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The Impact of Sewage Pollution on Polychaetes of Al Khumrah, South of Jeddah, Saudi Arabia

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ABSTRACT

Al-Khumrah is the most important sewage treatment station (STS) in the south of Jeddah, Saudi Arabia. There are two basins for sewage discharge in this area, the old discharge outfall (southern corniche) and the new discharge outfall (3 km south of the old station).The present contribution studies the polychaete community structures and its response to sewage discharge in the two basins. Four stations and a control site were sampled around Al Khumrah area. At each station water quality variables were also measured and a total of 40 species were encountered. The control station, situated 6 km from the effluent, had the highest species richness, species diversity and evenness with the dominant polychaete species being *Owenia fusiformis* and *Lumbrineris garcilis*. The most impacted stations, situated at the effluent, had the lowest species richness and diversity. *Capitella capitata, Heteromastus filiformis* and *Notomastus aberans* were most abundant at the stations nearest to the effluent. *Caulleriella alata, Cirratulus cirratus* and *Syllis gracilis* reached their highest abundance at stations near the old sewage discharge outfall and were characteristic of the control site. There is a strong similarity of polychaete assemblages in and near the old discharge outfall basin and that of the control site. This can be explained as a result of cessation of organic enriched sewage input to the former site creating favorable environmental conditions for polychaete life. The capacity of the sewage treatment plant in the new sewage discharge outfall is largely insufficient and does not meet the environmental requirements.

Key words: Polychaetes, sewage, pollution, Al Khumrah Jeddah, Saudi Arabia

INTRODUCTION

Jeddah is the second largest city in Saudi Arabia located on the eastern coast of the Red Sea and is the major urban center of western Saudi Arabia (Magram, 2009). The city has a population of more than 3.5 million. With the population increase, the amount of sewage became a major problem as the capacity of the sewage treatment plants is largely insufficient and much of the raw sewage (~146,000 m^3/day, PERSGA, 2006) is dumped into the coastal area creating a dramatic environmental impact (El-Rayis, 1990; Basaham, 1998; El-Sayed and Niaz, 1999; El-Sayed, 2002a; Turki *et al.*, 2002; Al-Farawati, 2010).

One of the most important sewage treatments plant in Jeddah is Al Khumrah (Fig. 1). Its nominal treatment capacity is 100,000 m^3/day, however, it often receives more than 400×10^3 m^3/day, most of which is released without any treatment. Recent studies (El-Sayed, 2002a, b, c) have shown that the effluent of the STS discharges considerable quantities of solid material, nitrogen

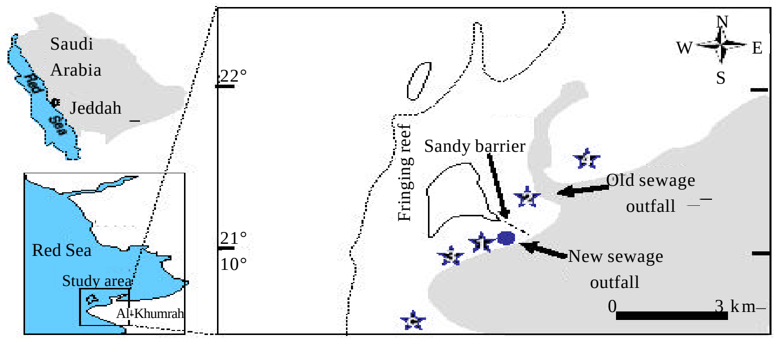

Fig. 1: Location map of the studied area showing sampling sites around sewage effluent of Al Khumrah, south of Jeddah, KSA

and phosphorus. The concentrations of nitrogen and phosphorous in the coastal waters immediately adjacent to the discharge are from 10 to 100 times greater than normal values for the Red Sea (El-Sayed, 2002a). Based on the presence of coprostanol, a fecal sterol indicator of sewage pollution, El-Sayed and Niaz (1999) have detected the dispersion of the effluent several kilometers away from the discharge point.

The natural marine ecosystems are generally polluted by the release of by-products of human activity (Kaplan *et al.*, 2011). Analysis of macrobenthic marine communities is a good indicator of environmental modifications caused by anthropogenic effects (Ahmed *et al.*, 2007; Amar *et al.*, 2007; Mani *et al.*, 2008; Omoigberale and Ogbeibu, 2010; Shokat *et al.*, 2010). Different studies have examined the response of macrobenthos to both spatial and temporal effects of sewage discharge in subtidal and intertidal habitats (Pearson and Rosenberg, 1978; Elias *et al.*, 2003, 2006; Saunders *et al.*, 2007; Shin *et al.*, 2008; Tabatabaie and Amiri, 2010). An opposite response is also known when an organically enriched discharge is reduced (Moore and Rodger, 1991; Roberts *et al.*, 1998; Archambault *et al.*, 2001).

Among the macrobenthos polychaetes often serve as indicators of organic enrichment (Tomassetti and Porrello, 2005; Tabatabaie *et al.*, 2009; Musale and Desai, 2011), environmental disturbance (Khan and Murugesan, 2005) and habitat recovery (Cardoso *et al.*, 2007).

In this context, the aims of the present study were to describe the distribution pattern of polychaete assemblages and to investigate the response of polychaetes to the effects of sewage discharge at different stations of Al Khumrah area.

MATERIALS AND METHODS

Study area: Al Khumrah sewage treatment station (STS) (south of Jeddah city) (Fig. 1) discharges 100,000 m^3 of treated and untreated sewage daily into the coastal waters, representing 12 tons of organic matter. This is likely to have considerable impacts on local marine habitats. Many sewage treatment plants are operating beyond their intended capacity, resulting in the discharge of untreated effluent to the marine environment, eutrophication of coastal lagoons and malodorous inputs into the human environment (UNEP/PERSGA, 1997; PERSGA/GEF, 2001).

Prior to the year 2000 the semi-treated sewage was dump into the coastal water south of Jeddah, in the area known as Southern Corniche. The waste water outlet was placed on the shore about 1m above the sea surface. Sewage was dumped into a semi-enclosed lagoon of about 2.3 km^2, artificially constructed by the addition of a sand barrier to prevent sewage dispersion southwards due to the prevailing wind induced surface water current (Fig. 1). 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. In 2000, treatment was modified and the effluent was transferred about 3 km further south. The new effluent is about 500 m from the shore, just on the edge of the fringing reef, 10 m below the surface. Although, the effluent is no longer visible, the threat has increased for both the environment and public health. Perhaps this is manifested by the presence of algal mats layers (red-brown color) in the area between the edge of the reef and the coast particularly south of the new effluent, the dark color of the sediments indicating more reducing conditions.

Sampling locations: The present study focused on the coastal location of Al-Khumrah, south of Jeddah, Saudi Arabia (Fig. 1). Five stations were chosen around the old and the new sewage outfalls. Two stations (# 1 and 3) were selected near the recent outfall, two stations (# 2 and 4) around the old outfall and a control station (C) 6 km far from the recent outfall. Sampling was carried out during July and August, 2010.

Sampling and analytical procedures

Sampling procedure: Four replicate sediment samples were collected at each of the 5 using a van-Veen grab (0.04 m^2 area). In order to minimize the loss of organisms during their transportation ashore the samples were placed directly into polyethylene bags. Samples were immediately fixed in 4% formaldehyde (~10% formalin) and rinsed in the laboratory with freshwater. This processed sediment was then sieved through a 0.5 mm mesh sieve and animals retained were preserved in 5% buffered formaldehyde. The retained polychaetes were sorted under the stereomicroscope, identified to the species level and counted. Sorted and identified animals were preserved in 80% ethyl alcohol.

Physical and chemical variables of the water column were also measured at each sampling site. Dissolved Oxygen (DO) and temperature measurements were made using a YSI 95 m (Model 95/25 Ft) and salinity measurements using a WTW meter (LF 320) with a Tetra-Con 325 probe (both meters were calibrated following manufacturer instructions). Salinity measurements have been reported according to the practical salinity scale of 1978 (PSS 78) as dimensionless values. A sensorex combination pH electrode (450 C) with a Rex pH meter (Model pHb-4) was used for all pH measurements (in the field and in the lab) and was calibrated against standardized pH 4 and 7 National Institute of Standard and Technology (NIST) buffers before use. The concentration of nitrates, nitrites, ammonia and phosphates was determined spectrophotometrically with a Merck RQFlex Plus device which uses special Reflectoquant® strips.

Statistical analyses: The structure of the polychaete community was analyzed for species richness (S), total abundance (N), Evenness (D), frequency (F) and diversity. To measure species diversity, we used two indices; the Shannon-Wiener diversity (H') (Shannon index) and the Margalef's index (d).When indices were congruent, we reported the most significant value.

RESULTS AND DISCUSSION

Marine pollution is considered an important environmental threat throughout the eastern and western coast of Saudi Arabia (Al-Farraj *et al*., 2011; Alyahya *et al*., 2011; Karami *et al*., 2011;

El-Gendy *et al.*, 2012). Although, sewage treatment facilities are designed to accommodate and treat sewage from their service area, partly treated or even untreated sewage sometimes is discharged to the western coast of Saudi Arabia. Specifically, due to the rapid development in Jeddah City the treatment plants are overloaded and therefore, the effectiveness of treatment is very low. This leads to a considerable amount of effluent pollutants in marine water of the region. Many of these pollutants are known to exert a marked effect on marine benthic communities, particularly marine macrobenthics. Polychaetes are considered one of the most useful marine organisms for detect pollution because they live at the water-sediment interface (Warwick and Ruswahyuni, 1987; Guerra-Garcia and Garcia-Gomez, 2004; Jayaraj *et al.*, 2007; Dean, 2008; Santi and Tavares, 2009; Shen *et al.*, 2010; El-Gendy *et al.*, 2012).

Environmental variables: The values of dissolved oxygen concentration, salinity and pH were much higher in the control site and stations # 2 and 4 than in stations # 1 and 3 (Fig. 2).

The highest nutrient concentrations (nitrates, nitrites, ammonia and phosphates) were recorded at the polluted stations (# 1 and 3) and the lowest values were at the control site (C), stations # 2 and 4 (Fig. 3). These results are confirmed by the work of El-Sayed (2002a), who concluded that the effluent of the STS discharges considerable quantities of solid material, nitrogen and phosphorus. The dispersion of the effluent was traced using coprostanol and its presence was detected several kilometers away from the discharge point (El-Sayed and Niaz, 1999).

The fauna: A total of 40 polychaete species were identified during this study. The most common family near the new exchange outfall, both in term of abundance and species richness, was the Capitellidae. On the other hand the families Lumbrineridae and Oweniidae were most common in the control site.

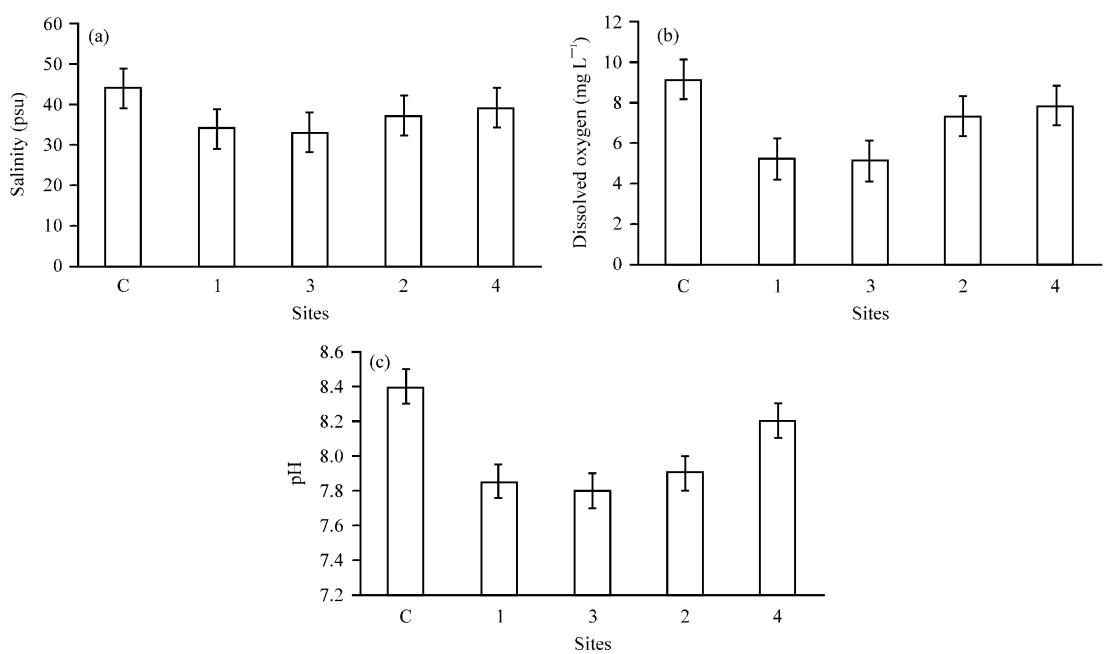

Fig. 2(a-c): Means of environmental variables in each sampling station. Verticle lines on each bar indicates standard error (SE)

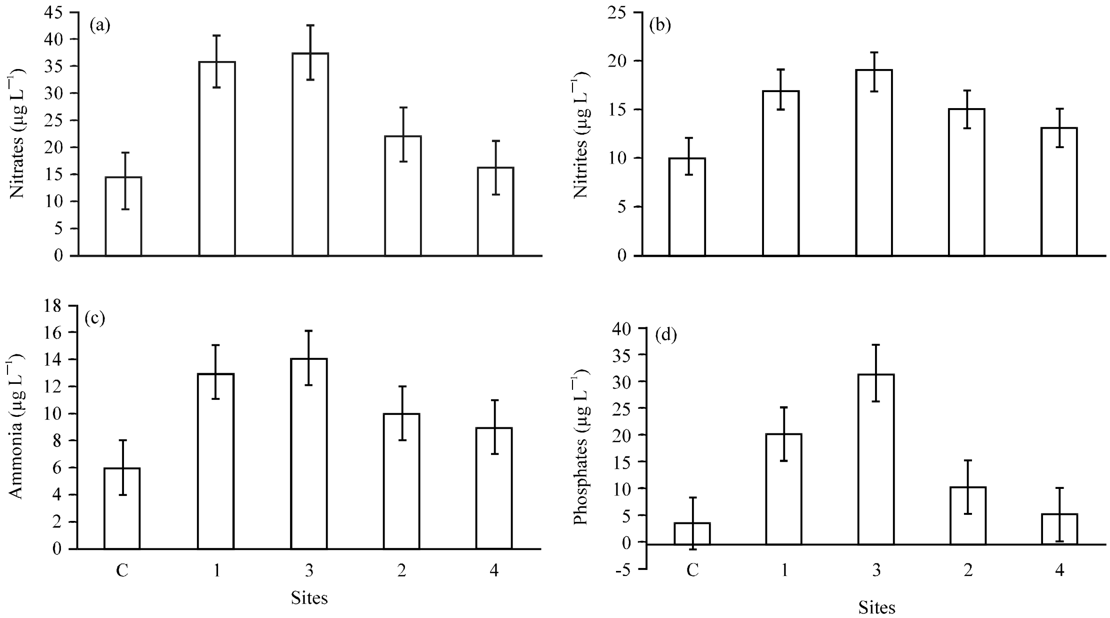

Fig. 3(a-d): Mean of nutrient concentrations in impacted (1 to 4) and control stations (C)

Community pattern: The number of polychaete species gradually increased from 8 species near the sewage discharge to 21 species in the control site (Fig. 4). Generally, species richness is significantly higher at the control site and station # 4 than at stations # 1, 2 and 3 (Fig. 4). Species richness is usually low in regions of the bay that are impacted by anthropogenic factors (Kennish, 1997; El-Gendy *et al.*, 2012).

The lowest population density at the polluted area is probably due to the low dissolved oxygen concentration, to the sharp decrease in salinity and to the high concentration of toxic compounds resulting from the decomposition of organic matter (hydrogen sulphide and ammonium). Nutrient enrichment significantly affects the composition of marine communities (Larsson *et al.*, 1985; Kotta and Kotta, 1997; Kotta *et al.*, 2000; Gao *et al.*, 2005; Posey *et al.*, 2006; Yucel-Gier *et al.*, 2007; Huang *et al.*, 2011). The discharge of domestic waste industrial sewage and drainage water from agriculture into the sea leads to a local increase in the quantity of the particulate and dissolved organic matter. This organic matter serves as food for many benthic surfaces or sub-surface deposit-feeders. If the quantity of domestic waste is large, the bottom-dwelling organisms cannot assimilate this increase. As a result of bacterial decomposition of this unassimilated organic matter the concentration of dissolved oxygen diminishes to critical levels. Because oxygen deficiency is the main ecological factor causing severe stress to the macrobenthos, the number of species and the number of individuals will decrease until they disappear altogether. The decline in dissolved oxygen concentrations can also promote the formation of reduced compounds such as hydrogen sulphide (H_2S), resulting in higher adverse effects on aquatic animals (Diaz and Rosenberg, 1995; Wetzel, 2001; Breitburg, 2002; Vaquer-Sunyer and Duarte, 2010).

The benthos in the study area exhibited moderate Shannon diversity values (1.43-2.78) suggesting environmental deterioration associated with anthropogenic activities. In a healthy environment, the Shannon diversity and Margalef richness are higher and in the range of 2.5-3.5 (Khan *et al.*, 2004). In addition, the Margalef richness displays the same sense with values ranging from 0.85 to 2.25. Low diversity indices and evenness were recorded in sites # 1 and 3, whereas, high values were in site # 4 and the control site (Fig. 4).

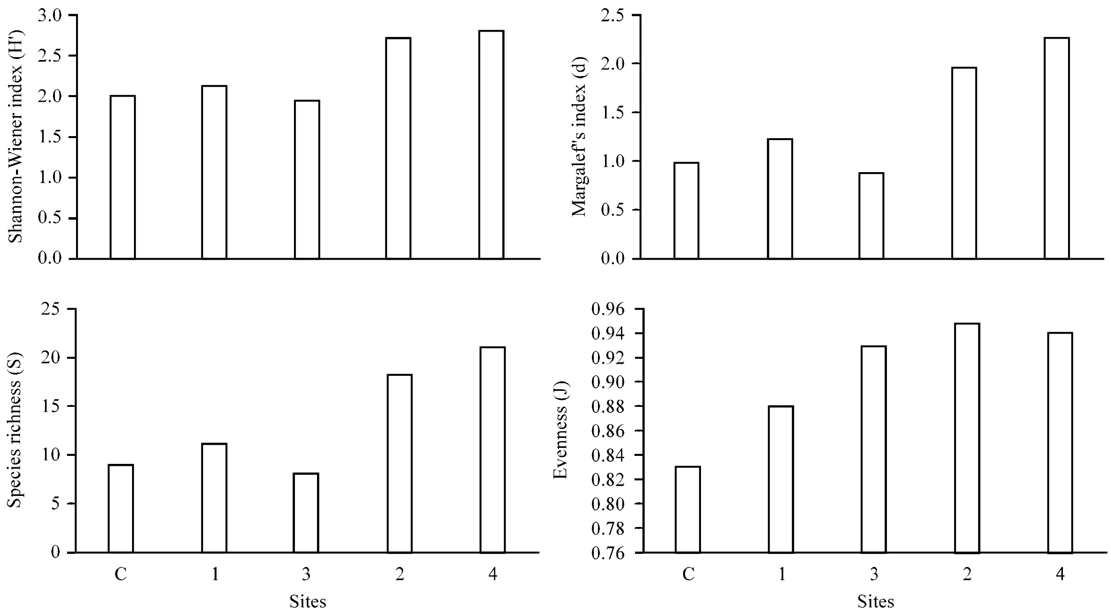

Fig. 4: Variation in univariate measures of the polychaete communities

The distribution pattern of polychaete species changes with distance from the source of pollutants. *Capitella capitata*, *Heteromastus filiformis* and *Notomastus aberans* were the most common polychaete species near the sewage discharge (sites # 1 and 3). Among them, *Capitella capitata* represents the greatest number of occurrences especially in site # 1. The opportunistic polychaete family Capitellidae becomes very abundant close to the sewage outfall and is an indicator for organic pollution (Pocklington and Wells, 1992; Kress *et al.*, 2004; Elias *et al.*, 2006; Jaubet *et al.*, 2011; Sanchez *et al.*, 2011). Moreover, Rygg (1985) considered *Capitella capitata* and *Heteromastus filiformis* as positive pollution indicators. In a study from western Norway, it was found that *Capitella capitata* and *Heteromastus filiformis* showed high tolerance to organic pollution and that both *Capitella capitata* and *Heteromastus filiformis* were negatively correlated with increasing diversity (Airas and Rapp, 2003).

On the other hand, *Owenia fusiformis* and *Lumbrineris gracilis* were the most polychaete species recorded in the control site. *Owenia fusiformis* is not known to have any strong opportunistic properties (Flaten *et al.*, 2007). They occur together with other species (e.g., *Pista fasciata*, *P. macrolobata*, *Lumbrineris debilis* and *Euclymene africana*) that characterize areas not exposed to environmental stress, e.g., pollution.

At station # 2, polychaetes were dominated by *Caulleriella alata*, *Cirratulus cirratus*, *Nereis persica*, *Nereis falcaria*, *Neanthes caudate* and *Syllis gracilis*. They are mainly related to families Cirratulidae, Nereididae and Syllidae. These families are not usually considered to be organic pollution indicators. Although, this site was considered the most organically polluted site at Al Khumrah prior to 2000, the findings of the present study indicated an absence of the deposit-feeding polychaete *Capitella capitata* a well known opportunistic species complex often associated with organically enriched and/or polluted sediments. The absence of *Capitella* sp. in less organically polluted areas with stable environmental conditions and the rapid decline of their population in the benthic recovery process following reductions in pollution can be ascribed to the shortage of organic intake and to their physiological demand for organic matter rather than to their poor ability to compete with other benthic animals considered to be less opportunistic (Tsutsumi, 1987; Linke-Gamenick *et al.*, 2000; Bach, 2005).

The composition of polychaets in site # 4 is more or less similar to that recorded in the control site with dominance of *Owenia fusiformis*, *Syllis gracilis* and *Syllis monilaris*.

Both of these sites have similar values of diversity, abundance and evenness (Fig. 4). This may be due to the protection of site # 4 beyond the natural arm away from the organic discharge outfall. The present study considered it as the least polluted site (with the exception of the control site) in the studied area.

CONCLUSIONS

The polychaete community structures were influenced greatly by sewage discharge in the two basins at Al Khumrah, south of Jeddah, Saudi Arabia. Four stations and a control site were sampled around Al Khumrah area.

The Environmental variables show a spatial gradient of organic enrichment related to increasing distance from the outfall. Poor environmental conditions near the outfall were indicated by low pH and dissolved oxygen values. In the same way, nutrient levels showed highest values near the outfall, indicating high organic matter input in the area.

The control station, situated 6 km from the effluent, had the greatest number of species as well as the highest diversity and evenness. The dominant species at this site were *Owenia fusiformis* and *Lumbrineris garcilis*. The station located near but outside, the old discharge outlet (# 4) site was relatively less affected by sewage pollution with a relatively high species richness, diversity and evenness.

To some extent, there are some similarities between the polychaete assemblages of the control station and those of stations near the old discharge outfall. This is most probably the result of reductions in organically enriched sewage at the latter site leading to partial recovery of the polychaete community.

In the study area, the most impacted stations (# 1 and 3), situated at the effluent, had the lowest species richness and diversity. The opportunistic polychaete family Capitellidae becomes highly abundant close to the sewage outfall and is an indicator for organic pollution.

Upgrading of the wastewater treatment plant at Al Khumrah may be required to handle increased organic loadings to meet existing effluent quality or to meet the environmental requirements.

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