 2003.

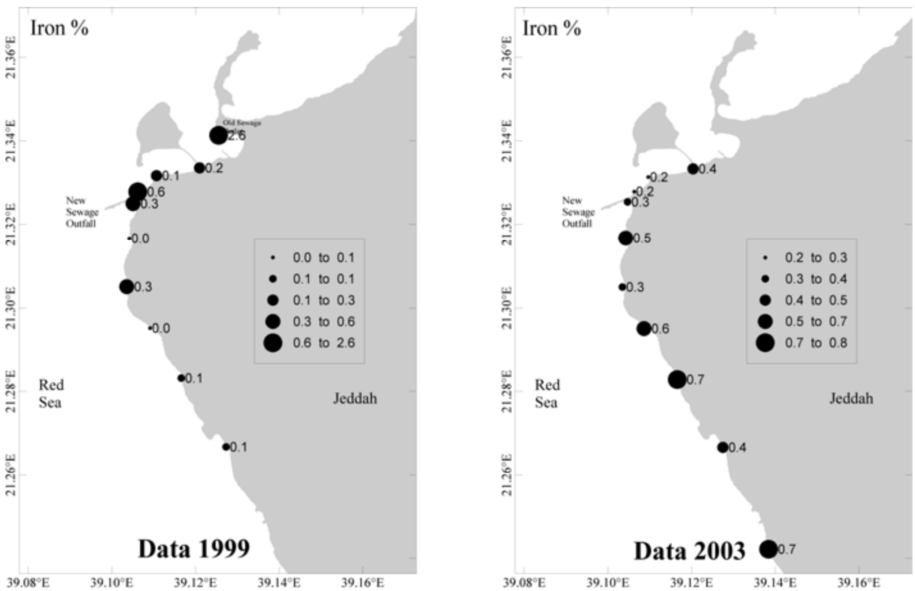

Fig. 6. Comparison of iron concentrations (%) in sediment samples between the years 1999 and 2003.

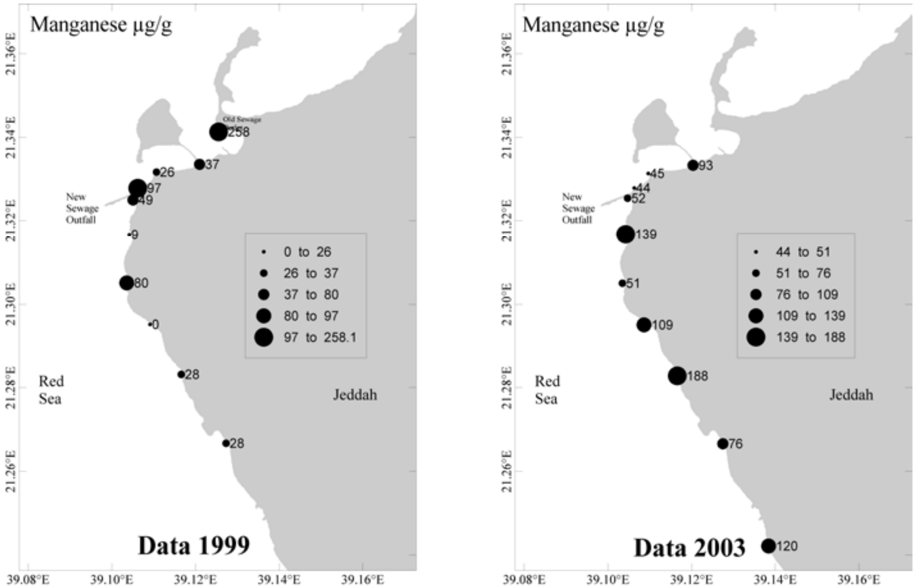

Fig. 7. Comparison of manganese concentrations (µg/g) in sediment samples between the years 1999 and 2003.

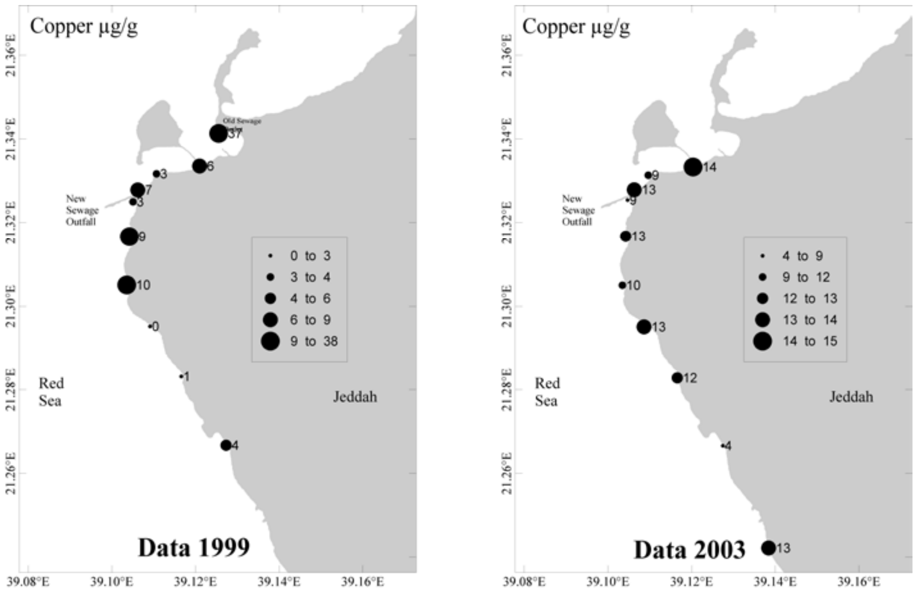

Fig. 8. Comparison of copper concentrations (µg/g) in sediment samples between the years 1999 and 2003.

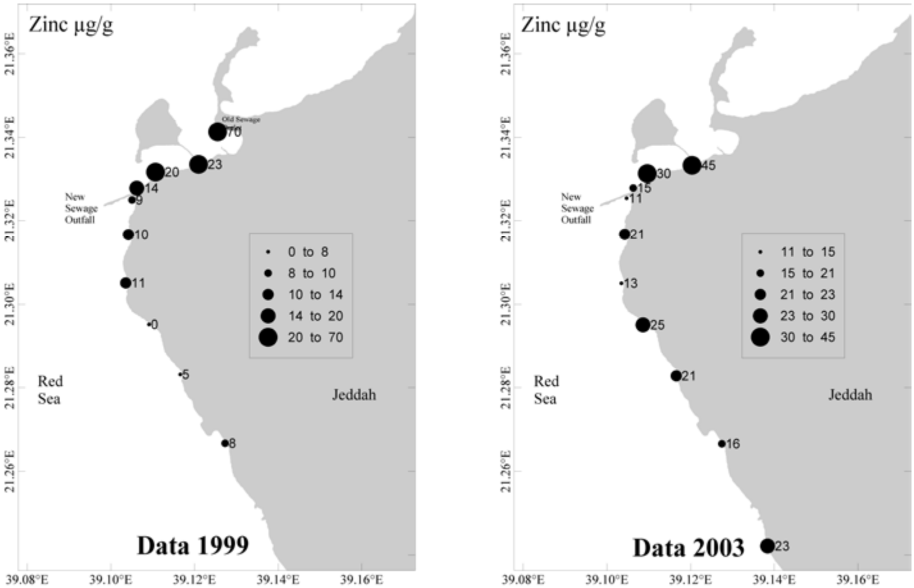

Fig. 9. Comparison of zinc concentrations (µg/g) in sediment samples between the years 1999 and 2003.

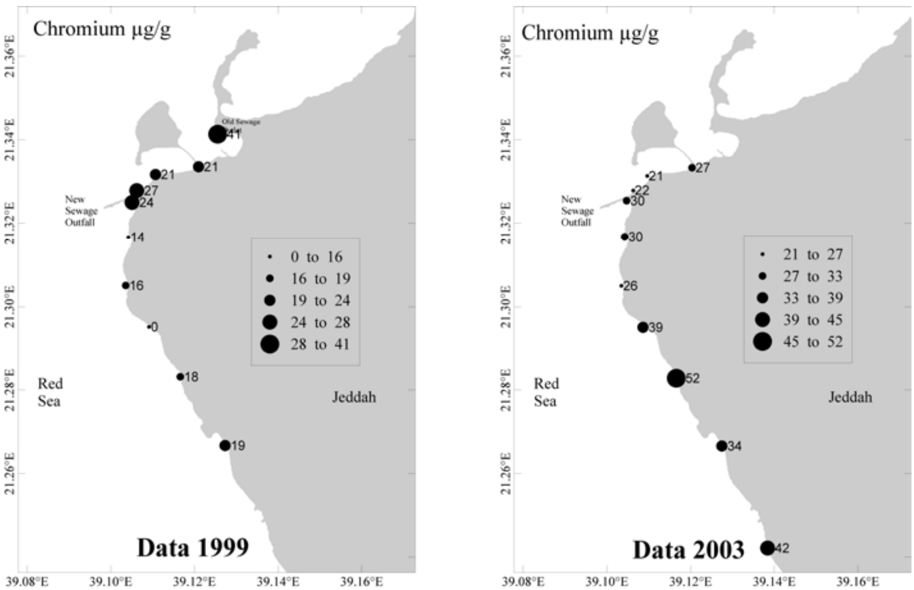

Fig. 10. Comparison of chromium concentrations (µg/g) in sediment samples between the years 1999 and 2003.

Table 1. Comparison between sediment data of the years 1999 and 2003.

Averages	Sand %	Mud %	CO3 %	OC* %	Al %	Fe %	Mn ppm	Cu ppm	Zn ppm	Cr ppm
Northern lagoon 2003	74.63	25.37	75.80	1.50	0.44	0.27	61	12	30	23
Southern area 2003	77.83	22.31	71.31	0.73	1.01	0.50	105	11	18	36
Northern lagoon 1999	83.63	8.94	51.37	1.14	0.73	1.01	107	15	38	28
Southern area 1999	71.08	25.12	59.55	0.81	0.71	0.25	49	6	9	20
Northern lagoon 2003/1999	0.9	2.8	1.5	1.3	0.6	0.3	0.6	0.8	0.8	0.8
Southern area 2003/1999	1.1	0.9	1.2	0.9	1.4	2.0	2.2	1.9	2.0	1.8

*Organic Carbon

In the southern region (area of the present sewage discharge), organic carbon contents did not vary significantly after the transfer. Accumulation of organic carbon in bottom sediments is a function of several factors such as rate of supply, degradation potential and grain size of sediments. Organic carbon might accumulate but slowly in the bottom sediments of the area. On the other hand, the non degradable-persistent elements Al, Fe, Mn, Cu, Zn and Cr have shown a remarkable concentration increase after the transfer of the effluent. No data are available for the concentration of cadmium and lead from the study carried out in 1999, therefore no comparison could be made. However, in general, cadmium concentrations tend to be higher in the southern region than in the northern one, while lead is higher in the northern region.

It is obvious from the results that the shift of the sewage outlet from the northern lagoon to the present location (Fig. 3) has a positive effect on the marine environment inside the lagoon where the heavy metals concentrations decreased significantly after the cease of sewage discharge; whereas it has a negative effect on the southern region. Generally, concentrations have almost doubled for all the elements of interest which represents a very rapid increasing rate.

The spatial variation of the measured variables was found to be explained by two factors representing ~92% of the variation within the data matrix. The first factor is indicated by the high positive loadings on Mud, Cu, Zn, Fe, OC, Pb, Cr and high negative loadings on sand and carbonate content. The other factor is represented by the high positive loadings on Al, Cd and Mn. Figure 11 presents the plot of the two factors (statistical factor analysis) affecting the spatial distribution of metal concentrations in sediments of the study area. It shows the association of organic carbon, mud and the heavy metals content in sediments. The negative association of these variables and both the sand and carbonate contents indicates the diluting effect of these parameters on the chemical composition of bottom sediments in the area. The association of metals with organic carbon and mud fraction of the sediments points to the sewage discharge as a probable source of contaminants to the marine environment in the area of study.

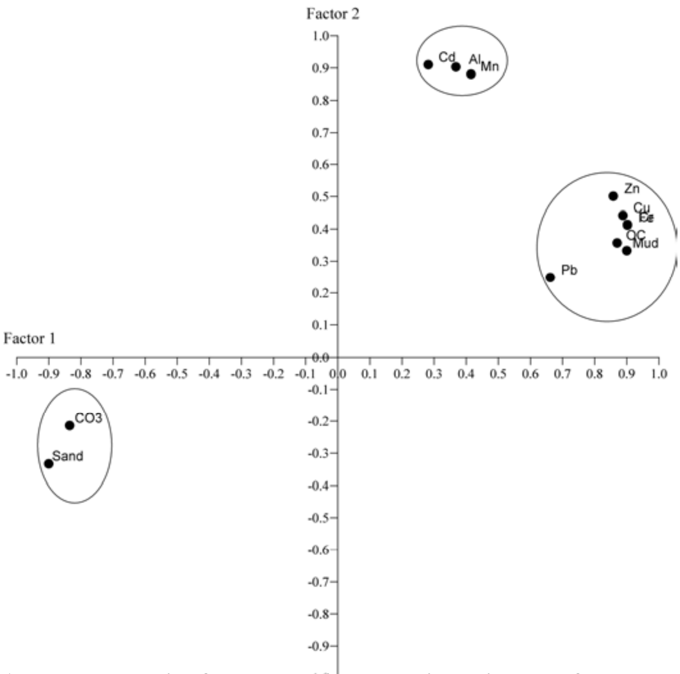

Fig. 11. Factor analysis of the determined data in sediments of the study area.

Conclusions

The objective of this study was to measure the environmental impact of the effluent of Al-Khumra sewage treatment station after the transfer of the dumping site from a sheltered lagoon to an open area. This transfer was accompanied by a change of the mode of dumping from point surface dumping to underwater diffuser at the edge of the fringing reef.

The study showed that, despite the very pronounced dilution effect, the impact of the effluent is measurable and extends north and south over the entire area of study. The impact is very pronounced in the coastal area as shown by the excessive development of algal production which is extending further southward and by the destruction of the mangrove stand. Sediments are becoming enriched in heavy metals where concentrations of Al, Fe, Mn, Cu, Zn and Cr are almost doubled. The present study is the first to be carried out since the effluent transfer. The authors therefore believe that the system did not yet reach a steady state and will continue to change and develop for several years.

Acknowledgement

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إعادة تقويم تأثير صب مياه الصرف الصحي على الرواسب الساحلية لمنطقة الكورنيش الجنوبي، جدة – المملكة العربية السعودية

علي سعيد بسحم، وأحمد السيد محمد رفعت،

ومحمد حمودة المأموني، ومحمد عبدالخالق السيد

كلية علوم البحار، جامعة *الملك عبدالعزيز* – جدة– *المملكة العربية السعودية*

المستخلص. قبل العام ٢٠٠١ كانت منطقة الكورنيش الجنوبي بمدينة جدة تستقبل عبر مصب محطة الخمرة لمعالجة مياه الصرف الصحي مايعادل ٣٠٠٠٠٠ م^{٣} من المياه الغير مكتملة المعالجة، التي تصب مباشرة من أنبوب صرف يقع على ارتفاع ١م فوق منسوب سطح البحر في بحيرة شبه مغلقة، الأمر الذي كان يحول دون انتشار جزء مما تحمله من ملوثات في المنطقة الساحلية. ومنذ العام ٢٠٠١، تم نقل موقع مصب الصرف حوالي ٣ كم جنوبًا، ليصبح أنبوب الصرف تحت سطح ماء البحر على حافة الحاجز المرجاني باتجاه البحر المفتوح.

وقد أجري هذا البحث لدراسة التغيرات التي طرأت على المنطقة الساحلية للكورنيش الجنوبي من جراء نقل المصب، وذلك بجمع وتحليل عينات رواسب حديثة من محطات سبق دراستها في العام ١٩٩٩ قبل عملية نقل موقع مصب الصرف، ومقارنة نتائج توزيع الحجم الحبيبي، والكربون العضوي، وتراكيز بعض العناصر الثقيلة بالدراسات السابقة.

وقد أظهرت الدراسة الحالية أنه على الرغم من ارتفاع معامل التخفيف في المنطقة، إلا أن التلوث لا زال منتشرًا على امتداد منطقة الدراسة، معرضًا البيئات الساحلية للخطر، ومسببًا تهديدا للصحة العامة من عملية صيد الكائنات البحرية بالمنطقة. وقد اتضح ذلك من النمو الكثيف للطحالب، وتدهور الحالة الصحية لنبات الشورى بالمنطقة الساحلية، والزيادة في تراكيز العناصر الثقيلة في الرواسب.

وتعتبر هذه الدراسة هي الأولى من نوعها التي تم القيام بها بعد عملية نقل المصب إلى موقعه الجديد، حيث يعتقد الباحثون بأن النظام البيئي في المنطقة لم يصل إلى حالة الاتزان، وسوف يستمر التغير ويزداد لعدة سنوات لاحقة.