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# Hydrographic parameters and distribution of dissolved Cu, Ni, Zn and nutrients near Jeddah desalination plant

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**Abstract:** The development of safe desalination plants with low environmental impact is as important an issue as the supply of drinking water. The desalination plant in Jeddah (Saudi Arabia, Red Sea coast) produces freshwater from seawater by multi-stage flash distillation (MSFD) and reverse osmosis (RO). The process produces brine as by-product, which is dumped into the sea. The aim of this study was to assess the impact of Jeddah desalination plant on the coastal water in the nearby of the plant. Total concentrations of dissolved Cu, Ni, Zn and nutrients in several locations around the plant were analyzed by cathodic stripping voltammetry. The average levels of dissolved Cu, Ni, and Zn on surface in the sampling locations were 15.02, 11.02, and 68.03 nM respectively, whereas the levels at the seafloor near the discharging point were much higher. Distribution of temperature, salinity, nutrients and dissolved oxygen were quite normal both on surface and in depth.

**Keywords:** Desalination plant; Dissolved Cu, Ni, Zn; Nutrients; Hydrographic parameters.

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## 1 Introduction

Water is a vital and irreplaceable resource for drinking, farming and other human activities. The total water reserve on earth amounts to ~1.4 billion km$^3$. The scarcity of fresh water resource is a major threat to many arid regions of the world and will be increasingly important in the future. According to the survey of the United Nations (UN), Environment program lighted up that one-third of the world's population lives in countries with inadequate freshwater to uphold the population [1]. Out of the ~1.4 billion km$^3$ of the total global water reserves, approximately 97.5% is present in the Ocean [2] and most interestingly, of this around 0.014% is the available quantity of human beings and other organisms [3]. The range of salinity in sea water is 35000-45000 ppm [4-7], however, the permissible level of salinity in the drinking water is 500 ppm and for special case up to 1000 ppm [8]. This makes the importance of desalination plant in the present era. Drinking water can be produced from seawater by desalination, *i.e.*, by removing salts and minerals. By desalination, the seawater salinity level (35000–45000 ppm) is lowered to a level acceptable for drinking water (500–1000 ppm) [5].

Due to the improvements in membrane technology [9-12], the production cost of desalination water has been considerably decreased and is expected to decrease even further [13,14]. The methods used in many arid countries are desalination from sea water. In the case of the Kingdome of Saudi Arabia, it is a relevant matter. It has scarcely of sufficient portable water resources. Therefore, Saudi Arabia depends entirely on desalination of sea water to supply potable water. In fact, more than 20 years' desalination technology has assisted freshwater scarcity in the Middle East [15,16]. Moreover, it appears to be saviors for lack of rainfall in such countries as Australia [17]. The countries in the Middle East, Central Asia, and North Africa primarily depend on desalination for their drinking water needs [18,19]. Desalination could be superior options to cope with water scarcities for the countries close to coastal lands which represent 97% of the global water [20].

In fact, the desalination has become a globally useful method for delivering potable water [21]. The United States, Europe, China and Australia have a larger number of expanding desalination capacities [22], while Saudi Arabia, United Arab Emirates and Kuwait have almost half of the world's desalination water produced [21]. It is important to point out that urgent need for potable water has meant that historically environmental issues with desalination plants have been considered secondary importance [23].

However, a vital concern of desalination plants is the effects of the high saline water, which may contain residual chemicals and heavy metals. Hence, it is widely recommended that desalination plants have clear evidence of harmfull effect on physical, chemical and biological attributes of receiving marine environment [24-26]. Hence the environmental concerns are important to investigate before desalination option is undertaken [27]. In order to develop a safe and clean marine environment, desalination activities should be controlled by proper management, that need to be estimate the adverse effect of desalination process and to reduce those contrary impacts as much as possible[22]. In fact, desalination of seawater has a range of advantages including, human's daily needs, socio-economic and providing of good quality drinking water, maintain agricultural productions and helping restrict saline intrusion into coastal zone aquifers [22,28]. Even though, many negative effects have been recorded [28]. The provision of potable water for Jeddah city was the most pressing issue for both its rulers and residents throughout its long history. Located on the shore of the Red Sea, the city of Jeddah grew and developed on a barren stretch of land which is not just devoid of rivers and springs, but also lack any forms of drinkable water, not to mention it's salty soil, high temperature and scarcity and even lack of rain. So the development of desalination plant without much alteration in the environment and ecosystem is much important.

The technology which is used in desalination is a highly-advanced system, but it may have severe impacts on the marine environment should be managed and investigated [22]. Two common desalination methods are multi-stage flash distillation (MSFD) and reverse osmosis (RO) [2-4,9,13-15,18]. MSFD is a series of flash evaporations in which each flash process uses the energy released from the condensation of the water vapor in the previous step. RO uses pressure to force water through a semipermeable membrane against salt concentration gradient.

Jeddah is a city on the eastern coast of the Red Sea, in the Central-West part of Saudi Arabia. With a population of about 4 million people [29], Jeddah is the second largest city in Saudi Arabia after the capital Riyadh; it is also the largest sea port on the Red Sea and Saudi Arabia's commercial capital. The provision of potable water is the most pressing issue for the city, which has no rivers, springs, and hardly any rain (average rainfall = 53.5 mm/year). Therefore, an assessment of the environmental impact of Jeddah desalination plant would be important to a large number of people.

In this research, we investigated the distribution pattern of dissolved Cu, Ni, Zn and some nutrients in the coastal waters along Jeddah desalination plant. We also studied the distribution of four physico-chemical parameters: salinity, temperature, dissolved oxygen and pH.

## 2 Materials and methods

The study area is shown in Figure 1. Samples were collected in a 'net format' from stations approximately 250 meters away from each other. The discharge point is located 33 meters below sea level. Vertical profiling was only done along the coast near to the dumping point (Figure 1, stations 1-4). Surface monitoring was performed for all the sampling locations (stations 1-14). Samples were collected using a Niskin sampler previously washed with nitric acid. Hydrographic parameters were measured using a YSI multi-parameter Sonde device (USA). The concentration of dissolved metals was measured by cathodic stripping voltammetry using a Metrohm 797 VA Computrace system. The level of nutrients was determined by UV-vis spectrophotometry using a Shimadzu UV-2450 spectrophotometer. Salinity samples were standardized by an MS-310 micro-salinometer, whereas pH samples were standardized using a pH meter. Dissolved oxygen (DO) samples were collected and analyzed on the same day using Winkler's method.

Ethical approval: The conducted research is not related to either human or animals use.

## 3 Results and discussion

### 3.1 Salinity and temperature

The salinity pattern in cross-section and in surface is shown in Figures 2b and 2d, respectively. Salinity was higher near the bottom of the effluent plumes than on

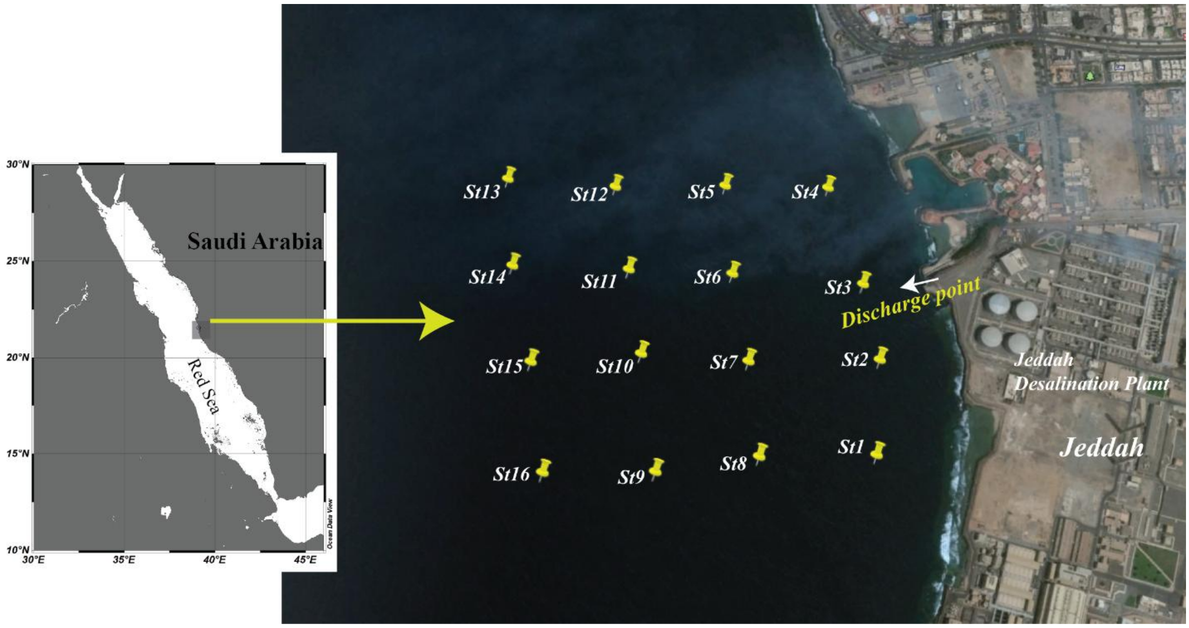


**Figure 1:** Sampling location in the coastal waters near Jeddah desalination plant.

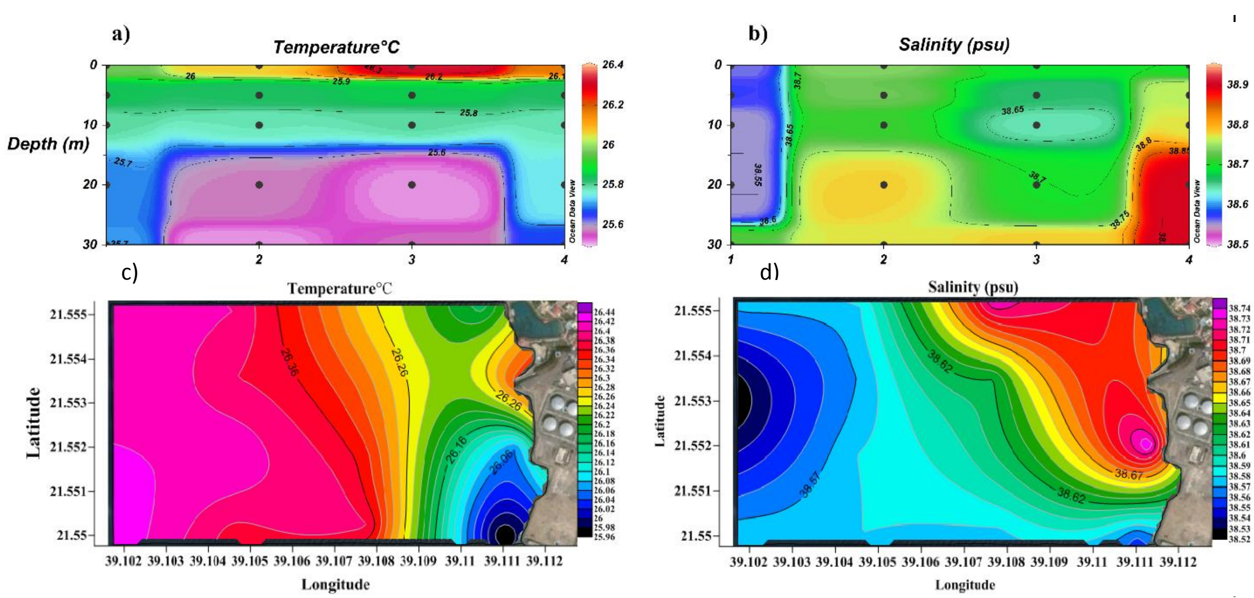


**Figure 2:** Cross-section profile of a) temperature and b) salinity; surface distribution pattern of c) temperature and d) salinity.

surface. This result can be easily explained considering that waste brine from desalination plants is almost twice as dense as intake seawater [17,30-32]; consequently, brine tends to stratify along the sea floor rather than on surface [33-36,38]. The highest values of salinity (38.90 psu) were found not in front of the plant (stations 2 and 3) but further north (station 4), probably due to the effect of deep sea currents.

On surface (Figure 2d), salinity remains 0.1 ppt higher than background value (38.62 psu) over an area of about 350 m alongshore × 100–400 m offshore (depending on latitude). Specifically, high salinity extends offshore more on the north side than on the south side of the plant, probably due to the effect of sea currents and tidal cycles [37,39]. Therefore, the coastal fringe is likely the most vulnerable to the harmful effects of desalination brine. Overall, the alteration in salinity observed in proximity of this desalination plant is lower than that measured for other plants (0.5–2.6 ppt, Table 1) [21].

**Table 1:** Extent and intensity of brine plumes in receiving waters surrounding desalination plant Discharge outlets.

| Reference | Capacity (ML/d) | Discharge(ML/d) | Brine salinity (ppt) | Location | Habitat | Plume extension and intensity |
|---|---|---|---|---|---|---|
| Abdul- wahab, 2007 [49] | 92.4 | NR | 37.3 | Muscat, Oman | Soft sediments | Returned to background levels within approximately 100 m of outlet. |
| Abdul-Wahab, 2007 [49] | 191 | NR | 40.11 | Muscat, Oman | Soft sediments | Return to background levels within 980 m from outlet. |
| Altayaran and Madany, 1992 [50] | 106 | 288 | 51 | Sitra Island, Bahrain | Soft sediments | Salinity of receiving water was 51 ppt relative to reference area (45 ppt); plume extended at least 160 m from discharge. Temperature also affected: discharged water at 10–15 °C above ambient, receiving water up to 7 °C above ambient. |
| Chesher, 1971 [33] | 9.1 | 22 | 40-55 | Florida, USA Artificial | hard and soft sediments | 0.5 ppt above background levels within 10-20 m of outlet. Slight elevation maintained for 600 m within the harbour basin. |
| Talavera and Ruiz, 2001 [51] | 25 | 17 | 75.2 | Canary Islands, Spain | Sub-tidal rocky reef | 2 ppt above background on the seabed and 1 ppt above background on the surface within the 20 m of the outlet; background levels measured at 100 m. |
| Einav et al., 2003 [52] | NR | NR | NR | Dhkelia, Cyprus | Not reported | Above background 100e200 m from outlet, occasionally as high as 60 ppt. |
| Fernández Torquemada et al., 2005 [53] | 50 | 75 | 68 | Alicante, Spain | Seagrass and soft sediments | 0.5 ppt above ambient for up to 4 km from outlet along the seafloor. |
| Malfeito et al., 2005 [54] | 28 | NR | 44 | Javea, Spain | Seagrass and | Slightly above background up to 300 m from the outlet. |
| Raventos et al., 2006 [44] | 60 | 33 | 60* | Blanes, Spain | Seagrass and soft sediments | Background levels reached within 10 m of outlet. No measurement or analysis of salinity. |
| Ruso et al., 2007 [55] | 50 | 65 | 68 | Alicante, Spain | Soft sediments | 2.6 ppt above ambient within 300 m of outlet; 1 ppt within 600 m; similar to background at 1300 m. |
| Safrai and Zask, 2008 [23] | 274 | 600 | 42 | Ashkelon, Israel | Not reported | Approximately 2 ppt above ambient within 400 m of outlet |

Desalination processes can increase the temperature of waste brine 10–15°C above seawater ambient temperature [22,40,42]. This happens because distillation plants heat the feedwater and this heat is largely retained in the waste brine. Such a temperature increase can play a significant effect on the marine ecosystem equilibrium [25,41]. Therefore, we analyzed the temperature distribution around the desalination plant. In cross-section, temperature raised quickly to background levels within 20 meters of outfall (Figure 2a). In the entire surface sampling area, temperature ranged between 25.5 and 26.4°C, very close to the Red Sea average temperature in that area (Figure 2c). Overall, the thermal effects associated to the desalination plant dissipate quickly to background levels [24].

## 3.2 Dissolved oxygen, pH and nutrients

Dissolved oxygen (DO) is an important indicator of water quality, because a reduction in DO may have a negative

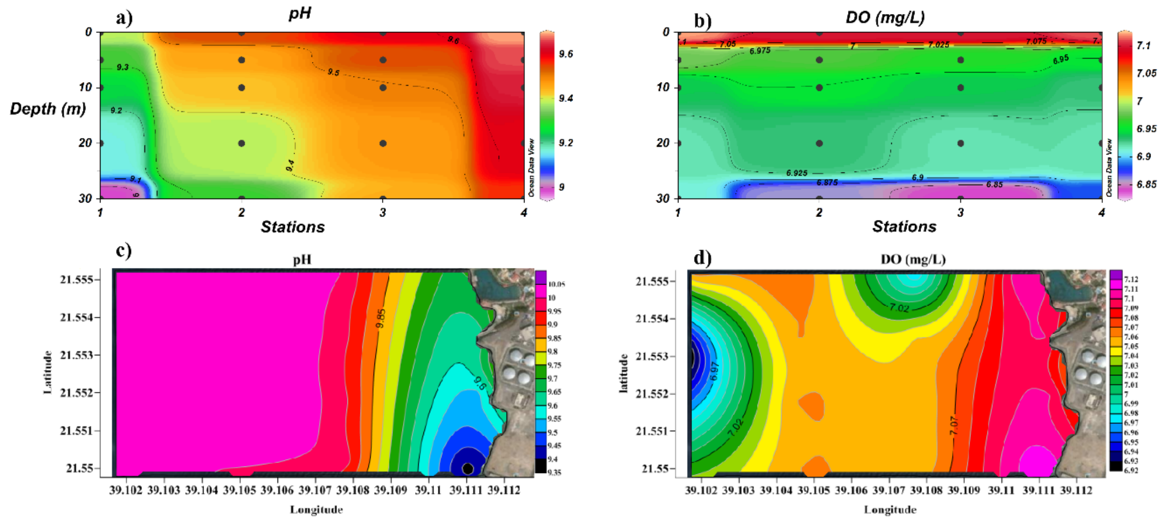


**Figure 3:** Surface distribution pattern of a) DO and b) pH; cross-section profile of c) pH and d) DO.

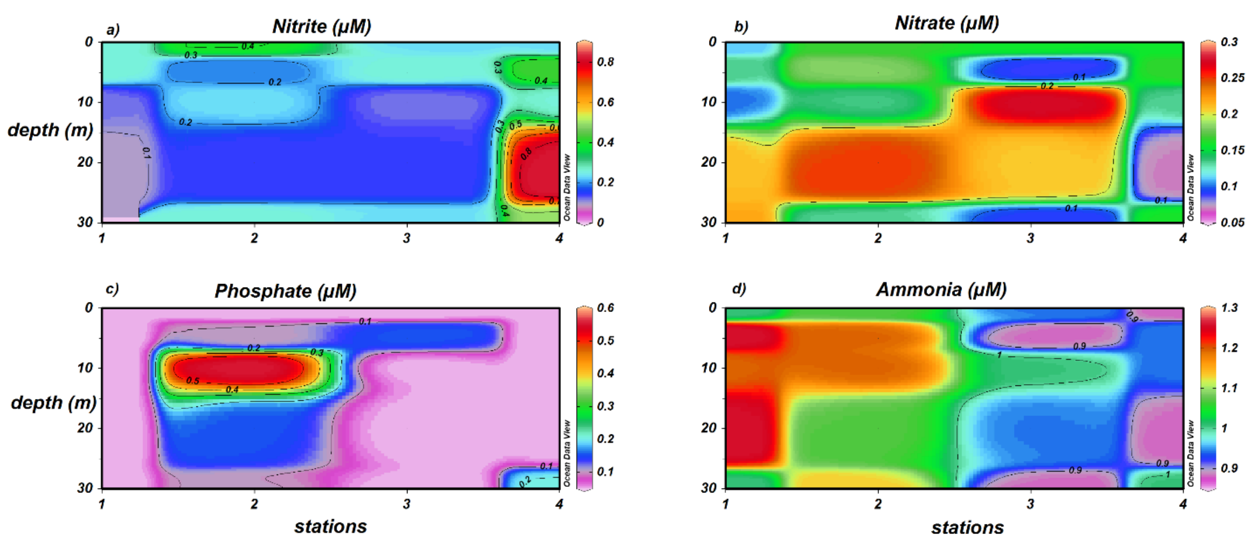


**Figure 4:** Cross-section profile of a) nitrite, b) nitrate, c) phosphate, and d) ammonia.

impact on marine life [17,22]. DO levels in proximity of dumping site, 30 m below sea level, are very low (<6.9 $mg\cdot L^{-1}$ at stations 2, 3 and 4; Figure 3b). Low DO levels are likely due to a combined effect of high temperature, which reduces the gas solubility in waste water, and the addition of oxygen-consuming chemicals (mostly sodium bisulfite) during the desalination process [22]. Most desalination plants that work by distillation actually produce brine with reduced DO levels [38,43]. DO concentration in surface water is sensibly higher (7.0–7.3 $mg\cdot L^{-1}$) and close to background values, indicating that the effluent plume gets diluted with natural water on moving away from the dumping site (Figure 3d).

pH of deep and surface water along the sampling locations varies over a range of 9–10 (Figures 3a and 3c, respectively). These values are higher than the normal oceanic range (8.1–8.3), probably due to basic hydrolysis of bisulfite ions. The lowest pH values (9.0–9.3), both in deep and surface water, were measured at 21.55 N and 39.111 E, near station 1. This point is located far from the discharge point of the desalination plant, with pH gradually increasing to background levels on moving towards the discharge point. Therefore, the observed pH alterations do not seem caused by the desalination plant. The point at 21.55 N and 39.111 E shows pH (9.35) and temperature (25.96°C) values much lower than background values, as

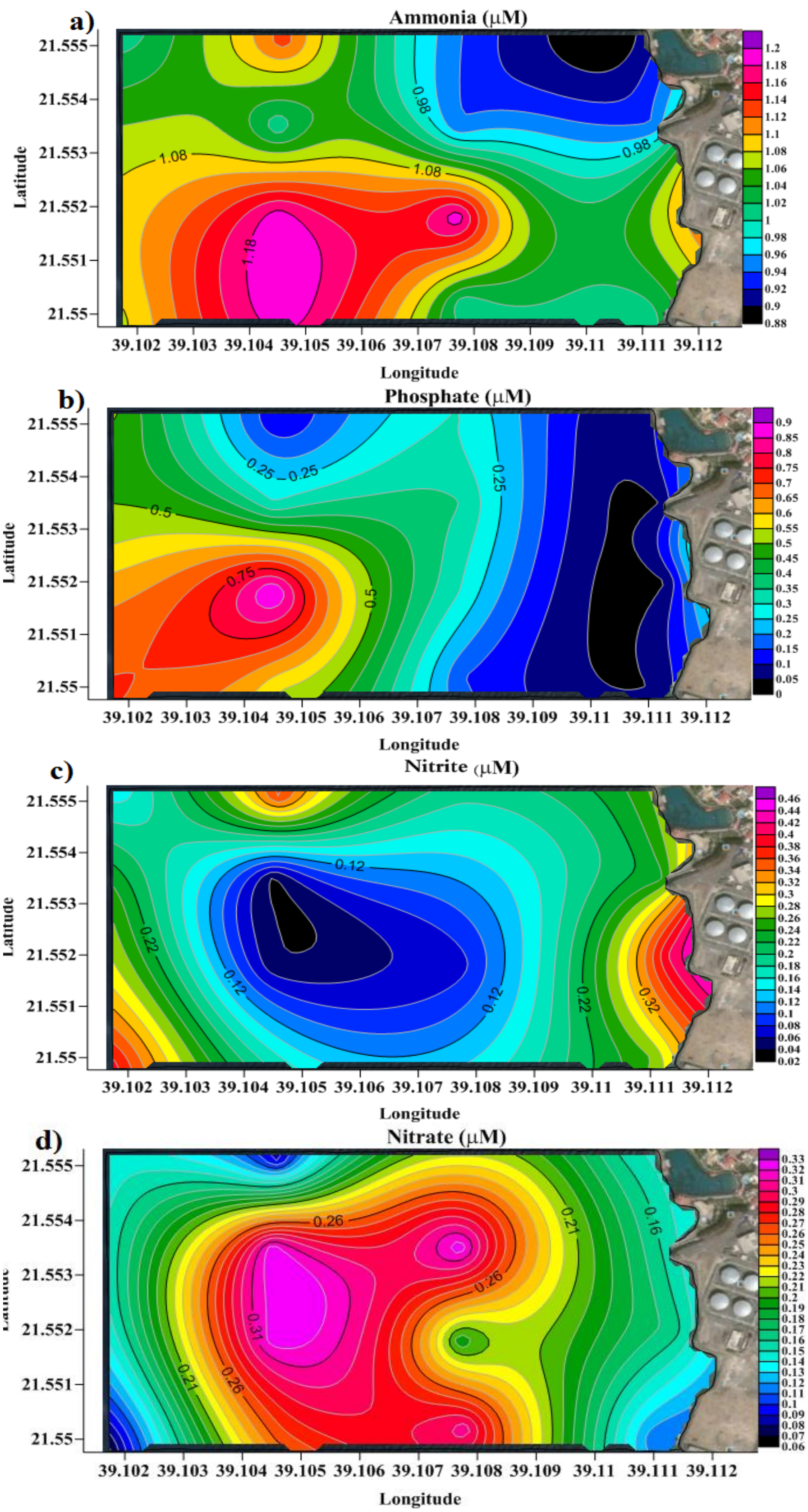


**Figure 5:** Surface distribution pattern of a) ammonia, b) phosphate, c) nitrite, and d) nitrate.

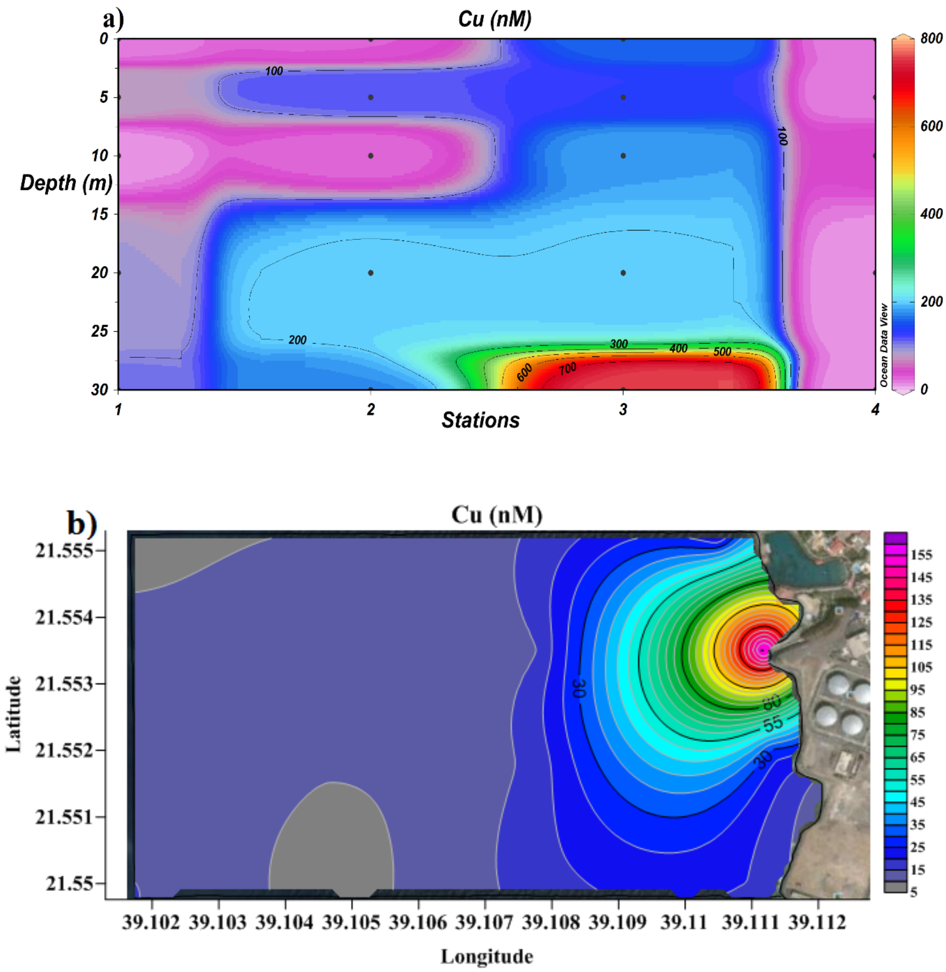


**Figure 6:** Cross-section profile (a) and surface distribution (b) of dissolved Cu.

well as DO levels (7.11 mg·L$^{-1}$) higher than background values. This observation suggests the presence of a dumping site of different nature (possibly of oxygen-rich chemicals) on the coast near that point.

Nitrogen and phosphorus also can negatively impact drinking water quality. The concentration of four nutrient ions (nitrite [$NO_2^-$], nitrate [$NO_3^-$], ammonium [$NH_4^+$], and phosphate [$PO_4^{3-}$]) was measured along the sampling locations in both the cross-section and surface. Cross-section concentration of nitrite (0.1–0.4 μM) fell within background levels except at station 4, where a concentration of 0.8 μM, four times higher than background level, was measured 20 m below sea level (Figure 4a). Similarly, cross-section concentration of phosphate was normal [45] except at station 2, where a concentration of 0.6 μM, six times higher than background values, was measured 10 m below sea level (Figure 4c). Nitrate and ammonia seemed to follow an irregular vertical distribution pattern (Figures 4b and 4d, respectively). The surface concentrations of nitrite (0.02–0.42 μM), nitrate (0.1–0.3 μM), ammonium (0.9–1.2 μM) and phosphate (0.1–0.8 μM) were all in the safe range. Particularly, the concentration of ammonium (0.9–1.2 μM) was much lower than that reported for Al–Arbaeen lagoon in central Jeddah city (30–50 μM) [46]. Along seashore (stations 1–4), nitrate and phosphate showed background levels on surface, whereas ammonia and nitrite exceeded background levels, especially at stations 1 and 2 (Figures 5a and 5c, respectively).

## 3.3 Distribution of dissolved Cu, Ni and Zn

The presence of heavy metals in discharge water of desalination plants is mainly due to the high temperature of distillation technique which enhances corrosion of metal alloys containing Cu, Ni, Cr, Mo, Fe and Zn [17,22]. Desalination plants operating by reverse osmosis are less likely to release heavy metals as a result of corrosion

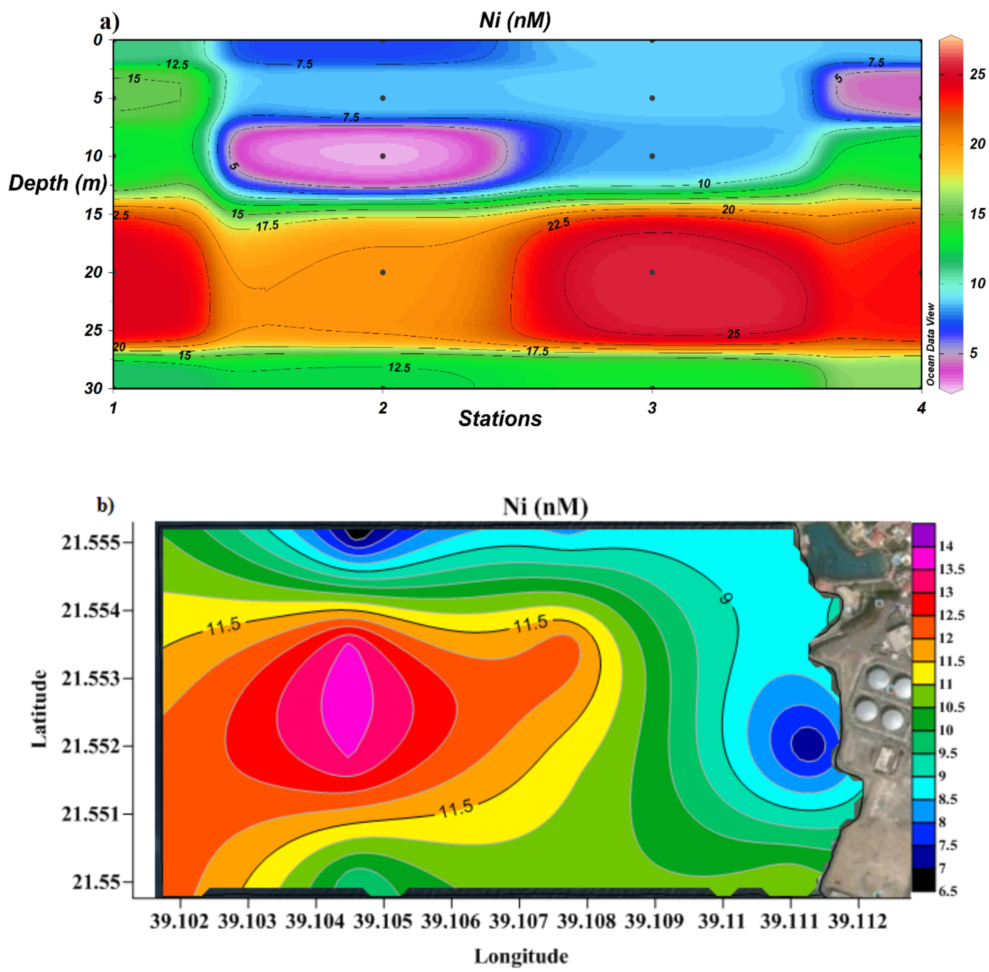


Figure 7: Cross-section profile (a) and surface distribution (b)of dissolved Ni.

because they do not use heating; the only heavy metals released by RO plants are those already present in seawater and concentrated during the osmosis process [38].

The distribution of Cu levels near the desalination plant is shown in Figures 6a (cross-section) and 6b (surface distribution). The United States Environmental Protecting Agency (US EPA) recommends a maximum Cu concentration in seawater of 75.94 nM for long-term exposure and 49.05 nM for short-term exposure. This value is exceeded not only close to the discharge location (station 3, 30 m below sea level, 800 nM), but also on surface at all stations (55-155 nM). The average surface value (15.02 nM) of dissolved Cu along the study area falls within safety limits but is sensibly higher than that reported for coastal Red Sea water (2.96±1.03 nM) [47].

The distribution pattern of Ni followed the same trend as that for Cu (Figures 7a and 7b). The highest Ni concentrations (25.6 nM) were measured at the discharging site (station 3) as well as at station 1 20 meters below sea level. The average value of dissolved Ni was 11.02 nM, far lower than the maximum value (1260.86 nM) recommended by US EPA.

Similarly to copper, the highest zinc concentration (143.81 nM) was found at the effluent site (station 3) 20 meters below sea level (Figure 8a). The average Zn level (68.03 nM) measured in the study area was lower than the US EPA-recommended maximum value (1376.56 nM) but higher than that reported for other regions of coastal Red Sea [47,48].

Overall, the levels of dissolved Cu, Ni and Zn measured in this study are in agreement with those reported in a recent work by Farawati et al. [47]. As a comparison, the distribution of Cu, Ni, and Zn along the world ocean is shown in Table 2.

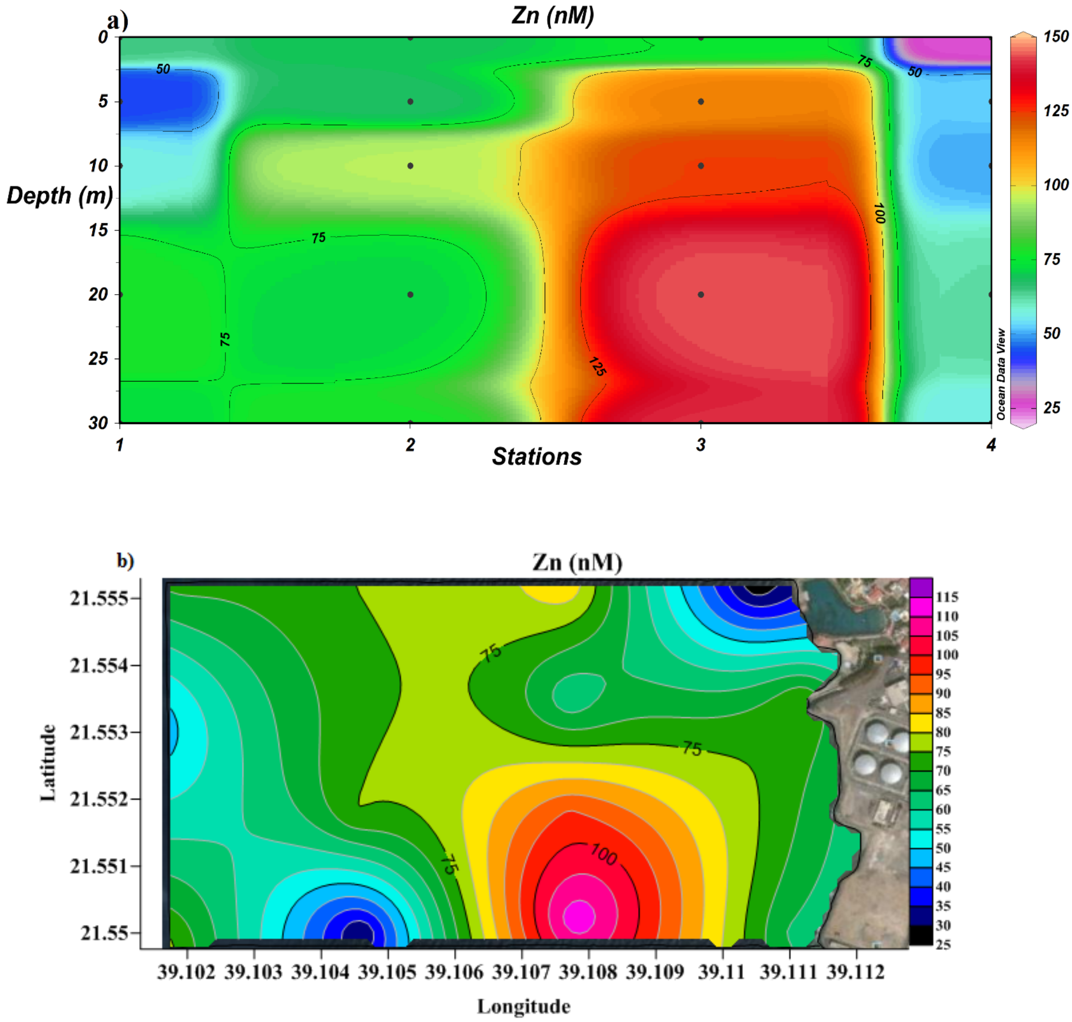


**Figure 8:** Cross-section profile (a) and surface distribution (b)of dissolved Zn.

**Table 2:** Comparative study of average Cu, Ni, and Zn levels in the surface water of world oceans.

| Study Area | Cu (nM) | Ni (nM) | Zn (nM) | Reference |
|---|---|---|---|---|
| Red Sea | 3.6 | 2.74 | 21.20 | Al Farawti et al, 2011[47] |
| Arabian Gulf-Kuwait coast (after Gulf war oil spill) | 9.1 | 21.8 | 55.52 | Olayan et al, 1998 [58] |
| Indian Ocean | 2.22 | 2.63 | 0.96 | Saager et al, 1992 [62] |
| South China Sea | 2.9 | 1.38 | 1.59 | Norisuye et al, 2007 [61] |
| South Japan coast | 9.4 | 20.45 | 27.5 | Chester and Stoner, 1974 [59] |
| South African coast | 4.72 | 10.22 | 15.29 | Chester and Stoner, 1974 [59] |
| North-eastern Atlantic coast | 4.72 | 18.74 | 12.23 | Chester and Stoner, 1974 [59] |
| Pacific Ocean | 0.5 | 2.1 | 0.07 | Bruland et al, 1980 [57] |
| Southern Ocean | 5.1-6.52 | 1.44-5.99 | 1.14 | Abbolino et al, 2004 [54] |
| California coastal waters, USA | 7.2 | 0.35-1.02 | 1.64-1.74 | Geen and Luoma,1993 [63]; Flegel et al, 1991 [60] |
| Massachusetts Bay, USA | 3.47 | 18.45 | 2.56-7.48 | Flegel et al, 1991 [60] |
| Jeddah coast, Saudi Arabia | 24.12 | 10.35 | 68.03 | Present study, 2017 |

# 4 Conclusions

The variations in dissolved Cu, Ni and Zn levels in the seawater around Jeddah desalination plant were evident, both horizontally and vertically. Concentrations were maximum at the discharging site, indicating the erosion of Cu, Ni and Zn from metal alloys of desalination plant. The surface concentration of Cu exceeded the recommended US-EPA values in all stations, highlighting the need for a more efficient purification of waste waters. The levels of Ni and Zn were in the safe range. The detailed monitoring of the hydrographic parameters and dissolved heavy metals both temporally and spatially will shed light on the tidal effects and currents around the desalination plant.

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**Conflict of interest:** Authors state no conflict of interest.

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