

Water Quality of Red Sea from Jeddah to Yanbu; A case study of comparison in the Water quality between the localized pollution at coastal cities and the undisturbed normal waters of Red Sea, Kingdom of Saudi Arabia

Dilshad Thalappil¹, Virupaxappa S Betageri¹, Latha M.S.² and Suresha Gududappa³

¹*Department of Chemistry, GMIT, Davanagere, Karnataka India,*

²*PG Department of Chemistry, Adikavi Sri Maharshi Valmiki University, Raichur, Karnataka, India*

³*Environmental Balance Research Institute, Jeddah, Kingdom of Saudi Arabia*

(Received 14 August, 2025; Accepted 3 October, 2025)

ABSTRACT

The Red Sea features include a long, narrow shape between Africa and the Arabian Peninsula, a high salt content, extensive coral reefs, and a unique ecosystem with many endemic species. The Red Sea has a high salt content, which contributes to its clear water because algae cannot spread easily. The present study was undertaken between January 2024 to December 2024 to identify the water quality between the coastal cities, Jeddah, Thuwail, King Abdullah Economic City, Rabigh, Al Rayees and Yanbu Industrial City to identify the impact of localized pollution. The water samples were collected at 6 stations from the coast of each township and 2 samples from the undisturbed area. The water quality results showed deviations in terms of Electrical Conductivity, Salinity, TDS, Turbidity, pH, BOD, COD, Nitrate, phosphates, TOC, Chlorophyll A and heavy metals (such as Copper, Iron and Lead),

Key words: *Red Sea, Water Quality, Physico chemical parameters, Salinity, TDS, TOC, Bio Diversity, Jeddah, Thuwal, KAEC, Rabigh, Al Rayees, Yanbu*

Introduction

A vast expanse of saltwater covers around 71% of the Earth's surface contains high levels of salt, making it unsuitable for drinking. Seas and Oceans provide habitats for a wide composition of marine plants and animals and vary in depth, with some areas being shallow and others extremely deep. One of the world's last hidden treasures, The Red Sea is home to the one of the world's largest barrier reef systems. This 28,000-square-kilometer have featured

an archipelago of over 90 untouched islands, dormant volcanoes, sweeping desert dunes, mountain canyons, and culturally rich historical sites.

The Red Sea water quality and Coral reefs are the oldest and richest habitats on our planet and provide a home for over 1,200 different fish species. Scientists have discovered over 250 different types of coral reefs, either naturally grown or artificially created over several decades through storms, wartime events and sunken ships. The Red Sea is the world's northernmost tropical sea and possesses unique geo-

logical formations and natural phenomena including deep trenches, giant walls and the most diverse and stunning coral in the world. The Red Sea has a total length of about 2000 km, a maximum width of 355km and an average depth of 490m (Yao *et al.*, 2014), with a maximum depth around 2860m (Augustin *et al.*, 2014).

The Red Sea has high salinity and temperature, with generally low nutrient levels, but water quality varies significantly between open water and coastal areas. Coastal areas, particularly near human activity, can show signs of pollution, such as high levels of organic matter, bacteria, and heavy metals, while the open water is relatively clean. Massive developments at the coastal cities and townships of Red Sea of Saudi Arabia.

Study Area

Saudi Arabia has numerous cities along the Red Sea coast, with Jeddah being its largest and most commercially significant. Other key cities include Yanbu, known for industrial and tourism purposes, Umluj, often called the “Saudi Maldives,” and Duba, a port city and a hub for NEOM. The coastline is also home to major luxury tourism projects like The Red Sea Project, which includes destinations like Al Wajh, and the elite travel destination of Sindalah Island.

The important cities and towns from South of Saudi Arabia to North of Saudi Arabia are Jizan, Shuqaiq, Jazan Economic city, Al Lith, Shoaiba, Jeddah, Thuwal, King Abdullah Economic City, Rabigh, Petro Rabigh, AlRayees, Yanbu, Umluj, Amaala, Duba, Neom, AlWajh and Haql

Jeddah: A major commercial capital and the

“Jewel of the Red Sea,” featuring modern infrastructure alongside the historic UNESCO World Heritage site of Al Balad.

Yanbu: A historic city on the coast, known for both its industrial importance and status as the “scuba diving capital of Saudi Arabia”.

Umluj: A coastal town famous for its pristine islands and crystal-clear waters, earning it the nickname “Saudi Maldives”.

Duba: A port city in the northwest that serves as a ferry hub for Egypt and Jordan and is a logistical hub for the NEOM project.

The Red Sea Project: A large-scale regenerative tourism destination stretching between Umluj and Al Wajh, featuring luxury resorts and pristine natural landscapes.

Al Wajh: A coastal city that is part of The Red Sea Project development.

AlUla: A city known for its cultural heritage and stunning desert landscapes, with Red Sea-linked experiences also offered.

King Abdullah Economic City (KAEC): A modern city with beaches, resorts, and golf courses.

NEOM (Sindalah Island): A luxury hub for yachts and elite travel experiences.

Materials and Methods

Materials and methods for water quality studies of Red Sea on the coastal cities and townships of Saudi Arabia involve

- Collecting seawater samples in sterilized bottles,
- On-site measurement of parameters like pH, EC, Temperature, Turbidity, Salinity, TDS, Dissolved Oxygen

Table 1. Climate and oceanographic condition of the study area

	Winter	Summer
Prevailing wind direction	NNW	NNW (SSE)
Average wind strength	>6m/s	>4m/s
Maximum storm strength	15m/s	
Maximum storm surge height	>1.5 m	
Prevailing dust storm direction	East	West-WSW
Average air temperature (maximum)	~21°C (>24°C)	~33°C (>40°C)
Average humidity range	>50%	>30%
Mean rainfall (1980 to 2015)	<0.25 mm/day	<0.1mm/day
Mean evaporation – Red Sea	>1.8m/year	<0.7m/year
Sea surface water temperature	21–23°C	29–31°C
Bottom water temperatures (30m water depth)	21–26°C	26–29°C
Tide daily	0.1–0.8m	0.1–0.8m
Tidal current speed	<0.1–0.5m/s	<

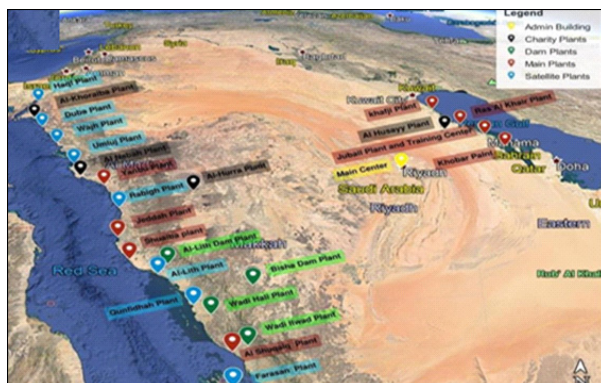


Fig. 1. The cities and Townships on the Eastern coast of Red Sea

- Laboratory analysis for physical, chemical, and biological parameters.

Methods include analyzing inorganic nutrients and heavy metals using standard protocols (e.g., AAS, and microwave digestion, HPLC). Statistical analyses like correlation, principal component analysis, and water quality indices are used to evaluate the data. Standard Procedures of USEPA (United States Environmental Protection Agency), APHA, AWWA A total of 6 Water Samples from, Jeddah, Thuwal, King Abdullah Economic City, Rabigh, Al Rayees and Yanbu during January 2024 to December 2024. Simultaneously two Water samples were collected between Jeddah and Thuwal, and another between Al Rayees and Yanbu as reference stations. The water samples were sent a third-party independent laboratory for the analysis of Physico chemical and biological parameters. At each station water samples were collected 1 meter below the surface ,1 meter above the sea bed and 1 from mid depth using Niskin water sampler and then a composite sample was made. In addition, on site measurements were taken using YSI Data Sonde portable water quality analyzer.

- **Nutrient analysis:** Standard protocols for sea-water analysis were used to measure inorganic nitrogen compounds (Chlorophyll A, Phosphate, and nitrate) and phosphate.
- **Heavy metal analysis:** Metals like Copper (Cu), Iron (Fe), and Lead (Pb) are quantified. Atomic Absorption Spectrophotometer (AAS) was used.
- **Organic matter:** Total organic carbon (TOC) is analyzed after removing carbonates.

Data analysis and interpretation

- **Statistical methods:** Statistical techniques such Average, Minimum, Maximum, Range, Standard deviation for all the stations including reference stations to identify patterns and sources of contamination.
- **Magnitude of pollution.:** Line graphs were plotted for the city stations and reference stations to visualize the deviations.
- **Spatial analysis:** GIS software like ArcGIS is used to create maps

The composite water samples were collected from the locations marked in Figure 2. Two liters of composite water samples were collected from 8 sampling stations as described below. The water samples were collected and preservatives were added. Then samples were sent to a Saudi Arabian Government certified laboratory for the analysis of physico-chemical parameters. Simultaneously the in-situ measurements were taken at all the eight stations using YSI data sonde for pH, Temperature, Turbidity, Electrical Conductivity, and Dissolved Oxygen.

Considering the pollution threat on water quality of Red Sea in specific the stretch between Jeddah and Yanbu, a total of 8 Stations were chosen for the present study, Following are the coastal cities and townships chosen for the present study.

1. **Jeddah:** This is a world class city commonly known as commercial capital of Saudi Arabia. There are several Power plants, Desalination plants, Five industrial city in the south, Jeddah Islamic port, Red Sea Gate way terminal, King Abdul International Airport, Recreational beaches, corniche and Boat clubs, marine traffic, new construction projects and Sewage Treatment Plants. All these infrastructure facilities are imposing stress on marine environment of Red Sea. The pollution from all the above components resulted in deterioration of rich coral habitat, in general marine flora and fauna
2. **Thuwal:** This is a township having a world class university "King Abdullah University of Science and Technology (KAUST)" situated 90 km north of Jeddah. There are coastal construction projects, Desalination plants, STP's Power Plant are depending Red Sea for water for power plants, potable water and discharge of treated sewage effluent. These activities-imposed stress on water quality of Red Sea
3. **Rabigh:** This is a small coastal city dedicating for power generation, production of fresh water,

oil refinery at Petro Rabigh and Arabian Cement Factory. There are 4 desalination plants and 4 Power plants, are located at this city supplying power and fresh water for Makkah, Jeddah, King Abdullah Economic City. Rabigh is situated 120 kms north of Jeddah.

- King Abdullah Economic City (KAEC):** This city is the vision of HRH King Abdullah in 2006, a new city built on the coast of Red Sea 160 km north of Jeddah consisting of Residential sector, an industrial valley with more than 150 major and minor industries, a commercial sector and a sea port King Abdullah Port. Desalination plants and Power Plants are dedicated to supply of Power and Fresh water. All these components including KA Port operations and STP's posing stress on Red Sea Water quality and affected fragile coral reef (Bleaching of Coral reef) and marine flora and fauna.

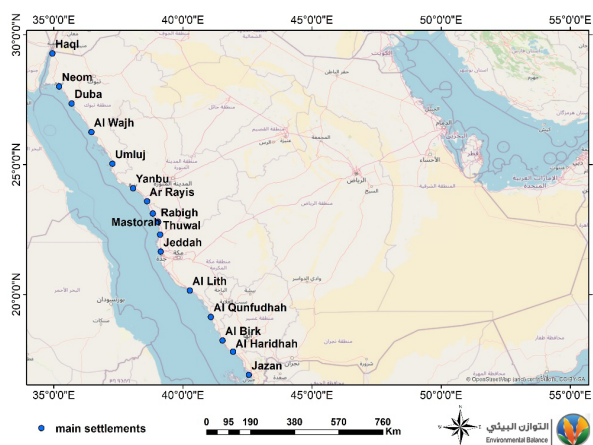


Fig. 2. Map showing Cities and towns on the coast of Red Sea, Kingdom of Saudi Arabia

- Al Rayees:** This town is also dedicated to fresh water to Makkah, Madinah. 2 Desalination plants were built on Red Sea Coast. The brine from these desalination plants is being discharged to Red Sea causing elevated levels of salts resulted in imbalanced osmoregulation.
- Yanbu:** This city is known as Yanbu industrial city having several, major, medium and minor industries. Apart from these there is a cluster of desalination and power plants are situated on the Red Sea coast. There are Yanbu commercial port and King Fahd industrial ports are operating undoubtedly polluting coastal waters of Red Sea.

In addition to these six coastal cities, two reference sampling stations Ref-1 between Jeddah and Thuwal and Ref-2 between Al Rayees and Yanbu as shown in Figure 3. These 2 locations are free from anthropogenic activities. There is no pollution and

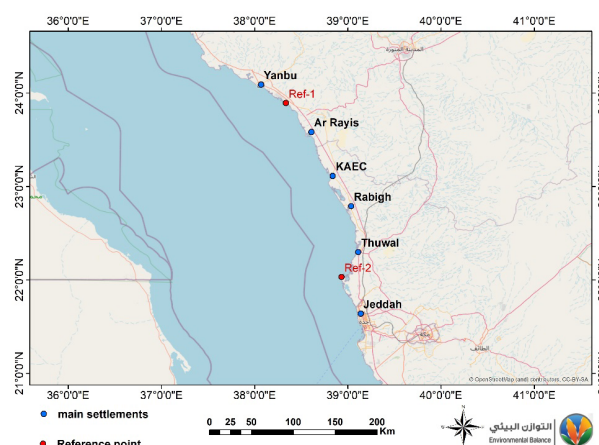


Fig. 3. Map showing Sampling Locations

Table 2. Present the results of physical parameters. (Measurement Time (10: 00 -11:00))

Location	Temp (C)	pH	DO (%Sat)	DO (mg/l)	Turb (NTU)	EC (µS/cm @25 °C)	Salinity Ppt	TDS mg/l
Jeddah	29.76	8.21	111.80	9.30	0.67	66323.25	39.80	46200.00
Tuwal	29.88	8.22	112.52	9.40	0.17	66080.00	40.10	43700.00
KAEC	29.53	8.21	112.02	8.50	0.00	65901.67	39.70	42900.00
Rabigh	30.10	8.20	136.10	9.20	0.20	65661.00	41.20	45800.00
Rayis	32.96	8.20	135.23	9.70	0.08	67169.50	39.50	46100.00
Yanbu	31.90	8.01	118.50	9.00	1.02	67750.00	39.80	45200.00
Ref 1	31.50	8.20	120.20	9.40	0.40	67032.00	39.40	41500.00
Ref 2	31.00	8.40	162.30	9.50	0.50	66080.00	39.20	41400.00
Average	30.83	8.21	126.08	9.25	0.38	66499.68	39.84	44100.00
Minimum	29.53	8.01	111.80	8.50	0.00	65661.00	39.20	41400.00
Maximum	32.96	8.40	162.30	9.70	1.02	67750.00	41.20	46200.00
Standard Deviation	1.22	0.10	17.62	0.37	0.34	730.92	0.62	2005.71

the locations are rich in mangrove strands, and Coral reef.

These two reference stations were chosen to compare the water quality with the water quality of the 6 cities with localized pollution

The study was organized to sampling and analysis of water samples from Jeddah, Thuwal, King Abdullah Economic City, Rabigh, Al Rayees and Yanbu.

Total 8 samples from 6 cities and 2 references were collected and tested for various physical and physico chemical parameters.

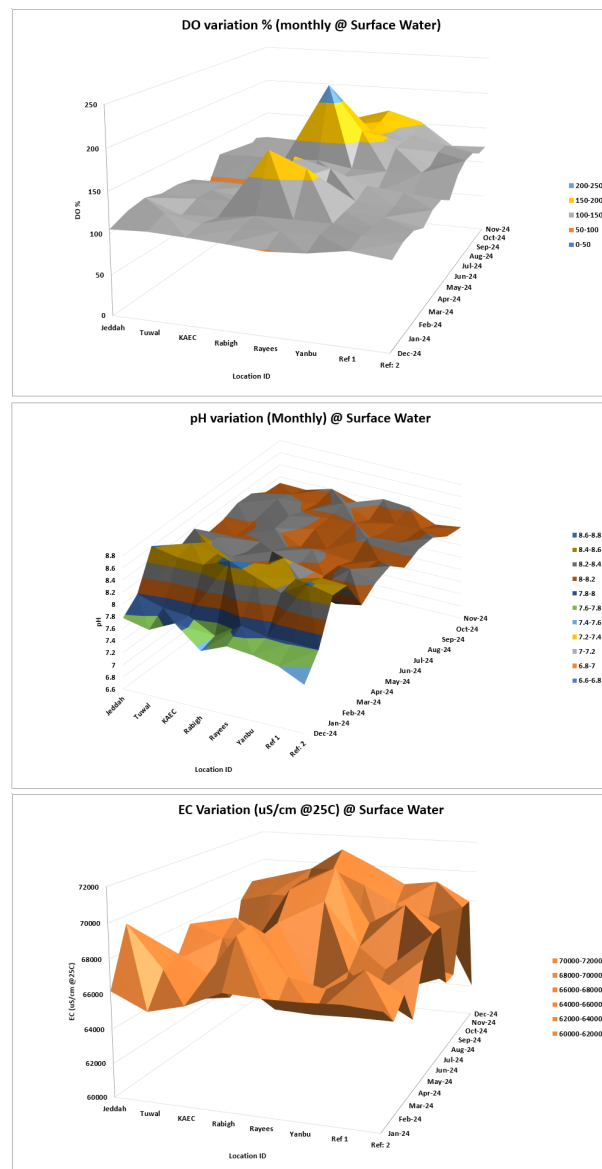


Fig. 4. Graphs showing the comparison of pH, DO and EC at all the 8 stations

Results of Water Quality

1. Physical Parameters

Discussion

The current study was conducted to assess the water quality of Red Sea from coastal cities where in localized pollution was observed due to various anthropogenic activities and the reference stations.

Red Sea water quality between Jeddah and Yanbu is generally unpolluted, characterized by high salinity, clarity, and warmth, but localized pollution from coastal activities (heavy metals, nutrients) near cities and industrial zones like Yanbu. This needs monitoring, with desalination, power generation efforts providing high-quality drinking water and progressively increased demand of power supply.

During the current investigation in all the 6 samples from the coastal cities with localized pollution from discharge of brine, cooling water, treated sewage disposal, recreational activities, dredging and reclamation of new developments, maintenance dredging at sea ports at Jeddah, King Abdullah Port, Yanbu commercial port and King Fahd Industrial port, turning basins and Navigation channels resulted in deteriorated water quality. These activities cause bleaching of Corals. In the present study it was found that the average values of Turbidity are too low to cause the mortality of corals the most fragile living beings. The higher concentrations of 162.30% dissolved oxygen concentration increase the photosynthesis activity and in turn favours the abundant biodiversity.

- BOD and COD values are ranging between 10 and 20 mg/l and 8 to 15 mg/l respectively which might be attributed closure of illegal discharge of raw sewage. Municipality of these cities implemented stringent rules with huge penalties. National center for wild life and National center for Environmental compliance have taken proactive steps to conserve marine resources. The discharge of brine, TSE, and cooling water are extended from 4 to 6.5 Km to the best mixing zone upon conducting marine recirculation, brine dispersion modeling studies. This is the reason for lower concentration of BOD and COD values.
- Further the nutrients, Nitrates, Phosphates and TOC values are far below the Saudi Arabian Environmental Standards. Due to stringent rules

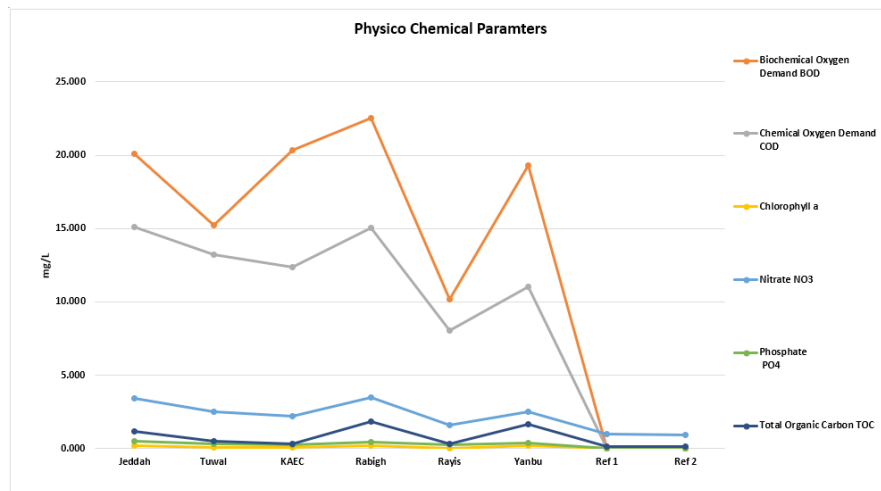


Fig. 5. Results of Physico-Chemical Parameters analyzed for 8 Stations

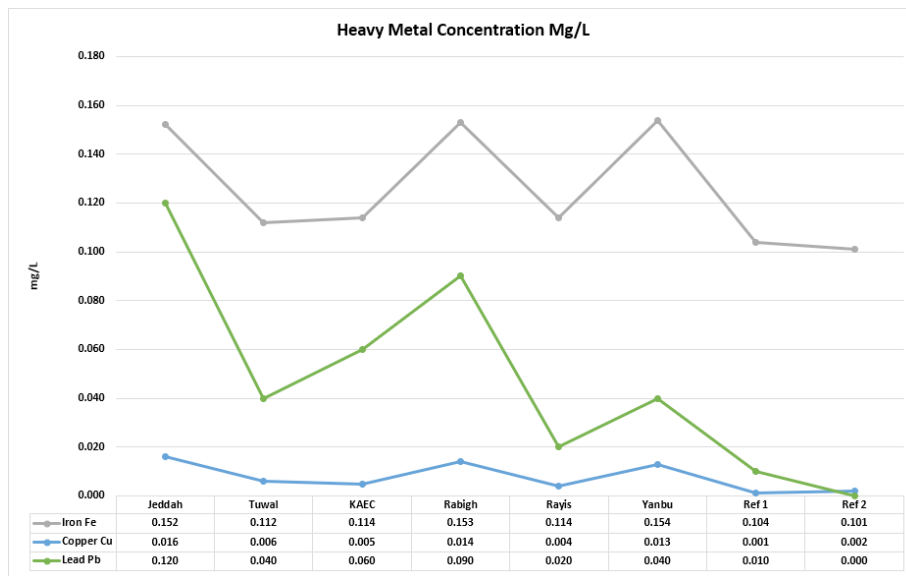


Fig. 6. Results of heavy metals analyzed for 8 Stations

Table 3. Results of Physico Chemical Parameters analyzed for 8 Stations

Location	BOD	COD	Chlorophyll a	NO ₃	PO ₄	TOC	Lead Pb	Copper Cu	Iron Fe
Jeddah	20.100	15.120	0.210	3.400	0.490	1.150	0.120	0.016	0.152
Thuwal	15.250	12.250	0.100	2.500	0.300	0.480	0.040	0.006	0.112
KAEC	20.360	12.350	0.080	2.200	0.240	0.300	0.060	0.005	0.114
Rabigh	22.500	15.050	0.180	3.500	0.440	1.850	0.090	0.014	0.153
Al Rayees	10.200	8.040	0.040	1.600	0.240	0.320	0.020	0.004	0.114
Yanbu	19.300	11.050	0.170	2.500	0.400	1.650	0.040	0.013	0.154
Ref 1	<5	<5	0.020	1.000	0.020	0.130	0.010	0.001	0.104
Ref 2	<5	<5	0.000	0.900	0.010	0.160	0.000	0.002	0.101
Average	17.952	12.477	0.100	2.200	0.268	0.755	0.048	0.008	0.126
Minimum	10.200	8.040	0.000	0.900	0.010	0.130	0.000	0.001	0.101
Maximum	22.500	15.120	0.210	3.500	0.490	1.850	0.120	0.016	0.154
Standard Deviation	4.479	2.681	0.079	0.986	0.180	0.694	0.041	0.006	0.023

Note: All values are in mg/l

and regulations of governmental authorities, the discharge of TSE, Brine and Illegal sewage are prohibited. The port operators are taking care of, Ballast Discharges, shipwrecks, oil spills.

Red Sea Water Quality Characteristics (Jeddah to Yanbu)

- **Salinity, TDS& Temperature:** High Salinity and TDS (around 39-42 ppt and 41,000 - 46,000 uS/cm @25C) due to evaporation and there is no inflow; temperatures gradually decrease from south (Jeddah) to north (Yanbu) but remain warm.
- **Clarity:** High transparency, though slightly lower in the south (Jeddah) compared to northern areas, Rabigh, Al Rayees and Yanbu.
- **Natural Inputs:** Mostly marine water, with some influences from wadis potentially introducing natural minerals and pollutants from the Arabian Shield.

Conclusion

In all the open Red Sea is pristine, coastal areas near cities and industries (Jeddah, Rabigh, KAEC and Yanbu) show signs of pollution, though desalination plants convert this seawater into high quality drinking water.

Key Areas & Concerns

- **Jeddah:** Experiences some localized pollution (heavy metals like Iron, Copper, Lead) in its lagoons, likely from urban and port activities, impacting overall water quality indices.
- **Yanbu:** This industrial hub, showing higher concentrations of certain heavy metals (Iron, Copper, Lead) in its lagoons compared to Jeddah, indicating industrial impacts.
- **Coastal Pollution:** General concerns exist across the Saudi Red Sea coast regarding anthropogenic sources (human activities) introducing potentially toxic elements (PTEs) and nutrients into sensitive mangrove ecosystems.

Drinking Water Quality

- **High Quality:** Water from Red Sea desalination plants (like those serving Makkah Al Mukarramah, Madinah Al Munawwarah, Jeddah, Thuwail, Rabigh, KAEC, Al Rayees and Yanbu) should be monitored closely in order to

meet the high standards, with low heavy metals compared to global standards.

Further Steps

Regular water quality monitoring has to be conducted to ensure the localized pollution from the Power Plants, Desalination plants, operation of sea ports careful maintenance works are minimized. Continuous monitoring of marine flora and fauna especially coral reef, Sea Grasses, benthic invertebrates, fishes. The discharge of brine, cooling water, treated sewage effluent, illegal discharge of sewage, capital dredging, ballast water discharge, loading and unloading of oil and petrochemicals, Oil and chemical spills, ship wrecks should be avoided using Best available Technologies.

Conflict of Interest- None

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- USEPA -United States Environmental Protection Agency (EPA) protecting people and the environment from significant health risks, sponsors and conducts research, and develops and enforces environmental regulations.