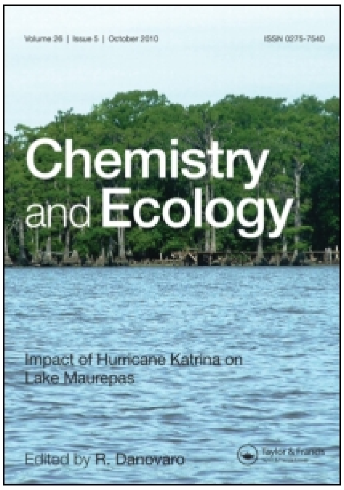

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Sea-water seasonal changes at a heavy tourism investment site on the Jordanian northern coast of the Gulf of Aqaba, Red Sea

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Sea-water seasonal changes at a heavy tourism investment site on the Jordanian northern coast of the Gulf of Aqaba, Red Sea

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The Gulf of Aqaba exhibits a strong seasonality due to convective mixing during winter and stratification during summer. The present study provides a detailed appraisal of summer and winter sea-water characteristics at the northern coast of the Gulf of Aqaba, that is witnessing rapid development and increasing changes in its geomorphological characteristics. Sea-water temperature, salinity, nutrients, and chlorophyll *a* concentrations were measured biweekly at five coastal and four cross-sectional stations during the periods February to April and July to September 2004. Meteorological conditions were continuously recorded at the Marine Science Station. The coastal study sites included four open coastal stations and a marina with one-way exchange with the open water. The effect of convective mixing was clearly apparent on the sea-water characteristics. Natural seasonal characteristics of higher nutrients and chlorophyll *a* concentrations were recorded during winter at most of the open coastal stations. In the cross-sectional stations, the concentrations of nutrients and chlorophyll *a* were not different between the surface and the bottom during winter, but the bottom waters had generally higher concentrations during summer. Some deviations from the natural seasonal cycle were recorded at the marina and other coastal stations. Here, higher nutrient and chlorophyll *a* concentrations were recorded in summer than in winter. These deviations that are most likely due to anthropogenic effects are discussed.

Keywords: Nutrients; Chlorophyll *a*; Mixing; Stratification; Coastal development; Sandy beach

1. Introduction

One of the most important features of the Gulf of Aqaba is the strong seasonality in its physical and biogeochemical characteristics. Waters of the Gulf of Aqaba are well mixed during winter and thermally stratified in summer [1–6]. During the winter mixing period, high nutrient concentrations exist in the euphotic zone leading to relatively high primary productivity and chlorophyll *a* concentrations [7, 8]. In temperate seas such a phenomenon does not exist because of the cold water temperature and the low irradiance which prohibit primary productivity during winter [9–11]. In summer when the water of the Gulf of Aqaba is thermally stratified, most nutrients are regenerated within the water column, and maximum

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primary productivity occurs at a water depth between 50 and 100 m [12, 13]. Only small amounts of nutrients can reach the surface leading to almost nutrient-depleted waters between the surface and 50 m.

The Gulf of Aqaba has received substantial importance in the recent years as a distinguished tourist resort and a strategic site for economic investment [14]. Aqaba in particular has been declared a Special economic Zone, managed by an autonomous authority in the year 2000. The focus of the Aqaba Special Economic Zone Authority (ASEZA) is to develop Aqaba in such a way that the limited Jordanian coast would be able to accommodate all different types of conflicting coastal investment. This includes, but is not limited to, tourism, industry, ports, and marinas.

The Jordanian northern beach of the Gulf of Aqaba has had a long history of being the main marine tourist site in Aqaba, where the major hotels existed. It is distinguished from other parts of the Jordanian coast in being a naturally sandy beach in contrast to most of the other parts, which are rocky, associated with coral reefs [15]. It is also protected from the northerly winds that blow most of the year along the main axis of the Gulf of Aqaba and experiences a distinguished current regime [5, 16, 17].

With the boosting investment in Aqaba, increasing environmental pressure is being exerted on the northern beach [6, 18, 19]. Tourism in Aqaba decreased during the 1990s following the Gulf war. Conditions improved after 2000, and more tourists visited Aqaba to enjoy the distinguished merge of the coastal and desert environments. Internal tourism in particular has increased dramatically associated with the economic benefits of the regulations of the Aqaba Special Economic Zone. Several new five-star hotels are being constructed. Two major tourist cities are being built, establishing two man-made lagoons and creating more than 20 km of new coastline. This calls for a close look at this area and emphasizes the importance of detailed environmental studies to be carried out there. The aim of the present study is to provide details on the summer winter changes in the sea-water characteristics at the northern coast of the Gulf of Aqaba and their likely impact on coastal tourism investment.

2. Materials and methods

2.1 *Sampling and study site*

The basic sea-water variables temperature–salinity, nutrients, and chlorophyll *a* were studied at the very north-eastern coast of the Gulf of Aqaba during winter and summer 2004. Samples were collected biweekly. The winter samples were collected between February and April, while the summer samples were collected between July and September.

The sampling program was designed to cover both the horizontal and vertical dimensions of the water column (figure 1). Four stations (S0, S15, S30, and S45) were aligned along a perpendicular axis to the coastal line at the very western edge of the Jordanian waters. Five stations of sea surface waters (0–10 m) were sampled at about 0.5 m depth covering the northern beach, in front of Al Saraya (AS), Royal Palace (RP), the Hotels Beach (HB), the Royal Yachting Club (RY), and the Public Beach (PB). Temperature, salinity, and density were recorded in situ using a self-contained conductivity, temperature, and depth meter CTD (Ocean Seven 316/319 Probes). The CTD measuring resolution and precision were 0.03% and 0.05% decibar for pressure; 0.001 and 0.003 PSU for salinity; and 0.0005 and 0.003 °C for temperature. For the other analysis, water was collected from the sampling sites, kept cold in a dark box and analysed immediately upon return to the laboratory, usually between 1 and 2 h.

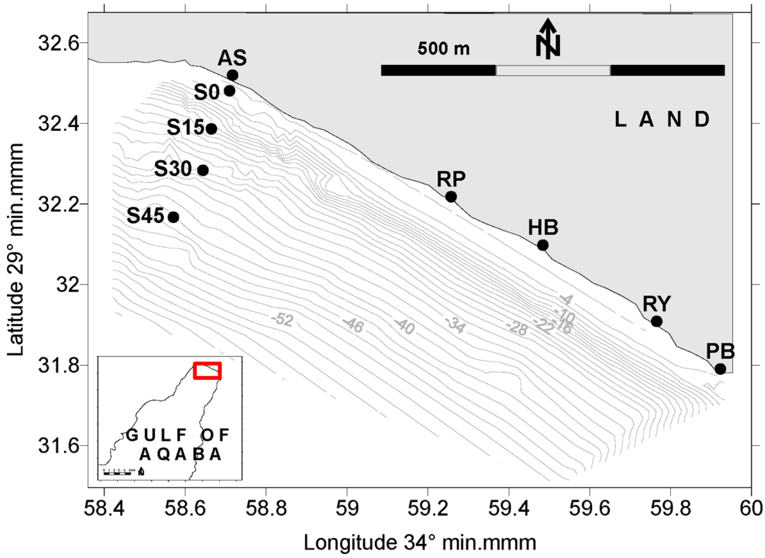

Figure 1. Map of the study area and location of measurement and sampling stations.

2.2 *Analytical procedures*

Upon return to the laboratory, water samples for nutrient and chlorophyll *a* analysis were filtered through 0.45 µm cellulose acetate filters. Inorganic nutrients ammonium, nitrate, nitrite, phosphate, and silicate were analysed immediately after filtration using well-established spectrophotometric techniques at the Marne Science Station [3] developed from previous studies [20, 21]. Chlorophyll *a* in the water samples was measured fluorometrically using the same filters after extraction in 95% acetone following a previous method [22].

3. Results

3.1 *Meteorological conditions and thermohaline structure*

Winds in the northern Gulf of Aqaba during the winter months February to April and the summer months July to September fluctuated mainly between calm and light breeze and blew from the north. About 80% of the wind records were NNE during both winter and summer. Wind speed in the ranges 0–2 and 2–4 m s^{-1} represented 56 and 21% of the total records during winter, while they represented 11 and 53% during summer. The strongest wind speed recorded during the study period (figure 2) ranged between 6 and 8 m s^{-1} and represented about 3–9% of the records during both seasons.

The daily average variation in air temperature during winter was in the range of 10.3–26.9 °C (figure 2). The daytime air temperature in summer rose to a maximum of 42.5 °C. The minimum summer night-time temperature was 20.5 °C.

The vertical profile of sea-water temperature (°C), salinity, and density σ_t distribution along a perpendicular transect at the study site during winter revealed clearly mixed waters in the vertical and horizontal dimensions (figure 3). The measured variables had ranges in the upper 45 m of 21.11–21.45 °C, 40.63–40.77, and 28.67–28.85 σ_t for temperature, salinity, and density respectively. During the summer, thermal stratification dominated the water column (figure 4).

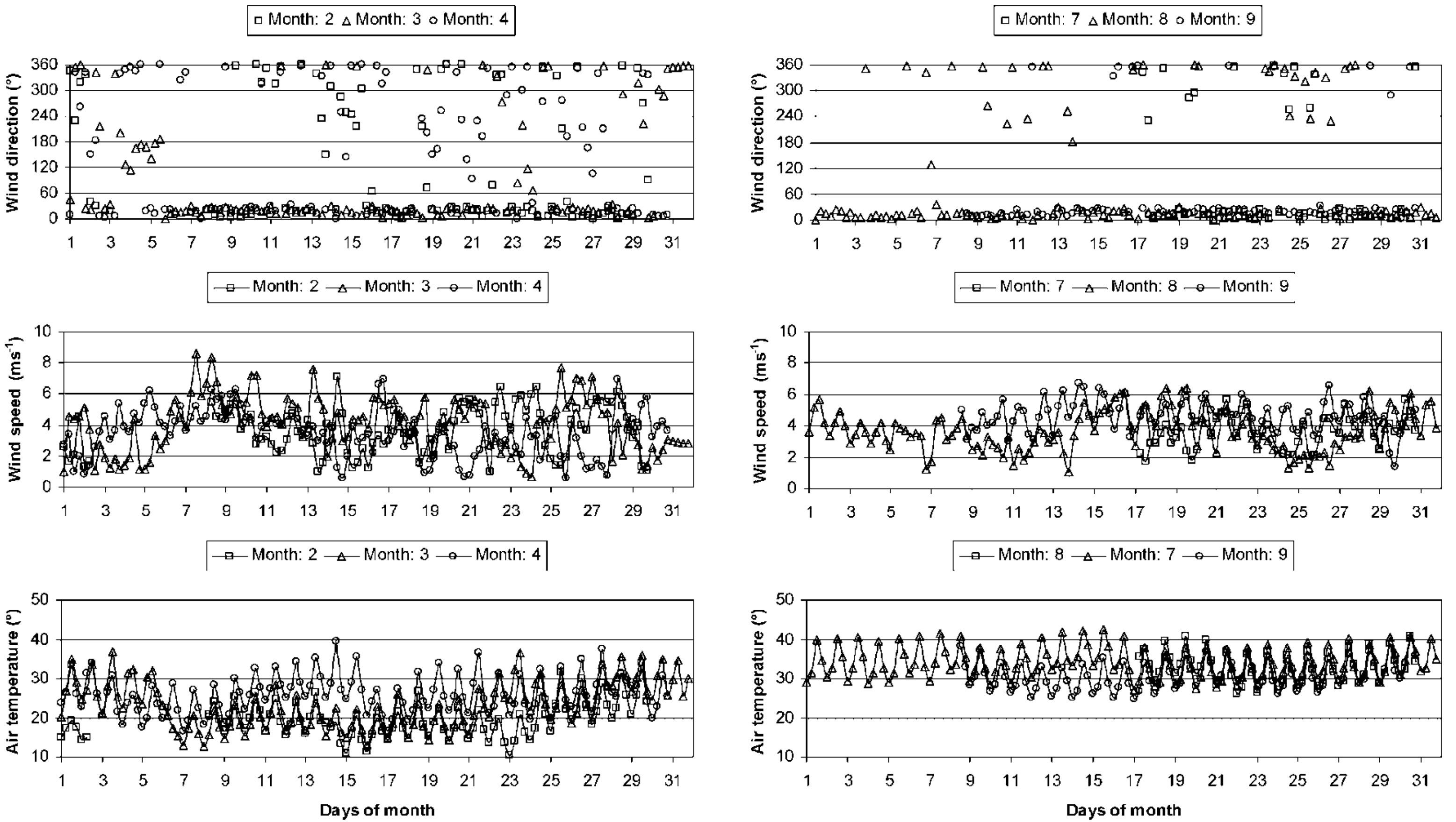

Figure 2. Meteorological conditions; wind direction (°), wind speed ($m\,s^{-1}$) and air temperature (°C) on the northern tip of the Gulf of Aqaba during the winter and summer months of 2004.

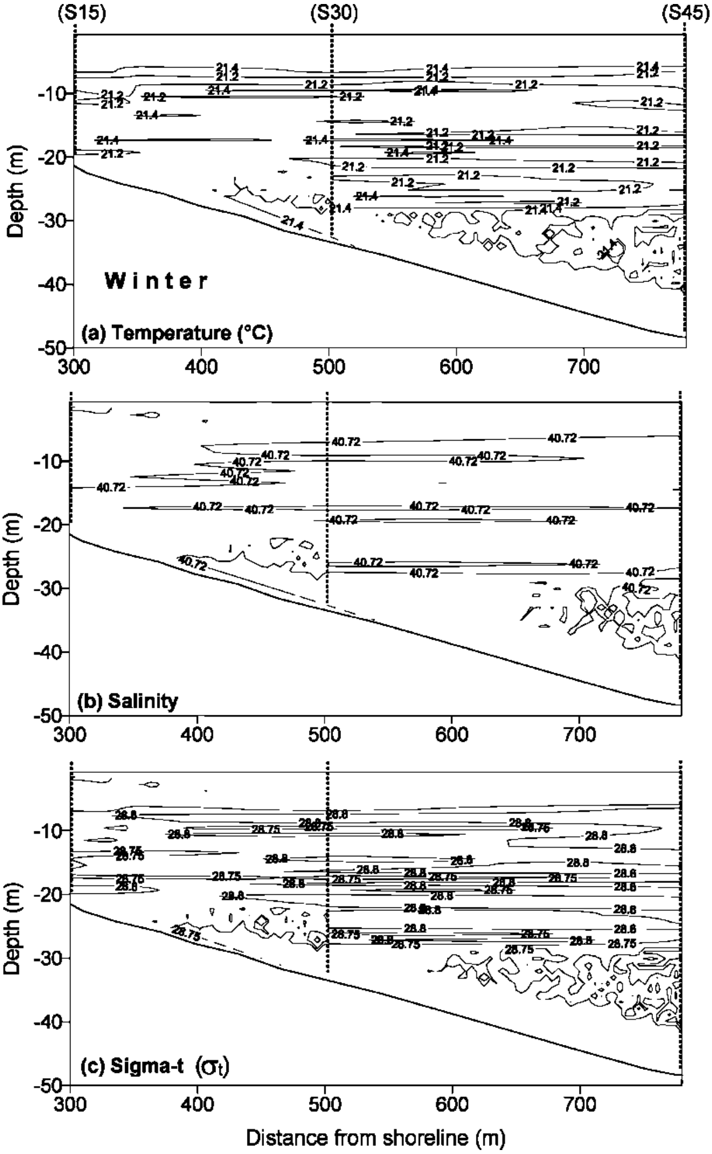

Figure 3. Average cross-section variation in temperature (°C), salinity, and σ_t during winter 2004 in the study area on the northern tip of the Gulf of Aqaba.

The temperature, salinity, and density σ_t ranges in the upper 45 m were 25.34–26.04 °C, 40.36–40.58, and 27.21–27.37 σ_t in the upper 26 m, respectively. The difference in average temperature between summer and winter was about 4 °C. Salinity during winter was slightly higher than in the summer, about 0.2 PSU. Density σ_t, being affected by lower sea-water temperature and higher salinity in winter, exhibited a clear winter–summer difference of about 1.5 σ_t.

Comparison of temperature, salinity, and density σ_t profiles at the horizontal dimension (AS, RP, HB, RY, and PB) revealed a homogenous spatial distribution of temperature both in the summer and in the winter, but a slightly lower salinity was recorded at the RY (figure 5).

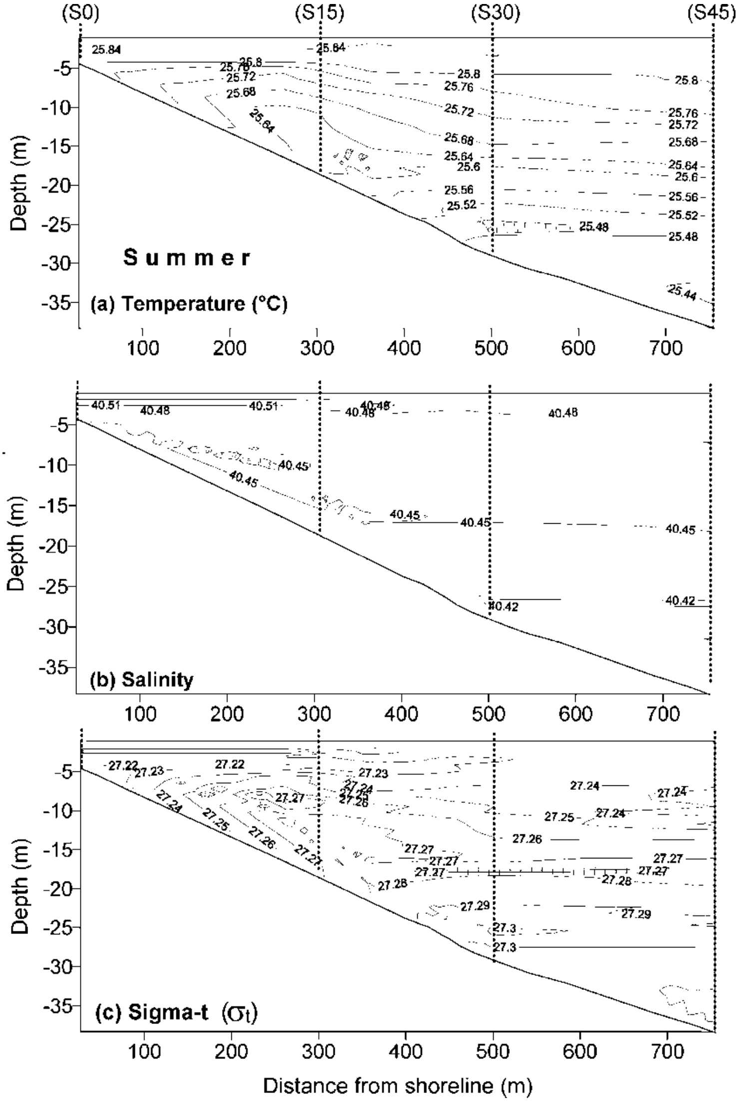

Figure 4. Average cross-section variation in temperature (°C), salinity, and σ_t during summer 2004 in the study area on the northern tip of the Gulf of Aqaba.

3.2 *Chemical characteristics*

Water samples were collected six times in summer between July and September and six times in winter between February and April. Average ± standard deviation nutrients and chlorophyll *a* concentrations during winter and summer on the horizontal dimension are shown in figure 6 and on the vertical dimension in figure 7. During summer, ammonium exhibited high concentrations at the very western edge of the Jordanian waters, next to the Fish Farms in Elat, in the Royal Yacht Club and on the Public Beach near the Public Cafes as compared with the Royal Palace and the Hotels stations. Nitrate, nitrite, and phosphate records also showed relatively high values at the same sites. Silicate however, exhibited the highest values of ~3.0 μM at a construction site in front of the Royal Palace, where dredging was in progress. Chlorophyll *a*

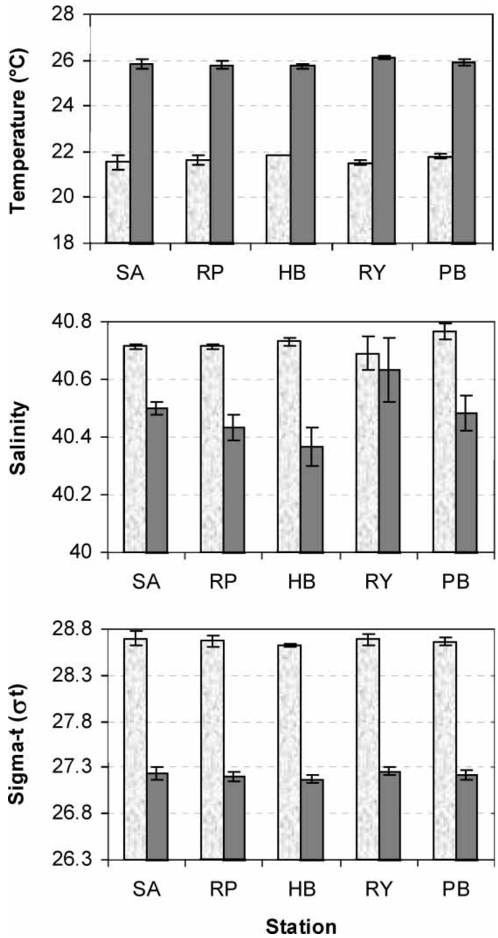

Figure 5. Average summer and winter seawater temperature (°C), salinity, and σ_t in the upper 10 m depth at Al Saraya Site (AS), Royal Palace (RP), Hotels Beach (HB), Royal Yacht (RY), and Public Beach (PB) on the northern coast of the Gulf of Aqaba, Red Sea.

concentrations were distinguishably high at the Royal Yachting Club, reaching concentrations eight times higher than those at the other study sites.

In the vertical transect at the Al Saraya site, samples were collected at the surface and near the bottom. In almost all cases and for most of the measured variables, the concentration at the bottom was higher than at the surface during summer. This was not the case during winter. Most measured variables were homogeneously distributed down the water column, and concentrations at the bottom were not notably different from those at the surface. Another interesting characteristic of the winter measurements is that the chlorophyll *a* concentration at the Royal Yacht Club was still higher than elsewhere but to a much less extent than in summer.

As to the winter summer comparison, higher concentrations of ammonium and nitrate were clearly observed as a general pattern during winter. However, there were individual cases when concentrations of both variables were higher in the summer, for example the ammonia concentration at the RP and the ammonia and nitrate concentrations at both RP and RY stations. Nitrite, phosphate, and chlorophyll *a* also exhibited higher concentrations during winter than in summer (~3-, 1.5-, and 2-fold for nitrite, phosphate, and chlorophyll *a*, respectively). Silicate

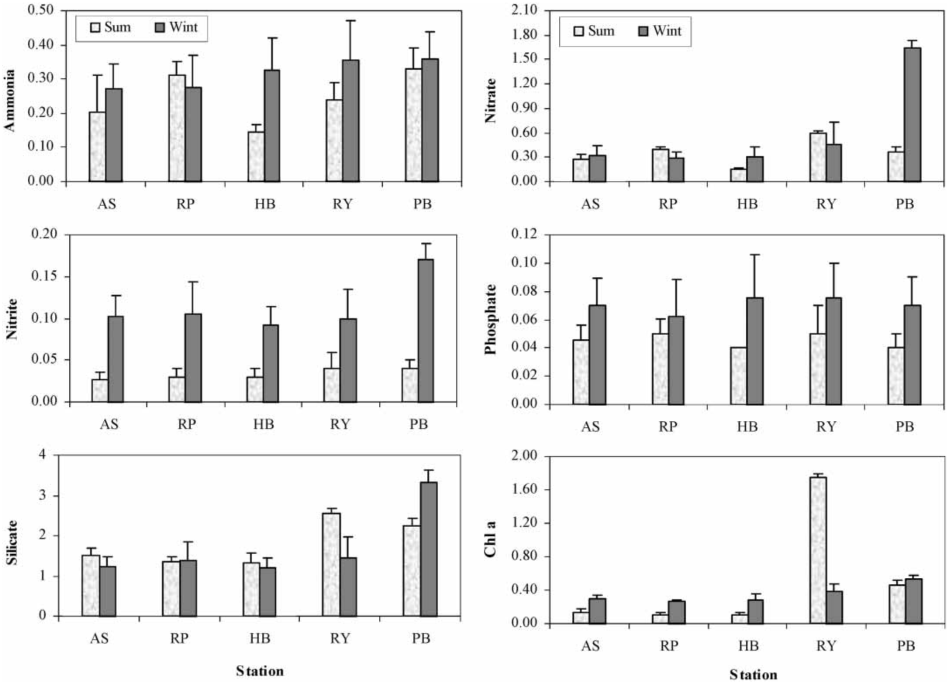

Figure 6. Average summer and winter nutrients (μM) and chlorophyll *a* (μg l^{-1}) concentrations in the upper 10 m depth at Al Saraya Site (AS), Royal Palace (RP), Hotels Beach (HB), Royal Yacht (RY), and Public Beach (PB) on the northern coast of the Gulf of Aqaba, Red Sea.

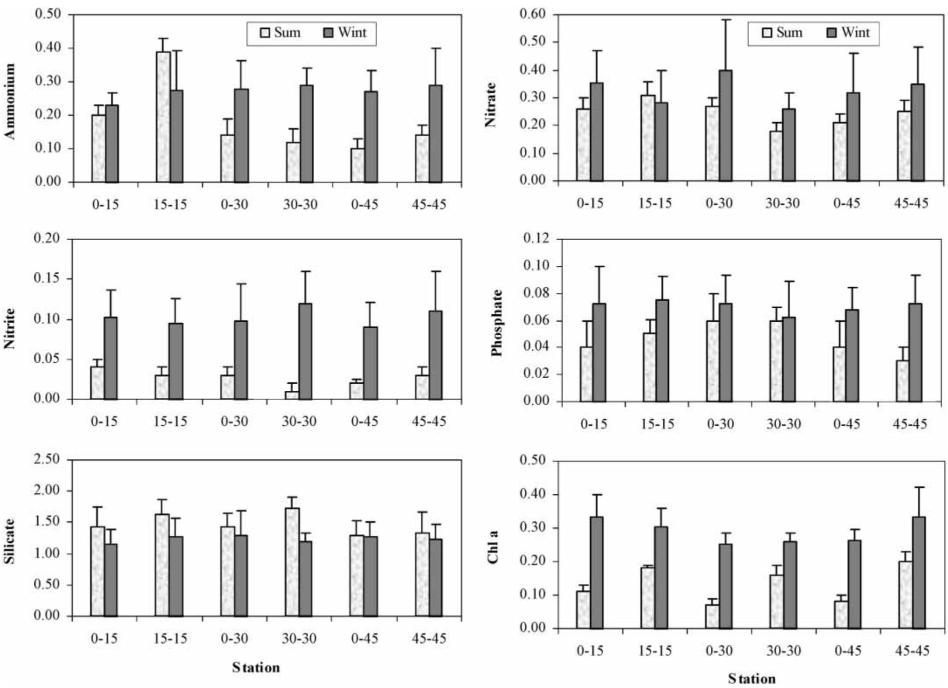

Figure 7. Average summer and winter nutrients (μM) and chlorophyll *a* (μg l^{-1}) concentrations in a vertical transect from the coastline to 45 m depth on the Jordanian northern coast of the Gulf of Aqaba, Red Sea.

did not show a clear difference between summer and winter. The source of silicate in sea water can be both atmospheric and oceanic through the physical and biogeochemical processes.

4. Discussion

Average nutrients and chlorophyll *a* concentrations measured during summer and winter at the northern tip of the Gulf of Aqaba, from the very western edge to the Public Cafes in the east, were generally higher during the winter than in the summer. Salinity also, in spite of the higher evaporation rate in summer, was higher in the winter than in the summer. Mixing in the open waters carrying a higher-salinity deep water to the surface via vertical convection is the most likely reason. This confirms the importance of winter mixing and summer stratification in shaping the coastal biogeochemical characteristics in the Gulf of Aqaba [2–6]. In general, the high concentration of nutrients in winter are attributed to offshore sources where vertical convective mixing, similar to the case of salinity, brings to the surface deep water with high nutrient concentrations. The deeper the mixing is, the higher the water column nutrient concentrations are [2]. Silicate concentrations in particular can be of atmospheric origin in addition to the sources resulting from oceanic physical and biogeochemical processes. These high nutrient concentrations associated with suitable conditions for primary productivity (reasonably high irradiance and warm sea water) lead to increased primary productivity resulting in higher chlorophyll *a* concentrations [2, 23, 24]. However, there were some exceptions to this seasonal pattern, where anthropogenic factors superseded the natural seasonal cycle.

The Royal Palace sampling site exhibited higher concentrations of ammonia, nitrate, and silicate during summer than during winter. This is most likely attributed to dredging activities that were in progress during collection of the summer samples. Higher nutrient concentrations, particularly ammonium, silicate, and chlorophyll *a*, were also recorded in the RY and in front of the public cafes in comparison with the other stations. These high concentrations may be attributed to uncontrolled anthropogenic discharge. Cleaning and servicing of the boats and yachts at the RY can be a possible source of contaminants. Similarly, the human activities at the beach of the public cafés can be another source of contaminants at this area. High concentrations of nitrite, silicate, and nitrate observed at the Public Cafes area may result from instantaneous anthropogenic sources like extensive swimming, fishing, and crowdedness associated with glass-bottom-boat activities. Also, under-surface seepage of municipal waters coming from the city of Aqaba can be another significant anthropogenic source of nutrients in the coastal waters. These sources, however, are not exclusive. Contamination with nutrients in the coastal waters at the northern beach may come from the fish farms in Elat or uncontrolled discharge from other coastal constructions [15, 19, 25]. The fish farms in Elat just next to the western edge of the Jordanian northern coast of the Gulf of Aqaba can be a major source of nutrients in the water column. There is more than 25 000 m^3 of floating cages that produce about 3000 tons of fish per year and release about the same amount of fish feed and fish waste in the soluble and particulate forms.

Variations in salinity at the RY as indicated by the high standard deviation were relatively high, and the difference in salinity between RY and the other stations was not statistically significant. However, the instantaneous changes in salinity at this site are of high ecological significance because they result in regular disturbance if the of this shallow and contained habitat. They are attributed mainly to less efficient mixing at the RY semi-enclosed site with the well-mixed saline water in the open water column. Another possible reason can be significant freshwater going into the marina, resulting from yacht servicing. The exceptionally high chlorophyll *a* concentration recorded at the RY during summer is interesting, very important, and strongly relevant to investment at the northern beach. This is the stratification season, when all nutrients and chlorophyll *a* concentrations in the open water are at a minimum. Accumulation of nutrients at the RY, however, is the most likely reason for this high chlorophyll *a* concentration, which was much higher in summer than in winter. High summer water temperature, high irradiance, and restricted mixing due to stratification can all lead to the build-up of high chlorophyll *a* concentrations in partially closed areas. Such conditions are likely to develop at any enclosed lagoon system and should be considered carefully in the designs. Bell [26] considered coral reef waters to be eutrophic if the annual chlorophyll *a* concentration average exceeds $1\,\mu g\,l^{-1}$. Coral reef ecosystems are well known for rapid recycling and efficient utilization of nutrients, resulting in local changes of chlorophyll *a* concentration [27–29]. Indeed, the annual chlorophyll *a* concentration average at the RY does exceed $1\,\mu g\,l^{-1}$, but this is an enclosed area that has no direct effects on coral reefs. Besides, the bottom habitat at the northern coast is not a typical coral reef but rather a sandy seagrass bottom habitat [15, 30]. Badran and Zibdah (2005) [6] defined standard codes of reference for the coastal Jordanian waters of the Gulf of Aqaba. According to the authors, safe chlorophyll *a* concentrations may increase to about $1\,\mu g\ l^{-1}$ in winter and $0.5\,\mu g\ l^{-1}$ in summer. These limits are exceeded at the RY, particularly in summer, but the authors did not associate water usage with water quality. It will be advantageous if sea-water standard codes of reference are defined in such a way that takes into consideration the type of water usage, as bathing water for example has to be of a higher quality standard than waters in a marina, as long as the water in the marina is confined and does not have a significant direct effect on the coastal ecosystem.

In conclusion, the present paper provides an appreciation of the summer and winter sea-water conditions at Jordanian northern coast of the Gulf of Aqaba during the year 2004. Although we do not expect dramatic seasonal changes over different years, we emphasize that reliable assessment of water quality needs to consider several years of data with good repetition of samples during the year, especially when the coastal activities are rapidly changing. To this effect, we recommend continuous high-resolution monitoring of the northern coast and advise that such monitoring would be managed by the coastal stakeholders. This would have the advantage of the coastal environment being regularly appraised and the coastal investors being regularly updated of the environmental changes that may have some adverse effects on their investment. They will also have the scientific knowledge and know-how of managing the coastal resources to optimum sustainability and developing adequate mitigation measures to face emerging environmental problems.

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