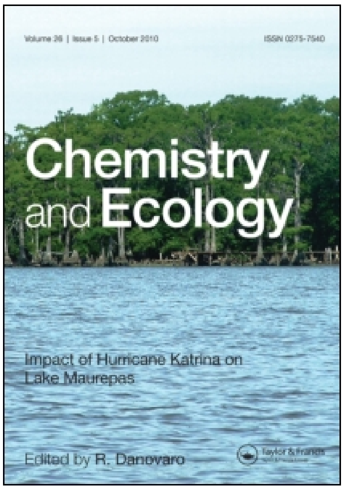

Chemistry and Ecology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713455114

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To cite this Article Rasheed, Mohammed , El-Hihi, Entisar , Al-Rousan, Saber and Abu-Hilal, Ahmad(2009) 'Chemical evaluation of sand material sources for beach replenishment along the coast of the Gulf of Aqaba, Red Sea', Chemistry and Ecology, 25: 5, 371 — 384

To link to this Article: DOI: 10.1080/02757540903192033
URL: http://dx.doi.org/10.1080/02757540903192033

Chemistry and Ecology
Vol. 25, No. 5, October 2009, 371–384

Chemical evaluation of sand material sources for beach replenishment along the coast of the Gulf of Aqaba, Red Sea

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(*Received 18 January 2009; accepted 15 July 2009*)

Four potential borrow sites (sources of sand) for beach nourishment were selected at the Aqaba terraces and dredged offshore sand along the Jordanian coast of the Gulf of Aqaba, and at Al-Humaimah and Wadi Rum sand dunes north and northeast of Aqaba town. An elution test has been performed on the sand materials of these potential borrow sites to determine the levels of dissolved inorganic phosphorus and dissolved inorganic nitrogen that might be leached from the sand particles when they come into contact with seawater, and examine their suitability for beach replenishment works. The levels of total phosphorus, total nitrogen, organic matter and selected heavy metals were also measured in the sand materials after the elution test and compared with their levels in the same samples before elution and with their levels in the natural beach sand of the study area. The results of the tests show that the concentrations of the measured pollutants are low in the sand materials of the borrow sites, and the amounts of these pollutants that may reach the seawater of the Gulf of Aqaba, if quantities as large as 100,000 tons of the sand materials were used in beach nourishment projects, are very low when compared with their levels in seawater. The results of the tests, as well as organic matter and mud contents of the sand materials, indicate their suitability for use in beach nourishment. However, the Aqaba uplifted terraces would be the most suitable and the lowest cost source because they are common along the shores of the Gulf of Aqaba.

Keywords: beach nourishment; sand material; borrow sites; nutrients; heavy metals; Gulf of Aqaba; Red Sea

1. Introduction

As the coastal economy becomes more service oriented, their continued viability becomes more dependent upon tourism, and because tourists are drawn to the 'pristine' wide beaches [1], widening the recreational beaches becomes an important purpose for the nourishment process [2,3]. The benefits of a nourishment project include improvement of the beach, addition of more dry area, and improvement of access to facilitate recreational activities [4]. In contrast, the adverse impact of such projects varies widely according to the characteristics of the native environment and material used in the nourishment. Direct impact includes physical changes to the beach and the impact on the associated marine environment during and after nourishment [5,6]. For example, increased turbidity can impact light-dependent organisms such as seagrass, algae and corals. The effect on

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ISSN 0275-7540 print/ISSN 1029-0370 online

DOI: 10.1080/02757540903192033
http://www.informaworld.com

organisms is through direct settlement, if the settling rate is too high [7,8]. Indirect impact on beach nourishment includes the impact of any material that may reach the water system and may lead to seawater pollution. Some of these pollutants may be deleterious to human health or be potentially harmful to marine life [9–11]. Heavy metals constitute one of these pollutants because they tend to accumulate in the sediments and biota [12–15]. As a consequence, any new addition of toxic heavy metals such as Cd and Pb [16] through new inserted sediments to the beach should be taken into consideration before beach nourishment. Other pollutants that should also be taken into consideration before beach nourishment are inorganic nutrients such as nitrogen (ammonium, nitrate and nitrite), phosphate and silicate species, which are considered essential nutrients in the ocean [1,17–19]. However, excess concentrations of these nutrients can cause ‘eutrophication’, which can affect the original character, properties or functions of marine ecosystems, especially coral reefs. Consequently, the sources of sand material for beach nourishment should be free from any chemical, physical, biological, and radioactive pollutants, have a small fraction (low percentage) of fine grain sizes, sand grain size that is similar to or coarser than the native beach sand, and the sand must be obtainable economically and in sufficient quantities [1].

1.1. *Study area*

The Gulf of Aqaba is 180 km long and constitutes the eastern segment of the V- shaped northern extension of the Red Sea. The Gulf is bordered by Precambrian basement, plutonic, and metamorphic rocks, whereas sedimentary formations consist mainly of early Paleozoic clastic and predominantly carbonatic Cretaceous-Eocene rocks. The lands bordering the Gulf have been uplifted, causing the exposure of wide areas of Precambrian basement due to intensive erosion [20]. The Jordan coastline on the Gulf of Aqaba is 27 km long (Figure 1) and represents the only marine resource of the country. This shoreline has been used for urban, port, industrial and tourist development. Consequently, the plans that have been formulated and updated several times specify the land use allowed on each development, take into consideration the environmental aspects, and recommend specific actions and measures to reduce the impact of development on the marine environment [21].

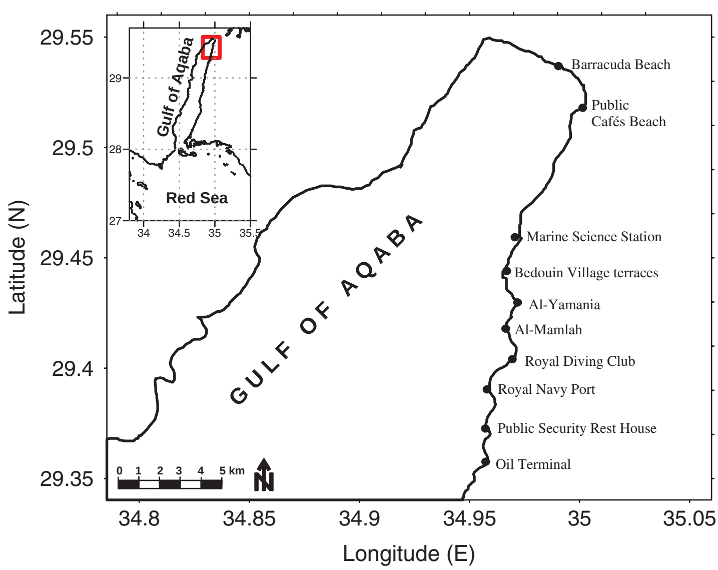

Figure 1. Location of the beach and Aqaba terraces borrow sites along the coast of the Jordanian Gulf of Aqaba.

Under the urgent needs for tourism development, the Aqaba Special Economic Zone (ASEZA) feels that the available area of the present beaches is not large enough for the anticipated tourism developments, and therefore extending the area of the present beaches is an urgent issue which would need some type of suitable nourishment practice. However, the Environmental Commission of ASEZA wishes to know the potential environmental consequences of any nourishment practices on the oligotrophic marine environment of the Gulf of Aqaba [21–24] before taking any decision to adopt a nourishment project.

The present study has been initiated to investigate the suitability of selected sites as possible sources of sand that can be used for beach nourishment, to examine the chemical and grain size characteristics of the sand materials of the potential sources, as well as its potential environmental effects on the quality of seawater of the Gulf of Aqaba, and to recommend to the decision-makers and coastal zone managers the most suitable sources.

2. Materials and methods

2.1. *Borrow sites of sand material*

(1) Aqaba terraces (AqT): six sites were selected in Aqaba as potential sources or borrow sites for sand materials that can be used in any future nourishment projects. All sites are located within the up-lifted terraces along the Aqaba south coast on the eastern side of Jordan Gulf of Aqaba, where potential tourist and development projects are planned to take place between the Marine Science Station (MSS) in the north and the Oil Terminal in the south (Figure 1):

1. Marine Science Station terraces;
2. Bedouin Village terraces;
3. Al-Mamlah (Big Bay/Tala Bay) terraces;
4. Royal Navy Port terraces;
5. Public Security Rest House terraces;
6. Oil Terminal terraces.

(2) Offshore sand (Off): dredged sand samples were collected during maintenance works in the Royal Navy Port area.

Another two sites were selected at about 65 km north-east Aqaba town:

(3) Al-Humaimah sand deposits (Hum): at the western side of Amman-Aqaba highway (N 29° 57’ 228, E 34° 26’ 242).

(4) Wadi Rum sand dunes (Rum): at the eastern side of Amman-Aqaba highway, near El-Disi village (N 29° 40’ 769, E 35° 28’ 539), at a distance of about 24 km north east of Wadi Rum Visitors Center.

2.2. *Natural beach sand*

For comparison purposes, sand samples that represent the natural sand deposits on various beaches along the Jordanian coastline of the Gulf of Aqaba were collected from three beach sectors at six selected sites, representing three beach sectors (Figure 1):

(1) North beach sector (NB): sand was collected from two sites:

1. Barracuda beach (Coral beach): at the most northern side of the Gulf of Aqaba.
2. The Public Cafés beach: at the most northeastern side of the Jordanian coastline.

(2) Marine Science Station beach sector (MSS).
(3) South beach sector (SB): sand was collected from three sites:

1. Al-Yamania beach;
2. Al-Mamlah (Tala Bay, Big Bay) beach;
3. Royal Diving Club beach.

2.3. *Sampling, treatment, and storage of sand material*

Representative samples of sand material were collected from two sampling points within each site by the use of pre-cleaned plastic scoops. At least 1 kg was collected from each site. The samples were put in pre-cleaned plastic bags. Immediately after collection all samples were transported to the laboratory for further treatment and analysis. In the laboratory, wet samples were placed in plastic container and oven dried at 60°C and then kept in plastic bags for future use. A mud fraction ($<63\ \mu m$) for heavy metal and organic matter analysis was separated using a sieve shaker.

2.4. *Elution experiment on sand material and beach sand*

An elution test was applied to the sand materials of the selected borrow sites. The experiment was performed in order to estimate the amount of selected potential pollutants. The test gives an estimate of loss in the concentration of nutrients and heavy metals which may be leached, washed out and lost to sea water if such sand materials came in contact with sea water in any beach nourishment project.

The test was performed as follow: two aliquots of 5 g of the dried sand material were placed into 500 ml Erlenmeyer flasks (duplicate samples). An aliquot of 250 ml of seawater was added to each flask. The flasks were then closed tightly and shaken continuously for 1, 24 and 72 hours. Two flasks containing 250 ml of sea water each, but not sand materials, were treated exactly as the test solution (blank). At the end of each shaking period a solution from each sand material under test was filtered through GFC filter paper. The filtrate from each sample was used to determine dissolved inorganic nitrogen (DIN; ammonium, nitrate, and nitrite) and dissolved inorganic phosphate (DIP) after subtracting the concentrations of these parameters in sea water samples (blank). The sand material samples retained on the filter paper were oven dried at 60°C to a constant weight. The samples were then analyzed for their organic carbon, total nitrogen (TN), total phosphorus (TP) and heavy metals (Cd, Co, Cu, Pb, Zn, and Mn) to compare with their levels in the same sand materials before the elution experiment. The results were used to determine the amount leached under the experiment conditions.

2.5. *Analytical procedures*

Nutrient concentrations including ammonium, nitrate, nitrite, and phosphate were measured as described by [25,26]. Organic carbon contents in the sediment were measured following the method of [27] with a modification to remove inorganic carbonate. Total nitrogen was determined in an aliquot of 1g powdered sediment using the Kjeldahl digestion method. Nitrogen was determined as ammonia using the indophenol blue method as described by [26]. For the determination of total phosphorus, 0.5 g of each sediment sample was ignited in a muffle furnace at 550°C for 1 hour. The sample was dissolved in 25 ml of 1 M HCl solution and made up 100 ml with distilled water [28]. Total phosphorous was determined as inorganic phosphate as described in [25].

The dilute (0.5 M HCl) acid treatment method, described by [29] was used for extraction of the 'dilute acid leachable' trace elements. According to [29], this treatment gives the values of trace elements that are 'biologically available'. An analytical Jena Nov AA 300 atomic absorption spectrophotometer (model 2004) was used for the measurements of element concentrations. Duplicate measurements were made for each sample. The precision of the whole procedure was assessed by 10 replicates for a sample and the results agreed to within 4%. Duplicate blanks were used for each batch of digested samples. In addition to the blank solution, three standard solutions were prepared to cover the expected range of the element concentrations in the samples and within the linearity of the procedure. The four solutions were used to establish a calibration curve for each element. The accuracy of the analysis was checked with the standard addition testing procedure. Percentages of recoveries were 95% for Cu, 92% for Zn, 110% for Cd and 92.5% for Pb. The quality of the method used was checked with a certified reference material (CRM) of marine sediment MAG-1. The agreement between the analytical results for the reference material and its certified values for each metal was satisfactory, with the recoveries being 95–102% ($n = 5$). In order to check the accuracy of this method, the extraction results for each metal were compared with that found by using direct digestion of aqua regia method. Our method was acceptable since satisfactory recoveries (92–102%) for the measured metals were found in analytical results when compared to those of the direct aqua regia method. Differences between mean concentrations of each chemical parameter measured in sand materials of each site before and after the elution test were tested by single factor analysis of variance.

3. Results and discussion

3.1. *Water analysis*

Dissolved inorganic phosphate (DIP)

The results show that phosphate concentration increases gradually with time during the period of the elution experiment (Figure 2). The rate of phosphate leaching (dissolution) is higher in the first hour compared with the rate after then (e.g. for SB, 0.1 and 0.005 μmol l^{-1} d^{-1} initial and final rates, respectively). Phosphate leaching rates ranged between 0.22 and 0.45 μmol l^{-1} d^{-1} for sand materials of all sites, with Al-Humaimah and North Beach sand exhibited the highest leaching rates compared to the other sites (Figure 3). The higher leaching rate of phosphorus at Al-Humaimah may indicate that the fraction of phosphorus that is bound to organic carbon is low in the sand materials of the two sites, and most of it is in the form of inorganic phosphate.

However, the leaching rates of phosphate from the sand materials of the potential borrow sites are close to the leaching values of the natural Aqaba beaches (Figure 3) which means that the use of these borrow site deposits in beach nourishment will not cause great deleterious effects on the coastal environment with regard to phosphate.

The results of the present test were used to predict the concentrations of phosphate when the sand materials come into contact with seawater for selected time intervals. Figure 4 shows that phosphate concentration in water would increase logarithmically until an equilibrium state is reached. Logarithmic equations inferred from the figure represent the change of phosphate concentration with time for the sand materials from each potential source (Figure 4). These equations can be used to calculate the concentration of dissolved inorganic phosphorous (DIP) in seawater at any time of contact between the sand materials and seawater. After one year, the residence time of water in the Gulf of Aqaba [30,31] of contact, the DIP released from the sand material of Aqaba Terraces, Offshore, Wadi Rum, and Al-Humaimah, will be 1.1, 1.0, 1.1, 1.6 μM, respectively.

On a larger scale, as in the case of beach nourishment, and assuming that 1000, 10000, or 100000 tons of sand are used for beach nourishment project and estimating the total water volume of the Gulf of Aqaba that is mixed well throughout the year as 2.9×10^{15} L (29000 Km^3)

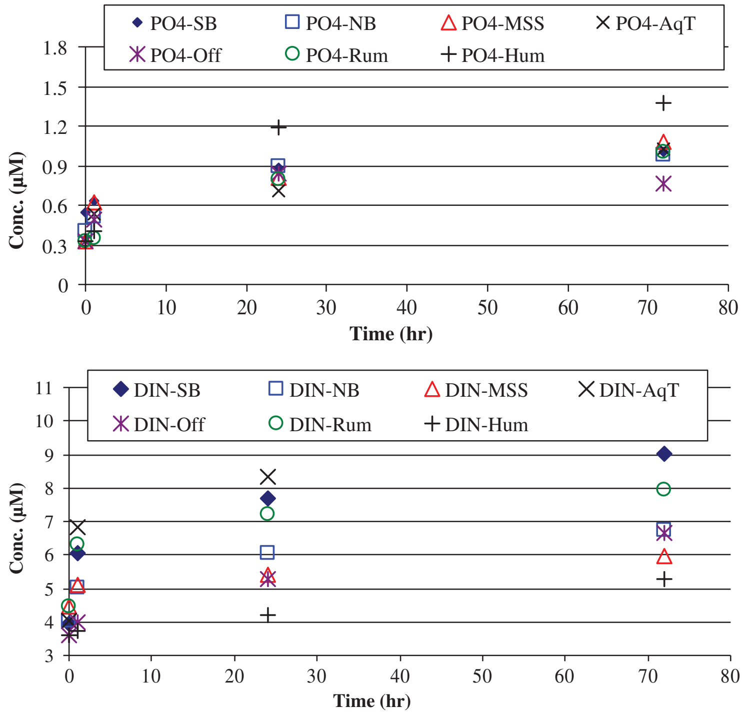

Figure 2. Change with time of DIP and DIN concentrations (µM) in seawater during the elution experiment. SB, South Beach; NB, North Beach; MSS, Marine Science Station; AqT, Aqaba Terraces; Off, Offshore; Hum, Al-Humaima; Rum, Wadi Rum.

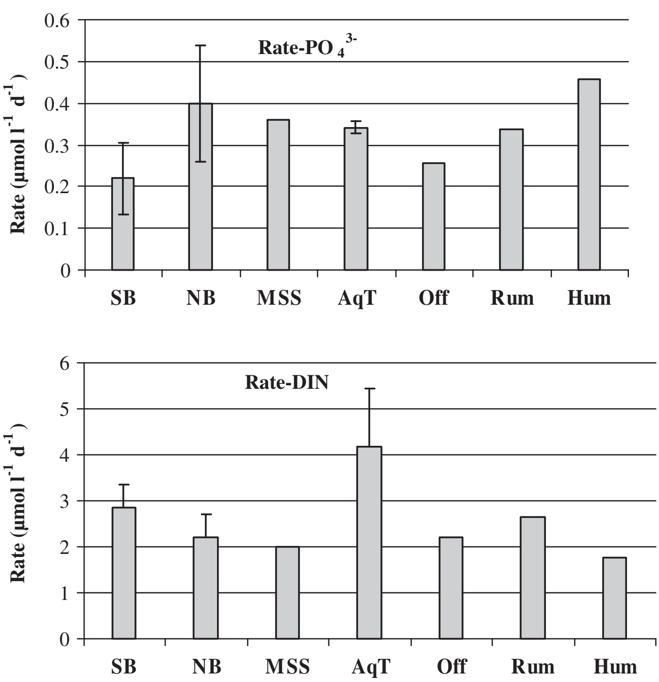

Figure 3. Leaching (dissolution) rate of DIP and DIN (μmol l^{-1} d^{-1}) as inferred from the elution experiment. SB, South Beach; NB, North Beach; MSS, Marine Science Station; AqT, Aqaba Terraces; Off, Offshore; Hum, Al-Humaima; Rum, Wadi Rum.

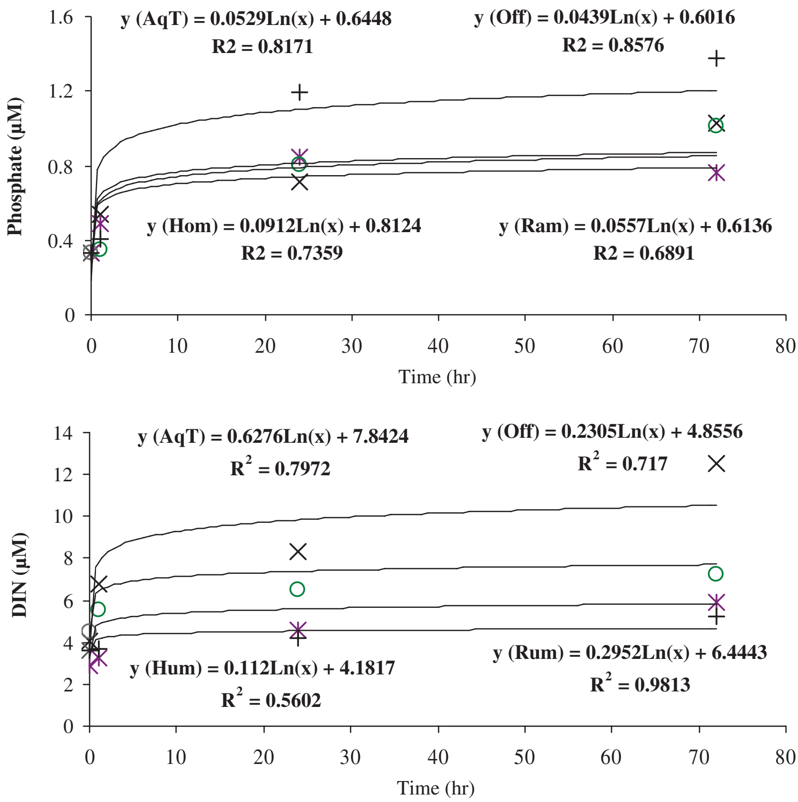

Figure 4. Logarithmic equations for the change in DIP and DIN concentrations in sea water with time. AqT, Aqaba Terraces; Off, Offshore; Hum, Al-Humaima; Rum, Wadi Rum.

Table 1. Phosphate concentration (µM) in seawater assuming that all phosphate in the sand materials used in beach nourishment is dissolved in seawater. AqT, Aqaba Terraces; Off, Offshore; Hum, Al-Humaima; Rum, Wadi Rum.

Sand wt (ton)	AqT	Off	Rum	Hum
1000	2×10^{-8}	2×10^{-8}	2×10^{-8}	3×10^{-8}
10,000	2×10^{-7}	2×10^{-7}	2×10^{-7}	3×10^{-7}
100,000	2×10^{-6}	2×10^{-6}	2×10^{-6}	3×10^{-6}

[30,31], then DIP concentrations resulted from leaching of the sand materials in seawater (density 1.27 g/ml) will be less than 1×10^{-5} µM even if 100,000 tons were used (Table 1). This estimated concentration is much lower than DIP concentrations reported by several authors [22,23,32,33] in the Gulf of Aqaba, which ranged from 0.01 to 0.50 µM. Accordingly, it can be concluded that the increase in DIP due to the leaching of sand would not cause substantial or significant increases in the natural levels of DIP in the water.

Dissolved inorganic nitrogen (DIN)

Similar to phosphorus, there is a clear gradual increase with time in concentrations of DIN during the period of the experiment (Figure 2). The rate of leaching was higher in the first hour compared to the rates after then (e.g. for AqT, 0.06 and 0.014 µmol l^{-1} d^{-1} initial and final rates, respectively).

In general, leaching rates of nitrogen have a similar pattern for sand materials of all sites, with AqT among the potential borrow sites and South Beach among the natural Aqaba beaches exhibited the relatively highest rates (Figures 2 and 3). DIN concentrations increase logarithmically until an equilibrium state is reached (Figure 4). Logarithmic equations inferred from these figures represent the change of DIN concentration with time for the sand materials from each potential source (Figure 4). These equations can be used to calculate the concentration of dissolved inorganic nitrogen (DIN) in seawater at any time of contact between the sand materials and seawater. From these equations, after one year (the residence time of water in the Gulf of Aqaba) of contact, the DIN concentrations released from the sand material of Aqaba Terraces, Offshore, Rum and Al- Humaimah, will be 13.54, 6.95, 5.20, and 9.12 μM, respectively. The concentrations of the DIN calculated (based on the same assumptions that have been used for DIP) will be less than 1×10^{-5} μM (Table 2). Here again the concentrations are less than those reported from the Gulf of Aqaba [22,32,33] which ranged from 0.1–5.0 μM. Therefore, the increment in the DIN will not significantly increase the normal concentration in seawater.

3.2. *Chemical characteristics of sand material after elution*

The results of the experiment showed that the concentrations of the measured chemical species in the sediment have decreased, after they have been subjected to the elution experiment. This is due to either solubility of the sediment in seawater or partial degradation of organic material during incubation [34,35].

Organic carbon concentration (% OC) decreases after the completion of the elution experiment (Figure 5). The less the amount of organic matter leached, the better the sand materials are for beach nourishment. Organic carbon concentrations (530–710 mg kg^{-1}) in the investigated sites (Figure 5) were comparable to or less than their concentrations in the marine sediments of the Gulf of Aqaba with reported values between 600 and 5000 mg kg^{-1} [23,34,36,37]. Organic carbon (OC) in the sand material of the selected borrow sites was comparable to the OC in the sediment of the existing natural beaches (NB and SB). This would show that the sediments of all borrow sites can be used in beach replenishment without any risk of inserting additional organic carbon into the sea.

Similar to organic carbon, Figure 5 shows that phosphates are leached or dissolved partially in seawater. The percentage losses were generally low for the sediments of all sites (13–18%). Total phosphorus concentrations (190–450 mg kg^{-1}) in the sand material of the selected sites (Figure 5) were within its range in the marine sediment of the Gulf of Aqaba as reported by [37–39], but lower than those of Abu Hilal [36]. This would also indicate the suitability of the sand material from all borrow sites for beach replenishment.

Total nitrogen is partially leached or dissolved in seawater (Figure 5). Total nitrogen range in all sites (20–50 mg kg^{-1}, Figure 5) was within the range reported by [40] and lower than the range of Al-Rousan (1998) and Al-Rousan et al. (2006) [37,38] who reported values between 270–500 mg kg^{-1}. In addition, the values of the potential borrow sites were comparable with the values of the natural sediment beaches.

Table 2. DIN concentration (μM) in seawater assuming that all nitrogen in the sand materials used in beach nourishment is dissolved in seawater. AqT, Aqaba Terraces; Off, Offshore; Hum, Al-Humaima; Rum, Wadi Rum.

Sand material used (tons)	AqT	Off	Rum	Hum
1000	3×10^{-7}	2×10^{-7}	2×10^{-7}	2×10^{-7}
10,000	3×10^{-6}	2×10^{-6}	2×10^{-6}	2×10^{-6}
100,000	3×10^{-5}	2×10^{-5}	2×10^{-5}	2×10^{-5}

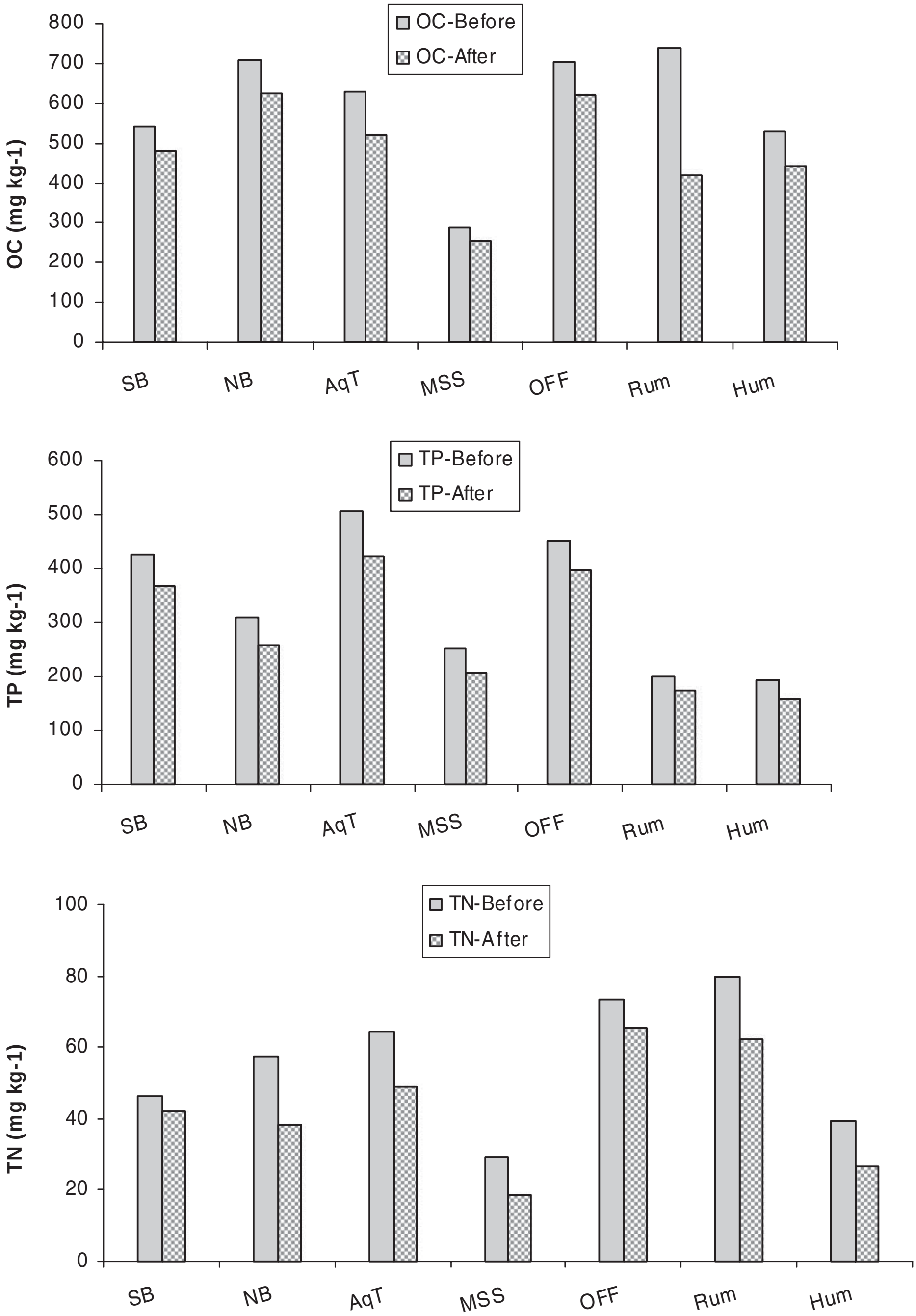

Figure 5. Concentration of organic carbon, total phosphorus and total nitrogen (mg kg^{-1}) in sand materials of different sites before and after elution tests. SB, South Beach; NB, North Beach; MSS, Marine Science Station; AqT, Aqaba Terraces; Off, Offshore; Hum, Al-Humaima; Rum, Wadi Rum.

Table 3. Concentrations of heavy metals (ppm) and OC in bulk samples and mud fractions of the borrow site sand material, beach sand of the study area, and sediments of the Gulf of Aqaba and the Red Sea. SB, South Beach; NB, North Beach; MSS, Marine Science Station; AqT, Aqaba Terraces; Off, Offshore; Hum, Al-Humaima; Rum, Wadi Rum.

Sand material	Site	Cd	Co	Cu	Ni	Pb	Zn	Fe	Mn	OC%	Mud%
Bulk	SB	0.8	4.5	4.2	187	N.D.	37.9	3419	274	0.05	1.71
	NB	0.01	4.0	1.5	165	N.D.	36.4	3485	203	0.07	2.70
	AqT	1.6	7.5	5.7	267	N.D.	62.2	3738	419	0.06	0.00
	MSS	2.4	3.1	1.7	29	N.D.	22.6	2876	63	0.03	2.30
	Off	0.04	4.9	4.6	99	N.D.	31.2	3456	155	0.07	2.25
	Rum	1.5	3.3	5.2	95	N.D.	7.6	3279	187	0.07	1.60
	Hum	1.10	1.7	0.7	N.D.	N.D.	N.D.	141	N.D.	0.05	0.13
Mud fraction	SB	2.60	15.2	16.9	418	28.21	96.9	3725	748	0.09	–
	NB	2.27	5.9	5.1	352	0	98.6	3687	569	0.09	–
	AqT	3.43	19.0	11.7	204	12.72	93.4	3865	715	0.07	–
	MSS*	–	–	–	–	–	–	–	–	–	N.F.
	Off	5.06	13.1	9.3	197	34.48	74.0	3742	398	0.08	–
	Rum	6.43	12.3	6.9	117	35.88	24.9	3447	553	0.09	–
	Hum	1.21	5.2	3.3	N.D.	N.D.	3.7	189	N.D.	0.06	–
Sediment	Gulf of Aqaba [46,48]	0.8–3.0	8.0– 28	3.0–12.3	–	–	16–135	6720–13110	44–189	0.10–0.48	–
	Red Sea [49]	0.9	–	13	–	–	10	758	51	0.17–0.27	–

Notes: N.D., Not detected; N.F., Not found; MSS*, The beach sand of MSS is void of mud.

Heavy metals

The results show that heavy metals concentrations in the bulk samples are lower than their levels in the mud fraction (Table 3). However, the results of the mud fraction and bulk samples show the same trend; the lowest levels were obtained at Al-Humaimah borrow site deposits, while the higher levels of Co (19.0 ppm) and Fe (7110 ppm) and high levels of Cd, Pb, Zn, Cu and Mn occurred at Aqaba terraces. Lead (Pb) however, seems to occur mainly in the mud fraction of the sand material as its concentrations in this fraction ranged between 0.0 and 35.88 ppm at Al-Humaimah and 34.88 ppm at Rum, while its concentration at Aqaba terraces was low (12.72 ppm). It is noteworthy that Al-Humaimah deposits contained the lowest levels of mud (0.13%) and organic carbon content (0.05%) which is consistent with the well-documented relationship between heavy metals concentration and both organic matter and mud content of the sand deposits. A negative association between grain size and heavy metals concentration; greater concentrations of trace/heavy metals in the finer mud fraction of sediments due to a greater surface area to volume ratio in this fraction compared to the coarser sand fraction [41–43]. By comparison, several authors have pointed out the role of organic substances in the concentration mechanism of trace elements in sediments [44,45]. Abu-Hilal and Badran (1990) [46] reported what they have described a striking positive relationship between the distribution patterns of trace element and that of organic carbon in all sediments cores collected from many depths at the Jordan Gulf of Aqaba. The results (Table 3) show that the concentration of heavy metals in the sand materials of the borrow sites are comparable with their concentrations in the sand of the existing beaches of

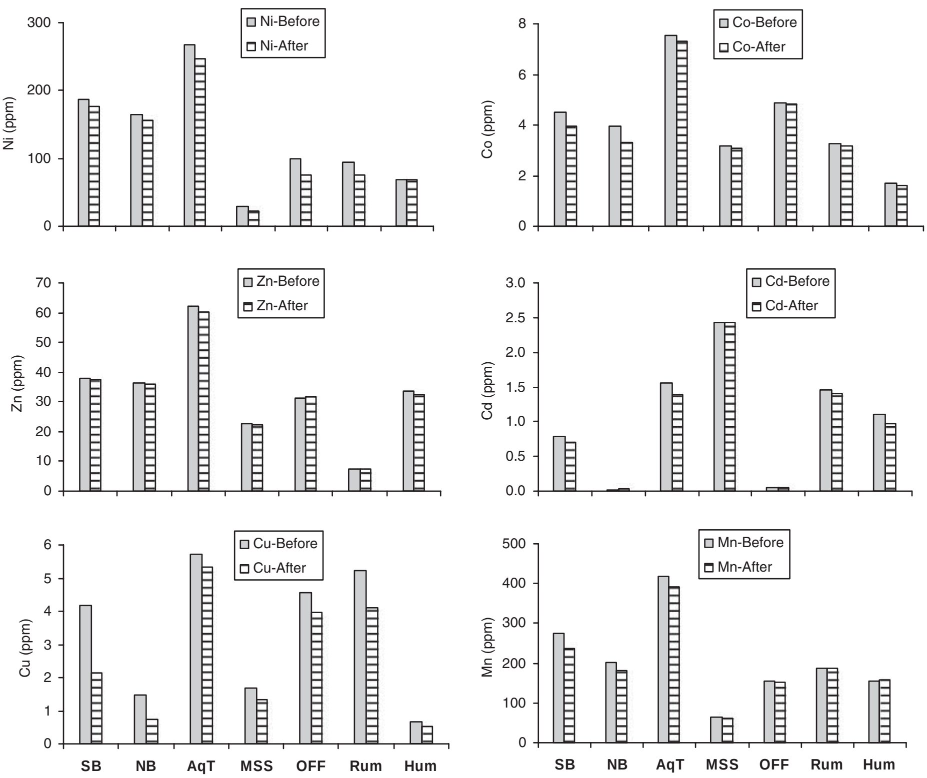

Figure 6. Concentrations of heavy metals (ppm) in sand materials from different sites before and after the elution test. SB, South Beach; NB, North Beach; MSS, Marine Science Station; AqT, Aqaba Terraces; Off, Offshore; Hum, Al-Humaima; Rum, Wadi Rum.

the Gulf of Aqaba (Figure 6, NB and SB). The comparison of the heavy metals levels obtained in the present work with the values reported by other workers (Table 3), shows that the levels of Cd, Co, Cu, Pb, Zn and Fe in the sand materials of the potential borrow sites and Aqaba beaches are within the range of or lower than their levels in the marine and coastal sediments of the Gulf of Aqaba [46–48] and the Red Sea [49]. The results of the elution test show that heavy metals concentration at different sites did not show considerable changes (% loss) in the concentrations of heavy metals after the sand materials of different borrow sites have been subjected to the test (Figure 6). The ANOVA test did not show significant differences between the concentrations of the measured metals in the sand materials of the borrow sites before and after they were subjected to the elution test.

4. Conclusions

The results of the study show that the contents of organic carbon, total nitrogen, inorganic nitrogen species, total phosphorus, inorganic reactive phosphorus, Cd, Co, Cu, Pb, Zn, and Mn in the sand materials of the potential borrow sites are generally within the range or less than their concentrations in the marine sediments of the Gulf of Aqaba and the Red Sea. The study confirms that organic carbon, total nitrogen, inorganic nitrogen species, total phosphorus, inorganic reactive phosphorus, Cd, Co, Cu, Pb, Zn, and Mn that may be leached into the seawater of the Gulf of Aqaba, if the sand materials came in contact with seawater in a nourishment project, is low and will not significantly increase the concentration of these species in the marine environment and seawater of the Gulf of Aqaba, even if the sand material was used in quantities as large as 100,000 tons. The low percentage of the mud fraction in the sand materials is an advantage, and allows the use of the material with minimum treatment before use in nourishment projects. The characteristics of the sand materials of the uplifted terraces which are common along the shores of the Gulf of Aqaba make it suitable and a low cost source of sand for nourishment of the eroded beaches along the whole Gulf of Aqaba. However, more research is recommended on the movement or transportation of the sand if it was placed in the subtidal zone. Pilot studies on selected beaches may be useful in studying the effect of waves, currents and tides on such transportations and movements.

Acknowledgements

The study was financially supported by the Deanship of Scientific Research and Higher Studies of Yarmouk University grant and the Higher Council for Science and Technology. The writing and the revision of this paper has been performed during the sabbatical awarded by Jordan University to Dr Mohammed Rasheed. The encouragement and support by the Council of the Marine Science Station representing the University of Jordan and Yarmouk University is highly acknowledged. The authors thank Mr Khalid Al-Tarabeen and Mr Khaldoun Mahafdha for their assistance in the laboratory work. Thanks are due to two anonymous reviewers who improve the paper significantly.

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