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Preliminary Assessment of Water Quality along the Red Sea Coast near Jeddah, Saudi Arabia

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Abstract: *This paper presents the results of preliminary assessment of water quality along Red Sea coast adjoining Jeddah, Saudi Arabia. Jeddah is a major city with a population of over 2.6 million and an area 1,200 km^2. To study the impacts, samples of the Red Sea were collected from 24 important locations near Jeddah and analyzed in the laboratory for various water quality parameters. These parameters included: biological oxygen demand (BOD), chemical oxygen demand (COD), phosphorus, dissolved oxygen, ammonia nitrogen, nitrates, sulfates, total alkalinity, chlorides, and pH. The results of the study show considerable variations in water quality depending upon the location along the Red Sea coast. The BOD values in the sea water are negligible except in the Balad downtown lake near treatment plant where the values are quite high ranging from 51 to 812 mg/l. Here, the total phosphorus is also high with value of 3.81 mg/l. Dissolved oxygen values along the coast vary from 2.5 to 6.4 mg/l. The variations in nitrate concentration in the Red Sea water along the coast are observed to range from 6.90 to 26.61 mg/l. This study provides a preliminary assessment of the coastal pollution and will act as a data base for future investigations and monitoring of the Red Sea coastal waters.*

Keywords: *environment, impact assessment, Red Sea, water quality, Jeddah City*

Introduction

Jeddah is a major metropolitan city along the eastern coast of the Red Sea with population of over 2.6 million with an area of 1,200 km^2 (Mohorjy, 2001) (Figure 1). Jeddah, an industrial, commercial, and educational center with many tourism resorts and marinas, is expanding fast at a population growth rate of 3.25 percent per year. It has one of the longest and most attractive corniches along the Red Sea, which is approximately 100 km long in the north-south direction (Mohorjy and Khan, 2000). New residential and recreational areas are being developed along the sea coast near Jeddah such as Madinatul Buhairat (City of Lakes) and Durrat Al Arus (Jewel of Bride).

Sewerage facilities are available to around 25 percent of population. The collected wastewater is carried to existing wastewater treatment plants located in different parts of the city. These facilities have been designed to provide secondary level of treatment. However, most of these plants are overloaded. A portion of the treated wastewater is reused for green spaces and landscape irrigation along the city roads and parks. The remaining goes direct to the Red Sea.

The non-sewered population relies on cesspools for the disposal of wastewater. As a result, the groundwater table has been rising at an alarming rate of 50 cm/year. At many places, it has reached the ground surface and created unhealthy and unaesthetic conditions. It is suspected that a portion of polluted groundwater also reaches the Red Sea. Due to the rising groundwater table and blockage of the soil pores, the seepage efficiency of the cesspools constantly decreases. For this reason, cesspools are regularly emptied using wastewater hauling trucks, which carry them to a wastewater storage reservoir 25 km east of Jeddah. Around 50,000 m^3/day of wastewater are discharged into the reservoir which is a containment reservoir without any outlet.

The Red Sea environment is thus presently subjected to impacts from the rapidly growing city, its long corniche, and traffic in the Red Sea and adjoining creeks. The Red Sea is famous for its beautiful coral reefs and marine life. Jeddah has been termed as “bride” of the Red Sea and offers excellent venues for fishing, surfing, sailing, and

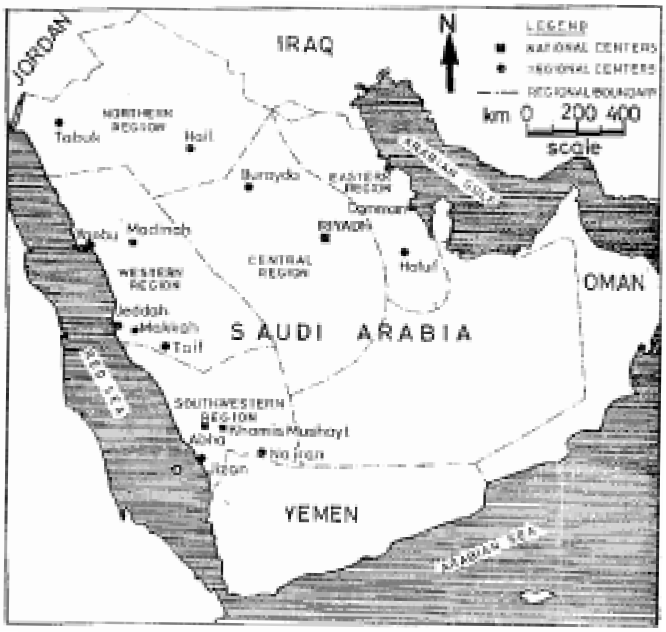

Figure 1. Map of Saudi Arabia

scuba diving. Fish from the Red Sea is a major source of food in Saudi Arabia. The Red Sea is used as a water supply source for desalination plants. Jeddah corniche attracts a number of visitors throughout the year for recreational purposes. Water contact from recreation is relatively limited; most of the people normally gather for picnics and partying. The Red Sea coastal areas near Jeddah receive waste discharges from the city sewerage system. They are also being adversely affected by the large influx of the visitors. As a result, the Red Sea coast is having serious environmental pressures requiring examination for the preliminary evaluation of the environmental impacts so that the future measures for its protection can be undertaken.

This paper aims to make a preliminary assessment of impacts on water quality along the Red Sea coast near Jeddah due to the discharge of municipal wastewater and other developments in the coastal region.

Previous Investigations on the Red Sea

The Red Sea has been a subject of investigation by various researchers: Abbas and Haddad (1984) investigated inorganic nitrogen forms as indicator of sewage pollution in the coastal water of the Red Sea near Jeddah. They studied the distribution of inorganic nitrogen forms, nitrate, nitrite, and ammonia for evaluating the state of pollution in the coastal water of Jeddah center. They also studied salinity, temperature, pH, transparency, and oxygen/hydrogen sulfide. They found that the degree of variation from natural conditions was high in the coastal dead reef area bordering Jeddah Center. The variations included lower salinity and transparency, depletion of oxygen, high concentration of hydrogen sulfide and the reduced form of nitrogen, ammonia. They attributed this to disposal of water of fresh water origin, highly turbid, and with high organic nitrogenous matter content. The concentration of inorganic nitrogen forms and total nitrogen in the southeastern part was high and it approached concentration that exist in raw sewage.

Slow mixing due to limited exchange of water with the open sea, as a result of partial isolation by the barrier reef, obstructed the rapid oxidation of organic matter. The authors cautioned that the continuous disposal of raw wastes into the coastal zones of the newly growing urban centers along the Red Sea coast will affect recreation, utilization of seafood, public health and further damage the coral reef areas.

Abu-Aisha et al. (1995) investigated impact of phosphorus loading on macro-algal communities in the Red Sea western coast of Egypt at three sites. The localized phosphate pollution at two sites significantly increased the phosphate level in water, which led to significant decreases in biomass of the macroalgae. The inter-tidal zone at one of the impacted sites supported very poor algae vegetation. The results obtained by the investigators showed that the abundance of macro-algae reached its maximum in August at all the study sites.

Abu Hilal (1997) examined the phosphate pollution and related problems in the unique and very sensitive coral reef area in the northern portion of the Gulf of Aqaba, 1000 km north of Jeddah. The various sources and magnitude of pollution were pointed out. They reviewed and discussed the levels and distribution of phosphates and other pollutants taking into consideration the effects of phosphate dust spills during loading operations in Aqaba port (Jordan).

Mohorjy (1997) presented importance weighting of impacts in environmental impact studies and applied this to Jeddah sewerage system. Jeddah being one of the largest cities in Saudi Arabia has undergone tremendous expansion and development during the last 30 years. As a result, the magnitude of domestic and commercial wastewater has considerably increased. Marine and coastal pollution due to disposal of untreated sewage to the sea, and soil contamination were considered as major impacts amongst the various identified impacts in the Environmental Evaluation System (EES) of cesspool system in Jeddah. The nature of these impacts was categorized as the marine environment at outfall diffuser and beaches, coral reef erosion, loss of fisheries productivity and geo-environment, respectively.

When the wastewater is discharged into the Red Sea as for example from Al-Khomra treatment plant site southeast of Jeddah, the effects include impairment of habitat for aquatic and marine life by accumulated solids, depletion of oxygen by decomposition of organic material, and marine organisms harmed by toxic substances, which may spread to higher organisms through bio-accumulation in the food chain. The discharge entering confined water body like nearby Salman Bay in the north of Jeddah coast, through its nutrient content causes eutrophication, with nuisance plant growth disrupting fisheries and recreation activities.

Awad (1997) reviewed the state of the marine environment in the Red Sea and Gulf of Aden and results of a project investigating the possible cause-effect relationship between oil pollution and coral reef health conditions along the Saudi Arabian Red Sea Coast. It was concluded that the Red Sea marine environment is subjected to high potential risks of oil pollution particularly in the coastal waters. They also indicated that the implementation of a monitoring program requires selection of a few capable laboratories.

Price et al. (1998) investigated several coastal and offshore island sites in the Saudi Arabian Red Sea. They reported that latitudinal trends include significantly increased abundance of mangroves and sea grasses (and other flora) and a decrease in abundance of reefs towards south of the Red Sea. Significantly higher levels of beach oil were encountered towards the north of the Red Sea; probably reflecting its greater proximity to the Gulf of Suez. They found that the Red Sea is less perturbed by human activities than the Arabian Gulf. It was however, concluded that the Red Sea is no longer a pristine environment.

Hodgson (1999) reported that globally few reefs remain unaffected by humans even at very remote sites. However, the ratio of live to dead coral cover was higher in the Red Sea than in other regions indicating that reef corals are in the best condition there.

The examination of literature survey reveals that the Red Sea environment along Jeddah's coast is subjected to impacts of various kinds but mainly from wastewater and an investigation covering the entire stretch of this coast has not been conducted so far. This study therefore is undertaken to have the pollution status of the whole coast of the Red Sea along Jeddah city.

Table 1. Categorization of Sampling Areas Along the Red Sea

Category of Area	*Description*
a_1	Lakes/lagoons not linked to the Red Sea from surface but receive waste discharges.
a_2	Lakes/lagoons not linked to the Red Sea from surface but do not receive waste discharges directly.
b_1	Lakes/lagoons linked to the Red Sea without free mixing but with waste discharges directly.
b_2	Lakes/lagoons linked to the Red Sea without free mixing and no direct waste discharges.
c_1	Open Red Sea and receiving waste discharges directly.
c_2	Open Red Sea but without waste discharges directly.

Methodology

Selection of Sampling Stations

Sampling stations were selected along the whole stretch of Jeddah corniche. The total number of sampling stations is twenty four and these are located keeping in view the discharge of municipal wastewater, use of the coast for recreational purposes, extent of the area with the sea with respect to water exchange rates and points indicating relatively unaffected background areas. Following this approach, sampling stations were categorized into six groups as given in Table 1.

The location of these sampling stations is shown in Figure 2. Table 2 gives these sampling stations with brief description.

Sampling Station 1 is located in the south of Jeddah

Table 2. Sample Locations Along the Red Sea Coast near Jeddah

Sample No.	*Location*	*Longitude°E*	*Latitude °N*	*Category (Table 1)*
1.	Adjacent mobile telephone tower south corniche	39° 11.5	21° 6.3	c_2
2.	Coastal wall south corniche	39° 7	21° 17.3	c_1
3.	Balad treatment plant outfall at lake	39° 10.3	21° 29.3	b_1
4.	Balad lake under bridge near Red Sea Hotel	39° 10.4	21° 29.3	b_1
5.	Baghdadia end of Balad lake	39° 10.8	21° 29.8	b_1
6.	Fish market	39° 9.9	21° 30.4	c_1
7.	Below bridge opposite youth club	39° 10	21° 30.5	b_1
8.	Opposite Zaki Farsi Building close to mosque	39° 9.9	21° 31.1	c_2
9.	Opposite Jamjoom Center	39° 9.6	21° 32	c_2
10.	In front of Al Hamra Palace close to mosque	39° 10.1	21° 32.7	c_2
11.	In front of Abu Shaqra after Tahlia	39° 8.1	21° 35.2	c_2
12.	In front of Sheraton hotel (lake sample)	39° 9.1	21° 38	a_1
13.	Boats monument in front of blue lagoon (sea sample)	39° 9.2	21° 38.9	c_2
14.	Boats monument in front of blue lagoon (lake sample)	39° 9.3	21° 38.6	a_2
15.	Science Museum (sea sample)	39° 9.4	21° 40.1	c_2
16.	Science Museum (lake sample)	39° 9.6	21° 40.1	a_1
17.	Lolo Park mosque (sea sample)	39° 9.6	21° 40.7	c_2
18.	Science Museum (lake repeated)	39° 9.6	21° 40.1	a_1
19.	Lolo Park lake	39° 9.7	21° 40.5	a_1
20.	End of Marine Faculty (sea sample)	39° 10.8	21° 44.2	b_1
21.	Marina Obhor	39° 13.2	21° 45.4	b_1
22.	Adjacent Holiday Inn Resort	39° 13.6	21° 45.8	b_1
23.	Madinatal Buhairat	39° 8.8	21° 52.7	c_1
24.	Durratal Arus	39° 7.8	21° 58.9	c_1

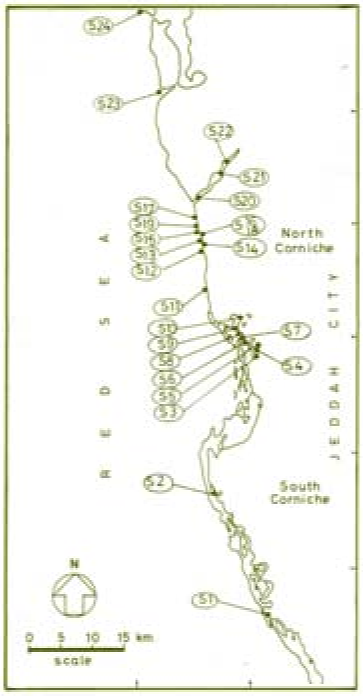

Figure 2. Location of the sampling stations along the Red Sea Coast

city about 40 km from the city center and the wastewater impacts are expected to be negligible; as such this sampling station provides a background reference water quality.

Sampling Station 2 is located on the sea coast where effluent from Al Khumra treatment plant enters. In the proximity of the sampling station, a number of industrial establishments are located, which also discharge their waste into the sea near this station.

Sampling Stations 3, 4, and 5 are located on a lake which receives wastewater effluent from Balad wastewater treatment plant. Here, the exchange of water between the sea and the lake is restricted due to the shape of the lake and its geometry as it joins the sea.

Sampling Station 6 receives the water discharges from the Fish Market. Sampling Station 7 is located at a narrow linkage between the open sea and artificial lake and receives waste discharges from a wastewater treatment plant located nearby. Sampling Stations 8, 9, 10, 11, 13, 17, and 15 are located along the sea shore open to the sea with little direct waste inputs.

There are several small lakes and lagoons which are not directly connected to the sea from the surface. Sampling Stations 12, 14, 16, 18 and 19 are located on these lakes/lagoons. Except the Sampling Station 14 all of other locations are suspected to receive waste discharges from the nearby areas.

Obhur creek extends 10 km into the land and does not have regular freshwater impacts except during the rains. This area is popular for various types of recreational activities including marinas. Approximately 2,000 boats are used in the creek over the weekends contributing various types of waste inputs to the sea. Sampling Stations 20, 21, and 22 are located in this creek.

Two new coastal recreational areas namely Madinatal Buhairat and Durratal Arusa are being developed toward north of Jeddah. The residential areas in these localities have direct boat access to the open sea through channels which have been dredged for this purpose. These areas have their own desalination plants along the Red Sea coast discharging concentrated streams back to the sea. Secondary level wastewater treatment facilities have been incorporated in the development plans of these areas with waste effluent discharging into the sea. Sampling Stations 23 and 24 are located near these areas.

The selected sampling stations thus cover locations with possible sources of pollution and use of the coast covering a reach of about 100 km along the Red Sea.

Collection and Analysis of Samples

Water samples were collected generally at a distance of about 5 m from the shore line where the water was around knee depth. The samples were collected from near the water surface. The sampling was started in February 2000 from Sampling Station 1. The sampling was done on Tuesdays every week before noon. Each station was sampled once throughout the sampling period which continued till November 2000. Clean plastic bottles of one liter capacity were used to collect the water samples. The bottles were properly sealed, labeled and transported to the laboratory for analytical measurements.

The samples were stored in the laboratory at 4ºC in the refrigerator and the analysis was started within two hours of receipt of samples. The samples were analyzed for the following parameters: (a) biological oxygen demand (BOD); (b) chemical oxygen demand (COD); (c) dissolved oxygen; (d) total phosphorous; (e) ammonia nitrogen; (f) nitrate; (g) sulfate; (h) total alkalinity; (i) chloride; and (j) pH. All analyses were carried according to the AWWA Standard Methods for the Examination of Water and Wastewater (1995).

Five day BOD at 20ºC was determined using appropriate dilutions. YSI dissolved oxygen meter model S4A was used for oxygen measurements. The measurements were occasionally verified by Azide modification method. Chemical oxygen demand (COD) was measured by open reflux method with addition of mercuric sulfate along with silver sulfate to avoid interference of chloride. Ammonia nitrogen was determined by distillation and collecting the distillate under the surface of boric acid solution; and subsequent titration with standard sulfuric acid. Total phosphorous was determined by persulfate digestion using ascorbic acid and spectrophotometer 20 at a wavelength of 880 nm. Ultraviolet spectrophotometric screening method using spectronic 21 was employed for the determination of nitrates. Sulfates were determined by gravimetric method wherein barium sulfate was precipitated with the addition of excess barium chloride in hydrochloric acid. The precipitate was digested and filtered subsequently for gravimetric measurements. Chloride was determined using argentometric method. Chloride titration was done with standard solution of silver nitrate using potassium chromate as indicator. Total alkalinity was determined by titrating the samples with 0.02 M sulfuric acid using phenolphathin and methyl orange as indicator. Fisher Accumet pH/ion meter was used for pH determination.

Results and Discussion

Table 3 presents the results of the analysis of the Red Sea water samples at various sampling stations during the period of the study.

Sampling Station 1 is a background station and shows that the impact of waste discharges are minimal at this point as indicated by the absence of BOD, phosphorous, and ammonia nitrogen and high levels of dissolved oxygen.

The results at Sampling Station 2 indicate that the wastewaters get readily mixed with the seawater as indicated by the chloride concentrations which are similar to those at Station 1. As a result, the BOD and COD are also low. Water is well oxygenated; however, phosphorous concentration is 0.74 mg/l which is quite high indicating high eutrophication potential. During the field visit, it was also visible that algal growth is quite high at this point.

In general, BOD and COD values are very high at Sampling Stations 3, 4, and 5 the BOD values range from 51 to 812 mg/l. As mentioned earlier, these sampling points are located on a lake which does not have free exchange with the sea and receives discharges from a municipal wastewater treatment plant. The values are much higher than one would expect from a treated or untreated domestic wastewater especially at Station 4. It appears that the wastewater being lighter than the sea water floats over and the pollutants are trapped in the lake. Levels of nutrients as given by the concentration of phosphorous and nitrogen are high. Concentration of phosphorous varies from 0.74 to 3.81 mg/l and nitrate concentration ranges from 28.3 to 130.0 mg/l. This suggests high input nutrient loads being discharged to the sea through municipal waste discharge.

Station 7 is also located on a lake which has a restricted water exchange with the sea and receives waste effluent from a treatment plant and other nearby areas. The concentration of various pollutants follows the same pattern as discussed earlier for the other lake. However, the COD levels are very high reaching 7,680 mg/l. Phosphorous concentrations do show potential for eutrophication. Comparatively, high pH value indicates algal photo-synthetic activity which will also contribute to COD

Fish handling and processing is a common activity in the vicinity of Sampling Station 6. The resulting wastes are indiscriminately dumped into the sea. As a result, levels of pollutants measured in terms of BOD, COD, phosphorous, and nitrogen are high. The corresponding values for these parameters are 19 mg/l, 352 mg/l, 0.92 mg/l as P, and 16.5 mg/l as NO_3. In comparison to Sampling Stations 3, 4, 5, and 7, the values of the pollution parameters are lower due to dilution by sea as the discharges are in an area where there is free exchange of water with the main sea.

Table 3. Water Quality of Red Sea along Jeddah Coast

Sample No.	*Biological oxygen demand B.O.D. mg/l*	*Chemical oxygen demand C.O.D m3g/l*	*Total Phosphorous mg/l as P*	*Dissolved oxygen mg/l*	*Ammonia Nitrogen mg/l as N*	*Nitrate mg/l as NO_3^-*	*Sulfate mg/l*	*Total Alkalinity mg/l as Ca CO_3*	*Chloride mg/l*	*pH*
1	Nil	88	Nil	6.4	0.00	26.60	2894	64	24492	7.30
2	Not available	105	0.740	6.2	3.70	28.30	4180	60	24073	7.20
3	296	376	3.120	6.1	18.00	119.00	270	72	6084	7.40
4	812	2095	3.810	5.9	36.00	130.00	919	70	1108	7.25
5	51	1265	0.100	2.5	2.24	48.00	3315	220	5498	8.50
6	19	352	0.920	6.3	35.00	16.50	1757	220	15100	8.00
7	29	7680	0.200	5.2	18.00	13.10	3407	136	22193	8.10
8	Nil	130	0.100	6.3	Nil	18.00	3500	65	22600	8.00
9	Nil	125	Nil	6.0	Nil	17.00	2900	68	22950	8.20
10	Nil	118	Nil	6.4	Nil	8.00	2600	84	23826	8.00
11	Nil	114	Nil	6.3	Nil	8.40	2820	90	23492	8.20
12	Nil	217	Nil	6.5	Nil	8.90	2680	114	24000	8.15
13	Nil	160	Nil	6.6	Nil	8.40	2940	69	24200	7.40
14	2	188	0.003	6.3	Nil	7.72	2770	84	24800	7.35
15	Nil	168	Nil	6.1	Nil	10.30	2750	110	24300	7.50
16	3	156	0.001	4.8	Nil	13.00	4800	240	66000	8.20
17	Nil	148	Nil	5.6	Nil	6.90	2950	92	22992	7.48
18	3	224	0.020	4.9	Nil	7.50	3210	84	22050	7.50
19	Nil	1270	0.010	4.6	Nil	40.0	4000	88	23200	7.70
20	Nil	233	0.010	6.3	Nil	8.15	3020	76	24192	7.60
21	Nil	480	0.001	6.0	Nil	9.44	2950	80	24000	7.40
22	Nil	236	0.010	5.9	Nil	6.40	2975	74	24240	7.50
23	Nil	180	Nil	6.4	Nil	8.40	3000	78	23900	7.75
24	Nil	181	Nil	7.3	Nil	7.50	2980	76	24020	7.80

Sampling stations 8 to 11, 13, 17, 15 do not receive directly any point sources of pollution. However, recreational activities are common all along this section of the coast. There is also free exchange of water between the coast and the main sea which will result in reducing the concentration of pollutants that find their way into the bottom. This is indicated by the absence of BOD, phosphorous, and ammonia nitrogen. The concentration of COD ranges from 114 to 217 mg/l and nitrates from 8 to 18 mg/l which are also low with values being closer to background sea levels. The concentrations of chlorides and sulfates are also similar to those of sea water. Relatively higher pH values at some of these sampling stations are indicative of the algal growth.

Stations 14, 16, 18, and 19 are located on small lakes/lagoons which are not connected to the sea at surface but may have connections to the sea through underground pipes. With the exception of lagoon corresponding to Sampling Station 14, all others are suspected to receive waste from the nearby buildings and recreational areas. These three lakes have low dissolved oxygen levels ranging from 4.6 to 4.9 mg/l indicating pollution by biodegradable organic matter. In addition, the chlorides and sulfates are very high at Sampling Station 16. Lolo Park Lake also has COD concentration of 1,270 mg/l which is quite high and sulfates are also high possibly resulting from the addition of chemicals, which also changes the general color of the lake water.

The condition of Obhur creek is indicated by the results at Sampling Stations 20, 21, and 22. As mentioned earlier, there are considerable boating and recreational activities in this section, but there is restricted water exchange with the open sea. The COD concentrations are higher in comparison to the background sea levels. The same is true for phosphorous concentrations. The results do not show very high levels of pollution but as the boating activity would pick up in future, the situation may worsen.

The Sampling Stations 23 and 24 receive waste from the recreational areas Madinat al Buhairat and Durratal Arus, which are still under the stage of development. The wastes generated are small in quantity and discharged to locations where free water exchange occurs. This results in low concentration of various pollutants as given in the Table 3. However, as the development of the coast proceeds, the pollution loads will increase significantly affecting the quality in the near-shore waters.

Conclusion

Samples of the Red Sea water were collected along the coast near Jeddah and analyzed for various water quality parameters. Based on the results and discussion of the results, the following conclusions are drawn:

1. There is a considerable variation in the quality of the Red Sea water along the coast. High levels of BOD up to 812 mg/l, COD up to 7680 mg/l, phosphorous up to 3.81 mg/l and nitrogen up to 28.30 mg/l. Some of the locations show that the coastal waters are receiving considerable amounts of pollutants from the urban population, recreational activities, and other development in the coastal area.
2. Highest levels of pollutants have generally been found at locations where the sea is contained in the form of lakes/creeks, which receive direct wastewater inputs. Here, the BOD values range from 51 to 812 mg/l near Balad Lake. The concentrations of the pollutants are the lowest at the sites where there is open exchange of water with the sea and the direct point sources of pollution are not present. At these locations, BOD concentration is negligible.
3. The use of Obhur creek as a recreational area is expected to increase significantly especially when the boating activity increases in future. This may have serious adverse environmental impacts since there is a limited water exchange between the creek and the open sea.
4. Secondary level of treatment is provided to the collected wastewaters from Jeddah city without removing nutrients. As a result, the coastal areas of the Red Sea are being enriched with nutrients especially the creeks/lakes with limited water exchange with the main sea. Signs of eutrophication are already visible at some of the locations.
5. The present study covers an important stretch of the Red Sea near Jeddah and provides a general picture of the impacts of the coastal development on the Red Sea water quality.
6. There are other cities and population centers along the eastern coast of the Red Sea which are contributing significant pollution loads. In order to assess the total input of pollutants to the eastern coast of the Red Sea, it is recommended that detailed investigations should be carried out in the vicinity of these areas.

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