ENVIRONMENTAL POLLUTION: IMPACT ON SHIPS AND INFRASTRUCTURE ON KARACHI HARBOR

S. M. Shahzad

Vice-Chancellor, Minhaj University Lahore
Commodore.shahzad@gmail.com

ABSTRACT: Karachi harbor has an immense operational infrastructure of Pakistan National Shipping Corporation (PNSC), Pakistan Navy (PN), and Pakistan Maritime Security Agency (PMSA). It is significant for the readiness of PN and PMSA for peace and wartime operations. Although the Government of Pakistan has declared Karachi Port Complex a National Vulnerable Area, Karachi's coast receives massive pollutants from various land and sea sources. The primary sources include liquid discharge from industry and solid effluents of the municipality. The non-availability of disposal facilities and the absence of effluent treatment plants add to the misery. Toxic liquids and solid pollutants remain in the harbor for extended intervals. This pollution threatens the marine environment and ocean life and degrades water quality. These pollutants also affect the life of assets and infrastructures, including incoming and parked ships, which deteriorate fast. This paper includes the sources of pollution and the current state of Karachi harbor. Also, possible outcomes of the growing pollution fall into the domain of this study.

Keywords: Karachi, harbor, pollution, infrastructure, environment.

(Received 16.03.2023 Accepted 25.06.2023)

INTRODUCTION

Since oceans make up such a large percentage of the earth's surface and are so profoundly deep, it may appear that littering them with waste and polluting them with chemicals would have no impact whatsoever. Yet, that is not the case. Human actions are damaging the world's waters. Marine pollution is an urgent problem that has to be solved quickly. Oil spills, land-based sources, persistent organic pollutants (POPs), heavy metals, radioactive materials, overfishing, marine trash, and the extinction of marine creatures are only a few of the numerous dangers that marine ecosystems face today (Aronson, et al. 2011). Since the 1980s, for instance, we have successfully prevented three-fourths of all oil spills and 75% of all tanker catastrophes (ITOPF 2022). Although heavy metal emissions are lower than in the past, this issue persists in other regions (Järup 2003). Electronic garbage and mining tailings significantly contribute to heavy metal contamination in the Arabian Gulf area (Ali, et al. 2021). Dredging increased coastal development, and the release of raw sewage into the ocean negatively affectcoastal marine ecosystems and contribute to the spread of excessive nutrients in these environments (Chen, et al. 2021). These things, as well as rising ocean temperatures, the loss of sea ice, and the potential for future shifts in ocean currents, may significantly affect marine ecosystems (Steiner, 2016).

Physical, thermal, chemical, and biological marine pollutants can be in the ocean (Wilhelmsson, et al. 2013). The marine environment divides into several categories depending on the origin of the pollution that is a direct consequence of human actions. Each typeaffects the many maritime ecosystems (Matthies-Wiesler and Fleming 2019). Chemical pollution, for instance, harms marine ecosystems and biota, whereas biological pollution may affect all three (Macleod, et al. 2016).

Mechanical Impairment: A rise in seawater temperature and salinity and an increase in the amount of sediment suspended in the water are all indicators of pollution (Omer 2019).High temperatures in the ocean may be brought on by the weather, whereas high salinity can be brought on by either geological or climatological processes (Olson, et al. 2022). The North Arabian Sea is becoming saltierdue to rising temperatures and solar radiation (Piontkovski 2014). Many marine creatures experience respiration and ecotoxicological impacts due to thermal stress (Madeira, et al. 2018). Increasing salinity due to brine flows impacts confined, relatively stationary water (Usman Tariq, Maritime Security Expert, Personal Communication).Raised floating debris in the ocean is another biological pollution that disrupts the natural equilibrium between light transmission and photosynthesis (Piontkovski 2014). Suspended matter concentrations are affected by the kind of bed sediments and the energy associated with water movements (Olson, et al. 2022). Construction projects, such as dredging, may drastically alter suspension states. Ecological consequences include habitat loss, fish species injury, and the loss of seagrass beds, which the government has documented in addition to the decline in photosynthesis and essential production (Erftemeijer and Lewis

2007).Air temperatures in the North Arabian Sea may reach 45 degrees Celsius in the summer. High-temperature, high-salinity effluent from desalination and power facilities become the basisfor the region's rising temperatures (Dols 2019).

Pollution from Chemicals: Chemical waste contaminates marine ecosystems. Sediments, water, and living organisms all contain it. Accidental or spontaneous oil spills, wastewater from industrial and agricultural operations, and air deposition associated with a chemically contaminated environment are all potential causes of chemical pollution (Briffaa, Sinagrab and Blundell 2020). Oil leak incidents cause a lot of this kind of pollution in the Arabian Gulf area. This kind of pollution results in the formation of oily layers, which may have devastating effects on marine life and force the closure of coastal infrastructure like desalination plants and the cessation of tourism. Many marine creatures are sensitive to petroleum hydrocarbons, which are present in oil spills and oil dispersion compounds employed during cleanup procedures (Saadoun 2015). Oil spills on the beach have a devastating effect on the intertidal and subtidal ecosystems. The presence of agrochemicals in water supplies has biological and ecological consequences (EPA 2019). Pesticides and POPs, or persistent organic pollutants, have devastating effects on marine life (Saadoun 2015). Industrial point or multipoint effluent is a significant contributor to trace metal contamination in the marine environment (Bandara and Manage 2022).

Radioactive Waste Disposal: Even though it has nothing to do with Pakistan's EEZ, nuclear dumping is a significant problem since it pollutes the ocean and endangers marine life and human health (Gillani 2019).Eutrophication is another negative consequence of nuclear waste disposal since it is a biological process in which oxygen is produced in excess owing to dissolved nutrients, leading to a hypoxic or oxygen-deprived environment that is hazardous to marine life (National Ocean Service 2022). In addition, nuclear waste disposal can potentially wipe out whole ecosystems (U.S. Energy Information Administration 2022). Recycling and reducing garbage production are two ways to curb ocean dumping. Beginning in 1969, people used incineration to regulate the dumping of hazardous substances. The 1970s widely implemented this practicedue to widespread adoption by various nations. Multiple studies have examined how reliable and secure this method is (Oppelt 2012). When hazardous materials burn, toxic substances are released into the air and may drift over the ocean. Every year, the quantity of trash discharged into the seahas to be reduced, yet incineration is an unsafe option because of the smoke it produces (IAEA 2011).

A Look at the Origins of Marine Pollution

Dredging and Reclamation: Extensive dredging and reclamation are necessary for construction projects. However, the Clifton Beach region of Karachi, which has seen significant recreational, housing, and commercial growth, is negatively impacting the coastal and marine habitats of the North Arabian Sea (Ahsanullah, et al. 2021). Dredging and reclamation may have immediate and delayed effects on the chemical, biological, and physical environments (Chen, et al. 2021). Deoxygenation of the subsoil and coastal waters may be a direct result of these operations, which can also cause physical damage to the species living there. Dredging and reclamation, which include chemical and biological changes, may reduce marine life's variety, number, abundance, and biomass. Heavy metal concentrations by dredging and reclamation projects are high. Shellfish and fish, two staples of the food web, might be harmed if these particles make their way up the chain (Ahsanullah, et al. 2021). The correct disposal of nuclear waste requires that it be stored in drums to prevent the material from spreading after it sinks to the ocean bottom. One curie (Ci) equals the quantity of radioactive material that disintegrates at 37 billion times per second (3.7 x 1010). At this rate, one gram of radium decomposes per second. The becquerel (Bq) is a relatively new measurement unit based on the quantity of radioactive material that causes one decay per second. About 27 urie are equivalent to 1 terabecquerel (TBq) (Choucri, 2001, p. 22).

Dangerous Waste Discharges: Sewage discharges from Karachi are the primary source of pollution in the harbor. Domestic runoff is dumped in considerable volumes in the Karachi harbor, despite the better standards of sewage treatment facilities managed by the Karachi Water Board and KPT (Shahzad 2020). Several nutrients, including nitrate, ammonia, and phosphate, are abundant in these outflows. The heavy metals and other chemical and biological contaminants in sewage dischargers harm fish reproduction in the Karachi mangroves (Shahzad 2020).

Pollution from Industry: The region around Qasim Port has seen considerable development, especially in the oil refining, chemical industry, and tannery sectors. As effluents, these large businesses release many substances, such as heavy metals, fertilizers, and hydrocarbons (Khan, et al. 2009). Grease, oil, sulfides, phenols, suspended particles, ammonia, and heavy metals, including iron, chromium, nickel, molybdenum, copper, selenium, zinc, and vanadium, are only some of the substances found in petroleum refinery discharges (Shahzad 2020). The harbor and port Qasim regions surrounding Karachi are "hotspots" for more significant amounts of highly polluted water.

Reverse Osmosis Systems: Increased industrialization, population expansion, and building activity along the coast of Pakistan have contributed to a rise in demand for potable water in the area (Maqbool 2022). Due to limited precipitation and excessive aridity in the coastal population, seawater helps supply most freshwater needs (Naorem, et al. 2023). Methods, including desalination, are used for this goal. Rejected water from desalination facilities flows into coastal and subtidal areas. Researchers have found higher concentrations of heavy metals and building materials near the Gwadar port's desalination facilities (Qari and Khalid 2018).

Oil Spills: Regarding oil, the Arabian Gulf is the world's most enormous reservoir. The pollution in the Arabian Gulf is a result of oil exploration, production, and transportation. Offshore oil wells, oil tanker accidents, undersea pipelines, oil terminals, loading, and other operations connected to oil, used oil, illegal dumping of ballast water, and military actions are all contributors to oil pollution in the Arabian Gulf (Al-Saad and Salman 2012). The Arabian Gulf has been the site of several accidental oil spills. In the 1991 Gulf War, for instance, roughly 10.8 million barrels of oil were lost in the Arabian Gulf. The Indian Ocean has also seen periods of increased oil discharge (Farrington, 2013).

Toxic Airborne Substances from Ship Emissions: Tank washings, ballast water, and engine room effluent releases are three forms of ordinary ship operations that contaminate the sea and are just as prevalent as accidental contamination produced by ships. These operations release a substantial quantity of oil daily into the ocean. Marine and coastal ecosystems are especially vulnerable to damage from pollution (BillFreedman 1995).Everyone from OPEC oil producers to bunker fuel distributors and shipping corporations is worried about the new laws came into effect in 2020 to cut pollution caused by the world's ships. Sulfur, a component of acid rain that harms plants and animals, will reduce emissions due to the legislation (Adeola, et al. 2022). However, the shipping and energy sectors are unprepared, with refiners likely unable to fulfill the increasing demand for cleaner fuel and few vessels equipped to decrease sulfur emissions (Bandara and Manage 2022). As a result, the likelihood of chaos during the transition to the new regulations and increased volatility in the oil market increases.

Unless a ship can reduce its sulfur emissions, the new IMO regulations will prevent it from using fuel with a sulfur level of more than 0.5%, down from the current 3.5%. Vessels that don't follow the rules will have to pay penalties, risk losing their insurance, and might even be labeled "unseaworthy" and banned from the water (Directorate-General for Mobility and Transport 2022).These new regulations wouldimpact on the market for fuel oil. The world's maritime fleet uses roughly 4 million barrels per day (BPD) of high-sulfur fuel oil (George and Ghaddar 2018). However, the average market prediction produced by Norway's SEB Bank predicts that this need will "vanish" by 2040 at a rate of about 3 million BPD. Marine gas, oil, and a low-sulfur distillate fuel can replace coal as the most popular alternatives. Over the next three years, this can increase distillate demand by at least 1.5 million BPD, according to Morgan Stanley's projections, for a total of 3.2 million BPD. As a result, costs will rise (Qaiser and Grigoriadis 2020).

The forward curve projects that the current gasoline premium of over $250 per ton above fuel oil will increase to almost S380 per ton by the beginning of 2021. According to data compiled by Thomson Reuters Research, fuel accounts for over 50% of a ship's daily operational costs (Sharafedin 2022). A ship that uses cleaner energy would incur customary charges of $6,000 to $20,000, based on average fuel consumption of 20 to 80 metric tons per day (MT/day) (United Nations Conference on Trade and Developments 2018). The ship's owner may utilize dirtier fuel oil by installing a "scrubber" to eliminate sulfur emissions. Certain vessels already had them installed (Hickin 2020).However, the most significant open issue is how these regulations will be in effect. As installing scrubbers is expensive and the premium for cleaner fuel is high, many ships may attempt to circumvent the new restrictions (Hickin 2020). However, estimates of the percentage of industrial cheaters range from 10-40%. If boats don't have scrubbers, the International Maritime Organization will prohibit them from transporting fuel oil, making them easier to apprehend. When the restrictions took effect in 2020, BP estimated that 10% of ships would violate them (Bergqvist, Turesson and Weddmark 2015).

It will be challenging for refineries to keep up with the increased demand. The global refining sector needs to process an additional 2.5 million BPD of oil to create distillates for cleaner fuel (Gallucci 2018). Though some refiners have invested in reducing sulfur output, experts estimate that it may cost as much as $1 billion to retrofit a refinery with a hydrocracker or Coker unit to increase the production of distillates with reduced sulfur content while decreasing fuel oil output. Some smaller refineries may discover they are producing fuel oil but have no customers because they cannot finance the upgrade (Bergqvist, Turesson and Weddmark 2015). According to a report, forty percent of Middle Eastern and European refineries are unprepared. Most of the difficulty may lie in producing fuel oil by European facilities, which are often less sophisticated than those in other locations (Turner 2022).

Meanwhile, the crude market isn't without its problems. Refineries can easily manufacture gasoline with less sulfur by purchasing and processing crude with less sulfur, which may alter the demand for various oil grades and cause higher volatility in the oil market. For comparison, companies produce roughly 12 percent of fuel oil from processing light, sweet North Sea crude with little sulfur concentration, while as much as 50 percent from processing the Basra Heavy grade from Iraq, which has a high sulfur level (Daily Times 2018). There will be a bidding war for sweet crude (Cho and Cheong 2020). Sweeter crudes, such as several grades used to produce dated IBrent, the benchmark for three-quarters of the world's oil, might see price increases. The price of processing "sour" crude from countries like Venezuela, Mexico, and Ecuador that contain higher sulfur "may be greater than its worth (Cho and Cheong 2020).Margin pressure is possible for energy and shipping companies. However, in the long run, shoppers may expect to pay more for goods like refrigerators and fuel due to increased transportation expenses. About 90% of international commerce takes place on the ocean. Wood Mackenzie predicts that by 2020, worldwide shipping fuel prices will have increased by S24 billion, or 25% (Mowat 2022).

RESULTS

This study estimates that a total of 472 MGD is produced by Karachites on the daily basis, out of which, at least 411 MGD liquid effluents, 122 MGD of municipal garbage and 350 MGD of industrial waste, is dumped into Karachi Harbour and the surrounding coastal waters of Karachi every day (Figure 1& Figure 2).

Both chemical oxygen demand (COD) and biological oxygen demand (BOD5) often quantify the load of organic pollution in water bodies. The Lyari River outfall location has high COD and BOD5 in the surrounding monitoring sites (LS-1, LS-3, S-1A, and S-1C). Authorities continuously discharge Karachi's home and industrial wastes, leading to a steady decline in water quality measured by the maximum value in Karachi Port, near the Lyari River mouth. Scientific analysis shows that the western backwaters of Karachi Harbour, where organic and inorganic wastes from homes and factories are dumped into the Lyari River, have a disproportionately negative impact on the marine ecology of the city. Further, the residents' untreated household garbage also drains into the harbor. Figure 3 and figure 4 show these findings in detail.

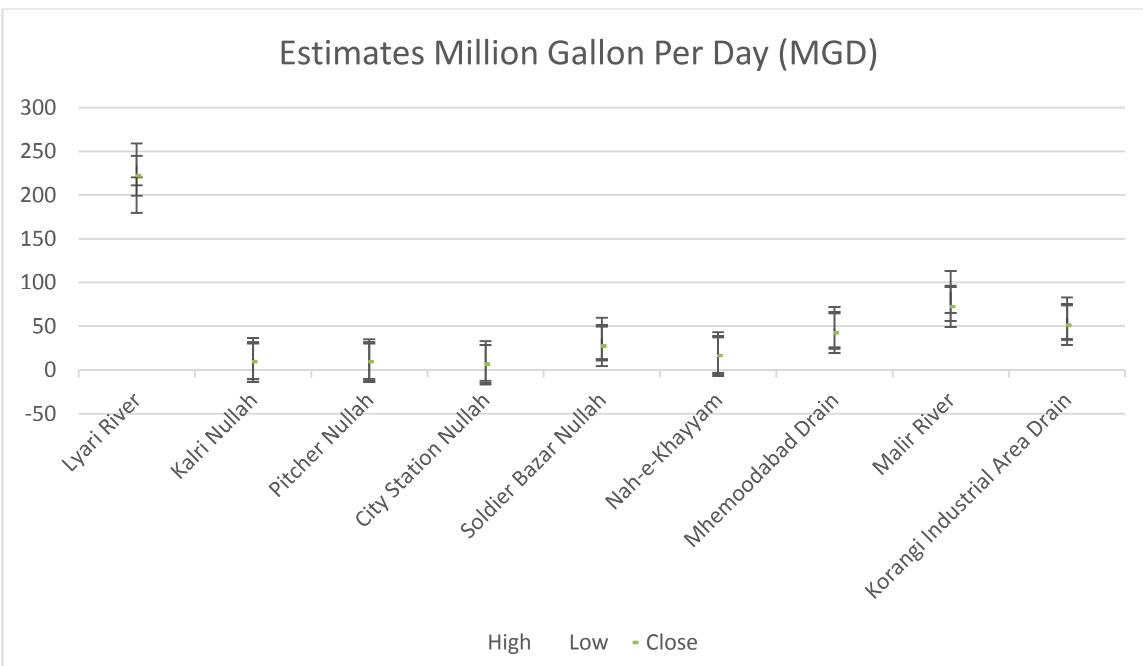

Figure 1: Land-Based Sources of Marine Pollution Dumped into Karachi Harbor (Karachi Water & Sewerage Board 2021)

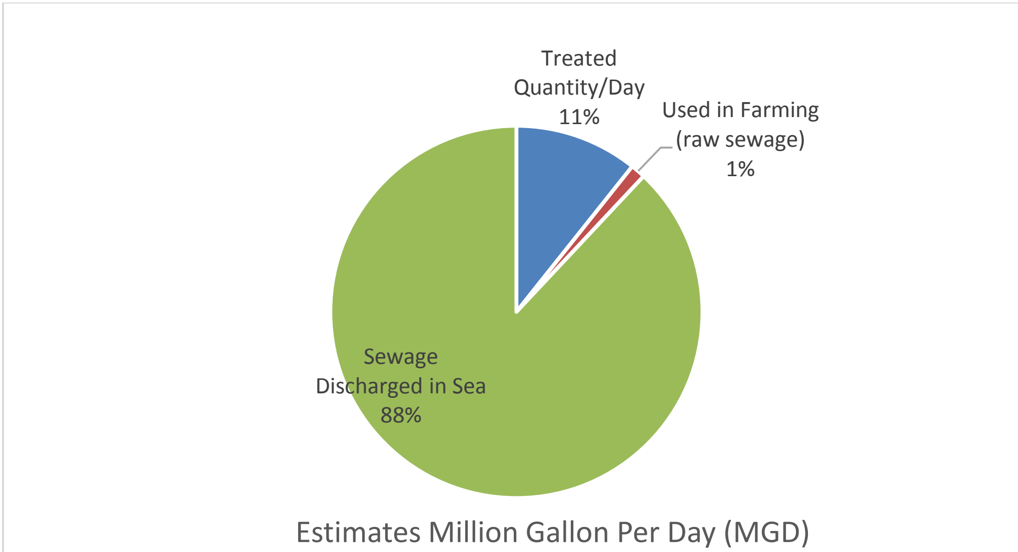

Figure 2: Current Ratio of Sewage Treatment from the Total of 55 MGD/Day (Karachi Water & Sewerage Board 2021)

There are three Sewage Treatment Plants (STP) with an optimum design capacity (ODC) of around 150 MDG/day. However, these plants are working below their ODC (Figure 3).

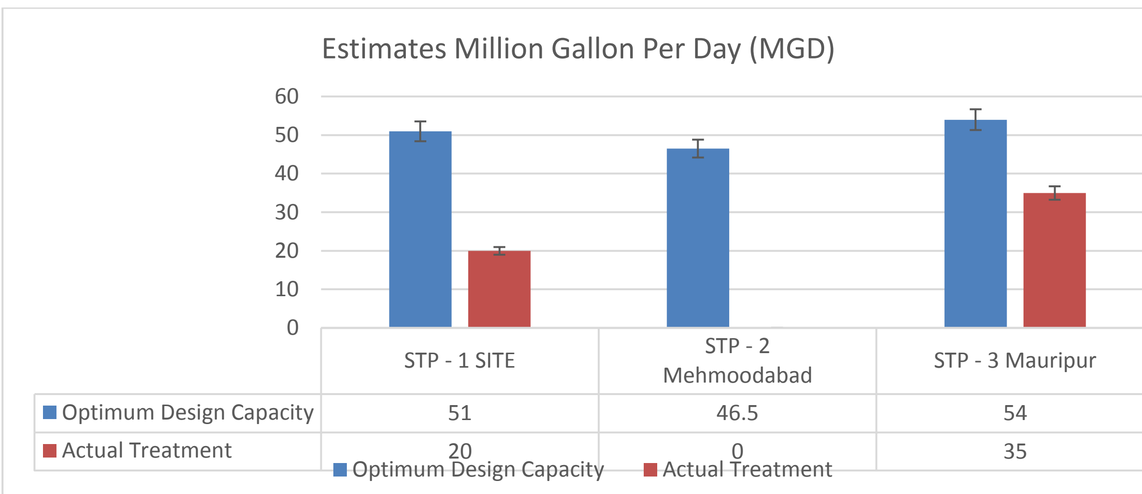

Figure 3: Status of Sewage Treatment Plants (STP) in Karachi with a Comparison of Optimum Design Capacity and Actual Treatment (Karachi Water & Sewerage Board 2021)

S.No.	Sampling Site	Physicochemical Parameters						Heavy Metals (mg/l)			
		Temp ^{0}C	Turbidity NTU	TDS (g/l)	Salinity (%)	COD (mg/l)	BOD (mg/l)	Pb	Cd	Ni	Hg
1	LS-1	32.3	1.70	30.1	31.5	2120	910	0.9024	0.9700	16.7673	0.0493
2	LS-3	32.6	1.35	32.0	33.4	2015	830	0.8798	0.6392	13.9764	0.0219
3	S-1 A	32.5	1.87	32.3	33.7	1150	640	0.7187	0.8957	14.4401	0.0116
4	S-1 C	32.3	1.20	33.2	34.7	1010	510	0.6887	0.6945	11.0631	0.0103
5	S-2 A	32.3	2.05	34.4	35.9	2040	870	0.5045	0.4973	13.4021	0.0325
6	S-2 C	32.0	1.68	33.7	35.1	390	174	0.2122	0.2649	12.4319	0.0107
7	S-3 A	32.1	1.68	30.6	32.5	570	220	0.5267	0.7091	16.9830	0.0126
8	S-3 C	31.8	1.57	34.3	35.8	2036	180	0.3796	0.3879	13.6080	0.0093
9	S-4 A	32.5	1.64	33.8	35.2	2098	215	0.7331	0.8095	14.5392	0.0208
10	S-4 C	32.2	1.40	33.8	35.3	750	340	0.6048	0.6002	11.4907	0.0120

Figure 4: Samples Data of Seawater Surface Karachi Harbor(Nergis, Butt and Sharif 2021)

S.No.	Sampling Site	Physicochemical Parameters						Heavy Metals (mg/l)			
		Temp ^{0}C	Turbidity NTU	TDS (g/l)	Salinity (%)	COD (mg/l)	BOD (mg/l)	Pb	Cd	Ni	Hg
1	LS-1	32.4	2.95	30.3	31.6	2240	1030	0.9911	0.9764	17.9874	0.0918
2	LS-3	32.6	1.96	31.7	33.0	1992	970	0.8952	0.7359	15.1397	0.0728
3	S-1 A	32.3	3.32	33.0	33.7	1030	490	0.8602	0.9243	15.3997	0.0562
4	S-1 C	32.4	1.53	33.2	34.6	870	380	0.8001	0.6333	13.4538	0.0494
5	S-2 A	32.2	1.61	34.6	36.1	1740	730	0.6271	0.5561	12.3927	0.0411
6	S-2 C	32.1	1.63	33.5	34.9	210	97	0.4958	0.4542	11.5024	0.0289
7	S-3 A	32.1	1.53	30.9	35.6	447	190	0.8050	0.9021	14.0764	0.0216
8	S-3 C	31.5	1.17	34.2	35.6	513	225	0.4128	0.8416	10.0284	0.0118
9	S-4 A	32.1	6.32	34.0	35.4	950	438	0.8870	0.7997	15.7752	0.0227
10	S-4 C	32.2	1.55	33.9	35.4	271	129	0.8024	0.7002	12.6082	0.0209

Figure 5: Samples Data of Seawater at 10 feet depth (Nergis, Butt and Sharif 2021)

DISCUSSION

The Consequences of Karachi Harbor's Marine Pollution: Karachi harbor is home to the precious operating and maintenance infrastructure of the Pakistan Navy and the Pakistan Marine Security Agency, in addition to being a hub for national and commercially critical maritime commerce infrastructure (Shahzad 2020). The necessary support structures must be in place for the Pakistan Navy and PMSA to carry out their many peacetime and military missions. The Government of Pakistan has identified the Karachi Port Complex as a 'National Vulnerable Area' for its strategic importance (Shahzad 2020).

Karachi Harbour Suffers from Marine Pollution: While much of Pakistan's coastline is clean, both inland and coastal sources often pollute the sea around Karachi. Land-based sources, including liquid effluent of industrial and municipal origin and solid trash, mainly pollute Karachi Harbour. Karachi is the hub of most polluting industries, where poor sewage treatment, disposal infrastructure, and a lack of effluent treatment plants are to blame for the city's pollution crisis (Javaid and Shahzad 2016).

Thousands of tonnes of household, commercial, industrial, and medical trash are produced daily in Karachi alone (Javaid and Shahzad 2016). Much of this garbage isn't collected and flushed away, so it ends up in Karachi Harbor's sewage system.

Toxic chemicals, metals, oil, and grease make their way into the coastal food chain from around 20% of untreated sewage and garbage, devastatingly affecting human health (PJ, et al. 2020). The chemicals make seawater more corrosive by changing its chemistry (Parvin, et al. 2020). The destruction of the coastal ecology and the subsequent potential effect on Pakistan's blue economy are further consequences of the ocean's absorption of excess carbon dioxide at the surface (PJ, et al. 2020). The Ministry of Defense informed the Commission on Water and Sanitation on June 4, 2018, that the Cantonment Board Clifton (CBC) and the Defense Housing Authority (DHA) had been instructed not to dispose of untreated sewage into the sea and a proposed to install a sewage treatment plant, which is one of the recent developments to control the release of raw sewage into the sea (Shahzad 2020).

Effects of Marine Pollution on Ships and Port Infrastructure: Liquid and solid pollutants remain in the harbor for prolonged periods as they are not wholly flushed out into the open sea due to the natural geography of the sanctuary, making harbor waters even more hazardous (PJ, et al. 2020). Polluted saltwater accelerates corrosion, which speeds up the hull degradation of ships and submarines. Dockyard Laboratory found that mild steel loses 5.48 g/m2 per day in open saltwater, whereas Karachi Harbor loses 9.20 g/m2 per day (Hussain, et al. 2022). The researchers estimate that Karachi Harbor marine pollution shortens ships' lifespan by roughly 33 percent.Frequent breakdowns and flaws in ship machinery, equipment, saltwater pumps, and pipelines directly result from seawater's high corrosion rates. Polluted water used for cooling purposes in ships' engines shortens their lifespan owing to corrosion of the water circulation channel and scaling of the intake (Nanan 2020).

Sheet piles of jetties, berths, docks, port terminals, and other harbor appliances deteriorate more quickly than other parts of the maritime infrastructure and need more regular repair (Nanan 2020). Hydrographic equipment, beacons, anchors, floats, and other installations are all susceptible to corrosion and malfunction when exposed to polluted and highly corrosive water.

Conclusion: When the floating trash, particularly polyethylene bags, clogs the cooling water intake of ships and boats, it causes problems for their operations in the harbor. Multiple times, solid garbage in the port has damaged the engines of PMSA's jet-propelled Fast Response Boats (FRBs).Floating trash and extremely harmful pollutants reduce the aesthetic value and quality of life in and around the port and pose operational and maintenance challenges.The approximate cost of a modern, large navy ship is $300 million. For the Pakistani Navy, losing a ship with a 33 percent life expectancy costs almost $90 million.Authorities have renovated the Naval jetties on the PIDC channel at around Rs. 470 million.The study estimates that over the course of their service careers, marine pollution will cost the Pakistan Navy over $1 billion in repairs to its ships, submarines, and equipment. On September 16, 2015, the Dockyard Laboratory confirmed (Shahzad 2020) this by testing a water sample from Karachi Harbor.

REFERENCES

Adeola, Adedapo O., Adedibu S. Akingboye, Odunayo T. Ore, Oladotun A. Oluwajana, Adetola H. Adewole, David B. Olawade, and Abimbola C. Ogunyele. 2022. "Crude oil exploration in Africa: socio-economic implications, environmental impacts, and mitigation strategies." *Environment Systems and Decisions* 42: 26-50. doi:10.1007/s10669-021-09827-x.

Ahsanullah, Shaukat Hayat Khan, Razzaq Ahmed, and Muhammad Luqman. 2021. "Morphological change detection along the shoreline of Karachi, Pakistan using 50 year time series satellite remote sensing data and GIS techniques." *Geomatics, Natural Hazards and Risk* 12 (1): 3358–3380. doi:10.1080/19475705.2021.2009044.

Ali, Mir Mohammad, Delower Hossain, Al-Imran, Md. Suzan Khan, Maksuda Begum, and Mahadi Hasan Osman. 2021. "Environmental Pollution with Heavy Metals: A Public Health Concern." In *Heavy Metals - Their Environmental Impacts and Mitigation*, edited by Mazen Nazal and Hongbo Zhao. doi:10.5772/intechopen.96805.

Al-Saad, Hamed T., and Nader A. Salman. 2012. "Status of Oil Pollution in the Arabian Gulf and Shatt Al-Arab Estuary: A Review." In *Coastal Environments: Focus on Asian Regions. Springer, Dordrecht*, edited by V. Subramanian, 36-46. doi:10.1007/978-90-481-3002-3_3.

Aronson, Richard B., Sven Thatje, James B. McClintock, and Kevin A. Hughes. 2011. "Anthropogenic impacts on marine ecosystems in Antarctica." *Annals of the New York Academy of Sciences* 1223 (1): 82-107. doi:10.1111/j.1749-6632.2010.05926.x.

Bandara, Kumudu R.V., and Pathmalal M. Manage. 2022. "Heavy Metal Contamination in the Coastal Environment and Trace Level Identification." In *Marine Pollution - Recent Developments*, edited by Dr. Monique Mancuso, Dr. Ahmed Abdelhafez and Dr. Mohamed Abbas. Intech Open. doi:10.5772/intechopen.106653.

Bergqvist, Rickard, Marcus Turesson, and Alexander Weddmark. 2015. "Sulphur emission control areas and transport strategies -the case of Sweden and the forest industry." *European Transport Research Review.* doi:10.1007/s12544-015-0161-9.

BillFreedman. 1995. *Oil Pollution.* 2. Elsevier. doi:10.1016/B978-0-08-050577-0.50011-X.

Briffaa, Jessica, Emmanuel Sinagrab, and Renald Blundell. 2020. "Heavy metal pollution in the environment and their toxicological effects on humans." *Heliyon* 6 (9). doi:10.1016/j.heliyon.2020.e04691.

Chen, Xi, Yanhua Wang, Tian Sun, Yu Huang, Yan Chen, Mingli Zhang, and Chun Ye. 2021. "Effects of Sediment Dredging on Nutrient Release and Eutrophication in the Gate-Controlled Estuary of Northern Taihu Lake." *Journal of Chemistry* 2021. doi:10.1155/2021/7451832.

Cho, Sharon, and Serene Cheong. 2020. "Oil Bidding War Underway Among Asian Refiners." *Bloomberg.* 11 17. https://www.rigzone.com/news/wire/oil_bidding_war_underway_among_asian_refiners-17-nov-2020-163878-article/.

Daily Times. 2018. "New rules on ship emissions herald sea change for oil market." *dailytimes.com;.pk.* 7 18. https://dailytimes.com.pk/241446/new-rules-on-ship-emissions-herald-sea-change-for-oil-market/.

Directorate-General for Mobility and Transport. 2022. "New shipping fuel standards to reduce sulphur oxides in the Mediterranean by 80%." *Mobility and Transport*, December 16. https://transport.ec.europa.eu/news/new-shipping-fuel-standards-reduce-sulphur-oxides-mediterranean-80-2022-12-16_en.

Dols, F.L. 2019. "Impact of Desalination and Climate Change on salinity in the Arabian Gulf." University of Twente, 7. http://essay.utwente.nl/79579/1/Dols%2C%20F.J.%201862227%20_openbaar.pdf.

EPA. 2019. *Understanding Oil Spills and Oil Spill Response.* Annual Reprt, United States Environmental Protection Agency - Office of Emergency And Remedial Response. https://www.epa.gov/sites/default/files/2018-01/documents/ospguide99.pdf.

Erftemeijer, Paul, and Roy Lewis. 2007. "Environmental impacts of dredging on seagrasses: A review." *Marine Pollution Bulletin* (PubMed) 52 (12): 1553-72. doi:10.1016/j.marpolbul.2006.09.006.

Gallucci, Maria. 2018. "At Last, the Shipping Industry Begins Cleaning Up Its Dirty Fuels." *YaleEnvironment360*, 6 28.

https://e360.yale.edu/features/at-last-the-shipping-industry-begins-cleaning-up-its-dirty-fuels.

George, Libby, and Ahmad Ghaddar. 2018. "New rules on ship emissions herald sea change for oil market." *Reuters*, 7 17. https://www.reuters.com/article/us-shipping-fuel-sulphur-idUKKCN1II0PP.

Gillani, Syed Anwar-ul-Haq. 2019. "Pakistan and the Sea: Preserving the Marine Environment." *The Pulse.* 1 19. https://thediplomat.com/2019/01/pakistan-and-the-sea-preserving-the-marine-environment/.

Hickin, Paul. 2020. "Don’t write an obituary for shipping’s dirtiest fuel." *Commodity Insights*, 6 3. https://www.spglobal.com/commodityinsights/en/market-insights/blogs/oil/060320-dont-write-an-obituary-for-shippings-dirtiest-fuel.

Hussain, Iftikhar, Haiyan Wang, Muhammad Safdar, Quoc Bang Ho, Tina D. Wemegah, and Saima Noor. 2022. "Estimation of Shipping Emissions in Developing Country: A Case Study of Mohammad Bin Qasim Port, Pakistan." *International Journal of Environmental Research and Public Health* 19 (19). doi:10.3390/ijerph191911868.

IAEA. 2011. *Disposal of Radioactive Waste.* IAEA SAFETY STANDARDS SERIES No. SSR-5, Vienna: International Atomic Energy Agency. https://www-pub.iaea.org/mtcd/publications/pdf/pub1449_web.pdf.

ITOPF. 2022. *Oil Tanker Spill Statistics 2022.* Accessed December 29, 2022. https://www.itopf.org/knowledge-resources/data-statistics/statistics/.

Järup, Lars. 2003. "Hazards of heavy metal contamination." *Br Med Bull* 68: 167-82. doi:10.1093/bmb/ldg032. PMID: 14757716.

Javaid, Umbreen, and S M Shahzad. 2016. "Development of Shipping Sector in Pakistan: Options and Proposed Strategy." *Political Studies* 23 (2): 537:559. https://www.researchgate.net/publication/338912956_Development_of_Shipping_Sector_in_Pakistan_Options_and_Proposed_Strategy.

Karachi Water & Sewerage Board. 2021. Accessed 1 3, 2023. https://www.kwsb.gos.pk/.

Khan, Muhammad Uzair, Kanwal Nazim, Moinuddin Ahmed, Syed Shahid Shaukat, Qadeer Mohammad Ali, Agha Tahir Hussain Durrani, and Wafra Matanat Zaheen. 2009. "An Assessment of Pollution in Major Creeks Around Port Qasim." *Pakistan Journal of Marine Sciences* 18 (1&2). https://core.ac.uk/download/pdf/200762016.pdf.

Macleod, Catriona K., Ruth S. Eriksen, Zanna Chase, and Sabine E. Apitz. 2016. "13 Chemical pollutants in the marine environment: causes, effects, and challenges." In *Stressors in the Marine Environment: Physiological and ecological responses; societal implications*, edited by Martin Solan and Nia Whiteley, 228–246. Oxford. doi:10.1093/acprof:oso/9780198718826.003.0013.

Madeira, Carolina, Miguel C.Leal, Mário S.Diniz, Henrique N.Cabral, and Catarina Vinagre. 2018. "Thermal stress and energy metabolism in two circumtropical decapod crustaceans: Responses to acute temperature events." *Marine Environmental Research* 141: 148-158. doi:10.1016/j.marenvres.2018.08.015.

Maqbool, Nazam. 2022. "Water Crisis in Pakistan: Manifestation, Causes and the Way Forward." *PIDE Knowledge Brief* (2022:60). https://pide.org.pk/research/water-crisis-in-pakistan-manifestation-causes-and-the-way-forward/#Content-e323acc63d1186b9bd42.

Matthies-Wiesler, Dr Franziska, and Lora E. Fleming. 2019. *Health, the Global Ocean, and Marine Resources.* Health and Sustainable Development, World Health Organization. https://www.euro.who.int/__data/assets/pdf_file/0009/404496/SDG-14-policy-brief.pdf.

Mowat, Iain. 2022. "Decarbonising global shipping - Can alternative fuels set the global maritime trade on a course for net zero?" *WoodMackenzie.* 7 2. https://www.woodmac.com/news/opinion/decarbonising-global-shipping/.

Nanan, Krystal. 2020. "Introduction to the Chemistry of Pipes in Seawater." *Corrosionpedia*, 10 10. https://www.corrosionpedia.com/introduction-to-the-chemistry-of-pipes-in-seawater/2/6684.

Naorem, Anandkumar, Somasundaram Jayaraman, Yash P. Dang, Ram C. Dalal, Nishant K. Sinha, Ch. Srinivasa Rao, and Ashok K. Patra. 2023. "Soil Constraints in an Arid Environment—Challenges, Prospects, and Implications." *Agronomy.* doi:10.3390/agronomy13010220.

National Ocean Service. 2022. "What is eutrophication?" *oceanservice.noaa.gov.* 28. https://oceanservice.noaa.gov/facts/eutrophication.html.

Nergis, Yasmin, Jawad Abdullah Butt, and Mughal Sharif. 2021. "Assessment of Marine Coastal Water Pollution from Karachi Harbour Pakistan Yasmin Nergis, Jawad Abdullah Butt,Mughal Sharif." *International Journal of Economic and*

Environmental Geology 12 (2). doi:10.46660/ijeeg.Vol12.Iss2.2021.583.

Olson, Stephanie, Malte F. Jansen, Dorian S. Abbot, Itay Halevy, and Colin Goldblatt. 2022. "The Effect of Ocean Salinity on Climate and Its Implications for Earth's Habitability." *Geophysical research Letters* 49 (10). doi:10.1029/2021GL095748.

Omer, Nayla Hassan. 2019. "Water Quality Parameters." In *Water Quality - Science, Assessments and Policy*, edited by J. Kevin Summers. IntechOpen. doi:10.5772/intechopen.89657.

Oppelt, E. Timothy. 2012. "Incineration Of Hazardous Waste." *JAPCA* 37 (5): 558-586. doi:10.1080/08940630.1987.10466245.

Parvin, Forida, Shariful Islam, Zakia Urmy, Shaharia Ahmed, and AKM Saiful Islam. 2020. "A Study on the Solutions of Environment Pollutions and Worker's Health Problems Caused by Textile Manufacturing Operations." *Journal of Scientific and Technical Research* 28 (4). https://biomedres.us/pdfs/BJSTR.MS.ID.004692.pdf.

Piontkovski, Sergey. 2014. "Long-term changes of temperature in the Sea of Oman and the western Arabian Sea." *International Journal of Oceans and Oceanography* 8 (1): 53-72. https://www.researchgate.net/publication/262415695_Long-term_changes_of_temperature_in_the_Sea_of_Oman_and_the_western_Arabian_Sea.

PJ, Landrigan, Stegeman JJ, Fleming LE, Allemand D, Anderson DM, Backer LC, Brucker-Davis F, and Chevalier N. 2020. "Human Health and Ocean Pollution." *Ann Glob Health* 86 (1). doi:10.5334/aogh.2831.

Qaiser, Imran, and Theocharis Grigoriadis. 2020. "Measuring the Ecological Efficiency of Thermal Power Plants: Evidence from Pakistan." *Asian Development Review* 37 (1): 159–184. doi:10.1162/adev_a_00145.

Qari, Rashida, and Khurrum Khalid. 2018. "Impact of sewage and industrial pollution on the hydrographic conditions of seawater in Gwadar (East Bay), Balochistan." *Global Journal of Biology, Agriculture, Health Sciences* 7 (2). https://www.walshmedicalmedia.com/open-access/impact-of-sewage-and-industrial-pollution-on-the-hydrographic-conditions-of-seawater-in-gwadar-east-bay-balochistan.pdf.

Saadoun, Ismail M.K. 2015. "Impact of Oil Spills on Marine Life." In *Emerging Pollutants in the Environment - Current and Further Implications*, edited by Marcelo L. Larramendy and Sonia Soloneski. Intech Open. doi:10.5772/60455.

Shahzad, Sajid Mehmood. 2020. *Impact of Pakistan Maritime Affairs on Blue Economy in Backdrop of CPEC.* Lahore: MQI Printers.

Sharafedin, Bozorgmehr. 2022. "Oil forward curves signal tight market, supporting price rally." *Reuters*, 1 21. https://www.reuters.com/business/energy/oil-forward-curves-signal-tight-market-supporting-price-rally-2022-01-31/.

Turner, Elza. 2022. "REFINERY NEWS ROUNDUP: Middle East's refineries on upgrades, region launches new plants." *Commodity Insights*, 6 17. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/petrochemicals/061722-refinery-news-roundup-middle-easts-refineries-on-upgrades-region-launches-new-plants.

U.S. Energy Information Administration. 2022. "Nuclear explained - Nuclear power and the environment." *eia.gov.* 11 7. https://www.eia.gov/energyexplained/nuclear/nuclear-power-and-the-environment.php.

United Nations Conference on Trade and Developments. 2018. *Review of Maritime Transport 2021*. UNCTAD/RMT/2021, United Nations. https://unctad.org/system/files/official-document/rmt2021_en_0.pdf.

Wilhelmsson, Dan, Richard C.Thompson, Katrin Holmström, Olof Lindén, and Hanna Eriksson-Hägg. 2013. "Marine Pollution." In *Managing Ocean Environments in a Changing Climate - Sustainability and Economic Perspectives*, 127-169. Elsevier. doi:10.1016/B978-0-12-407668-6.00006-9.