

## ARTICLE

**Estimation of the Total Inorganic Phosphate-Phosphorus in Sediments of the Old Phosphate Port at Jordan's Gulf of Aqaba****M. Rasheed<sup>a\*</sup>, S. Al-Rousan<sup>b</sup> and R. Manasrah<sup>c</sup>**<sup>a</sup> Department of Chemistry, School of Science, The University of Jordan, Amman, 11942 Amman, Jordan.<sup>b</sup> Department of Geology, School of Science, University of Jordan, Amman, 11942 Amman, Jordan.<sup>c</sup> Department of Coastal Environment, Faculty of Marine Sciences, The University of Jordan-Aqaba Branch, Jordan.Received: 14<sup>th</sup> Aug. 2022;Accepted: 9<sup>th</sup> Oct. 2022

**Abstract:** Between 1970–2013, huge amounts of phosphate particles were lost to the sea floor during the transport of phosphate to the port and loading it on ships sailing from the Gulf of Aqaba around the world. The dissolution of the lost phosphate was a major concern. Due to the importance of this issue, the amount of the total inorganic phosphate-phosphorus (TIP) was estimated in the sediment cores from different transects around the Old Phosphate Port (OPP). Additionally, some physical and chemical properties of seawater at OPP were measured. Samples for TIP were collected by SCUBA from 27 sites using metal pipes inserted into a certain depth (est. 1.5–2 m) of the bottom. In the lab, sediments of the cores were cut into layers as thin as 25 cm to measure TIP in each layer. The phosphate concentration in each layer revealed the highest amount in layers at 75–100 cm, with an obvious gradual increase from layers at 0–25 cm and from layers at 75–100 cm (91.4 and 3.0 million kg, respectively). In contrary, TIP tends to decrease from layers at 75–100 cm until layers at 150–175 cm. Obviously, phosphate concentrations decreased significantly in the layers at 150–175 cm. Based on the above estimations and taking into account the various calculations, the total mass of phosphate was around  $11.5 \times 10^6$  kg. The final recommendation to the decision maker in Aqaba is / that there is no need to remove the existing phosphate.

**Keywords:** Inorganic total phosphate, Pollution, Sediment layers, Gulf of Aqaba.

**Introduction**

The Gulf of Aqaba is a semi-enclosed water body located at the northern end of the Red Sea. The water of the Gulf is characterized by high clarity, temperature averages of (20–27 °C) and high dissolved oxygen contents (6–8 mg L<sup>-1</sup>), which creates almost ideal conditions for the sustenance of an abundant and diverse ecosystem<sup>[1]</sup>. The surface water of the Gulf of Aqaba is mostly oligotrophic (nutrient-poor)<sup>[2]</sup>. At this ecosystem lies the fringing reef of the Gulf of Aqaba, which holds diverse and rare species of animals and plants<sup>[3]</sup>.

Jordan has the fifth largest reserve and is the second largest exporter of phosphate in the

world<sup>[4]</sup>. In average, more than 3.5 million tons are exported through the Phosphate Port each year (Jordan Phosphate Mines Company, personal communication). Phosphate raw material was transported from southern Jordan to Aqaba by trains and trucks and exported through the OLD Phosphate Port (OPP) at the most northeastern tip of the Gulf of Aqaba until the year 2013. Since that time, Phosphate Berth was translocated to the southern part of Aqaba city. Substantial quantities of the phosphate dust were lost during shipment into the adjacent marine environment and settled at the seafloor in the form of particulate phosphate<sup>[5–7]</sup>.

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Phosphate pollution in waters of the Gulf of Aqaba, due to phosphate loss during shipment, has been a long ongoing concern since the mid-1970s. The Jordan Phosphate Mines Company has estimated the lost quantities to be between 0.05 and 0.1% of the total loaded quantities. In all cases, however, phosphate dust generated during storage and loading is considered an important environmental problem in Aqaba<sup>[5,8]</sup>. Phosphate rock is insoluble in seawater<sup>[5,9]</sup>. Besides, localized small amounts of soluble phosphate can be of minor significance, because it has been almost established that nitrogen rather than phosphate is the primary productivity-limiting nutrient and possible eutrophication<sup>[9–12]</sup>. The sediment acts as a sink as well as a source of nutrients (including phosphate) for the overlying water<sup>[13]</sup>. About 19–65% of inorganic phosphorus in sediment is exchangeable with the overlying water<sup>[14]</sup>. The maximum release of these nutrients is under anaerobic conditions<sup>[15,16]</sup>. Phosphate and other nutrients concentrations in the sediment pore water are higher than those in the waters overlying this sediment, which, under very calm conditions, resulted in fluxes of 0.1 and 0.01  $\mu\text{mol m}^{-2} \text{d}^{-1}$  for dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphate (DIP), respectively<sup>[2,13]</sup>. The total phosphorus concentration in bottom sediments was estimated by the Marine Science Station (MSS) to be in the range of 87 to 460  $\mu\text{g g}^{-1}$ <sup>[17]</sup>. According to Al-Rousan<sup>[13]</sup>, the bottom sediments of the Jordanian coast contain about 0.07, 0.05 and 0.35% of total phosphorus, total nitrogen, and organic matter, respectively.

The environmental effects of phosphate dust include increasing water turbidity, sedimentation on the coral reef that may depress coral growth and possibly increase the heavy metal content of sediments<sup>[7,18]</sup>. High concentrations of uranium were also reported in the raw phosphate<sup>[19,20]</sup>.

The main goal of the present study is to estimate the quantity of the phosphate dust that was settled during the operation times of the OPP. The estimation of the accumulated phosphate would help decision makers decide whether it is necessary to remove these layers or not before the start of any expected development in the OPP site, according to the plan of Aqaba Special Economic Zone Authority (ASEZA).

## Materials and Methods

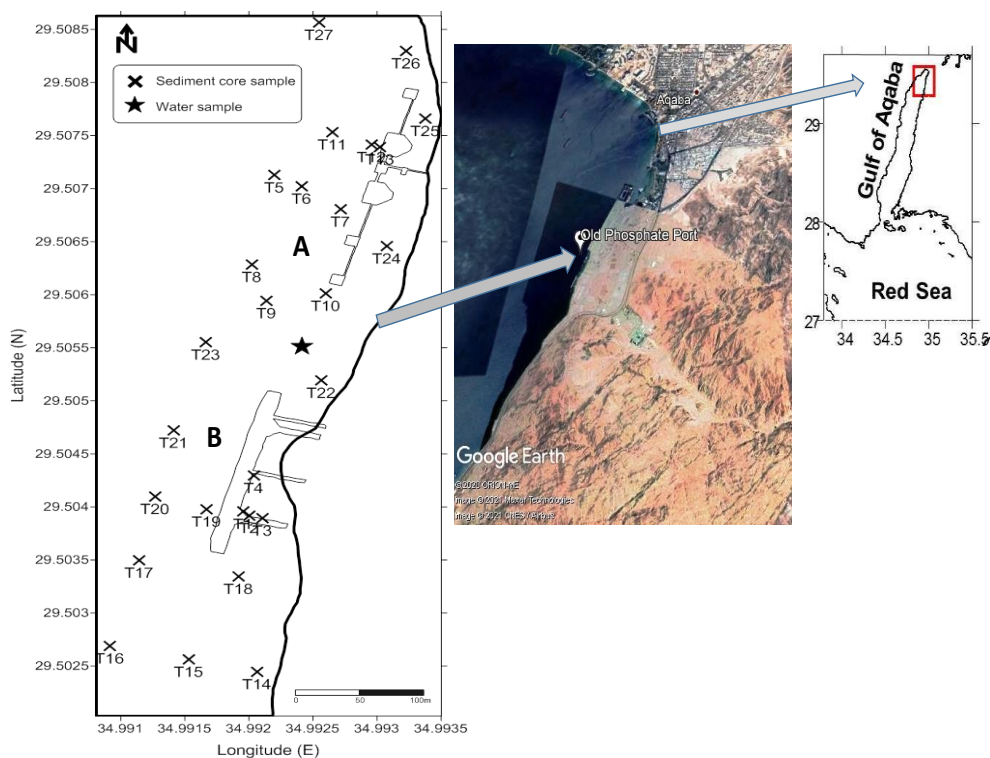
### Study Site and Samples Collection

The study site is located in the northernmost of the Gulf of Aqaba. The study area is located along the OPP (Fig. 1). The total area of the study site is about 8400 m<sup>2</sup> (700 m long and 120 m wide). Sediment cores were collected from 27 sites (T1-T27) along the OPP-AB (Table 1, Fig 1). The samples were collected by divers using metal pipes (2 m high, 5 cm inner diameter). The pipes were inserted into the sediment to about 1.5 to 2 m below the seabed or up to refusal. In the laboratory, the sediment's cores were cut into 25-cm slices.

Furthermore, water samples were collected from one location (Fig. 1) at 1 m below the surface water. Duplicate samples were collected from the OPP-AB and from the Marine Science Station (MSS; which is about 3 km to the south of the OPP) to serve as a reference site. Collected samples were immediately stored in a dark icebox at an internal temperature of around 0 °C. Back to the laboratory (2–3 hours from the collection site), the seawater samples were filtered under vacuum using 45- $\mu\text{m}$  cellulose acetate membrane filters and stored in a deep freezer at –20 °C till analysis.

### Sediment and Water Analysis

For the total inorganic phosphorus (TIP) determination in sediment, the ignition method was used as recommended by Andersen<sup>[21]</sup>. Following this method, 0.2 g of sediment was combusted in a furnace (450 °C) and the ash was boiled in 1 N HCl for 15 minutes. The sample was diluted to 100 ml with distilled water and phosphate was then measured spectrophotometrically following the method reported by Grosshoff et al.<sup>[22]</sup>. Similarly, the analysis of inorganic nutrients (ammonium, phosphate, nitrate and nitrite) in the water samples was carried out spectrophotometrically following the methods reported by Grosshoff et al.<sup>[22]</sup>. Chlorophyll *a* was measured spectrofluorometrically according to the method described by Arar and Collins<sup>[23]</sup>. Oxygen was measured using a YSI water-quality monitor model 600XL, whereas seawater pH was measured using a pH meter.



**Figure 1.** Map of the northern Gulf of Aqaba showing the sediment and water sampling site along the old Phosphate Port A and B (OPP-AB) in the northern Gulf of Aqaba.

**Table 1.** Coordination and core lengths of sediment cores collected from the OPP in the northern Gulf of Aqaba.

Area	Site	Longitude (E)	Latitude (N)	Total core length (cm)
OPP-AB	T1	34.9920	29.5040	100
	T2	34.9920	29.5039	125
	T3	34.9921	29.5039	100
	T4	34.9920	29.5043	125
	T5	34.9922	29.5071	25
	T6	34.9924	29.5070	125
	T7	34.9927	29.5068	125
	T8	34.9920	29.5063	100
	T9	34.9921	29.5059	125
	T10	34.9926	29.5060	150
	T11	34.9927	29.5075	125
	T12	34.9930	29.5074	125
	T13	34.9930	29.5074	150
	T14	34.9921	29.5024	100
	T15	34.9915	29.5026	175
	T16	34.9909	29.5027	100
	T17	34.9911	29.5035	125
	T18	34.9919	29.5033	150
	T19	34.9917	29.5040	100
	T20	34.9913	29.5041	100
	T21	34.9914	29.5047	150
	T22	34.9926	29.5052	100
	T23	34.9917	29.5056	125
	T24	34.9931	29.5065	125
	T25	34.9934	29.5077	125
	T26	34.9932	29.5083	125
	T27	34.9925	29.5086	125

## Estimation of the Quantity of Total Inorganic Phosphate

The estimation of the total mass of phosphate was performed based on the data of phosphate concentration ( $\text{g kg}^{-1}$ ) at all slices of each core and from all sites. Surfer software (V. 11.0.642, Golden Software) was used to draw contours of phosphate concentration at each sample (25 cm height) to interpolate the whole region of both OPP-AB. The gridding of the interpolation results in a homogenous data distribution with a resolution of  $6.5 \text{ m} \times 6.5 \text{ m}$  in the OPP-AB. The data of interpolation gridding was used to estimate the mass of each grid cell using the equation:

$$M = \sum h \times A \times C \times \rho \quad (1)$$

where  $M$  is the phosphate mass (kg) in each layer;  $h$  is the height of each core layer (0.25 m);  $A$  is the area of a grid cell ( $6.5 \text{ m} \times 6.5 \text{ m}$  in the OPP-AB);  $C$  is the average phosphate concentration ( $\text{g kg}^{-1}$ ) at each grid cell;  $\rho$  is the density of phosphate. Based on Equation 1, the total mass of phosphate was estimated for all layers.

## Results and Discussion

### Seawater Properties

Chemical properties of seawater samples that were collected from two locations (OPP-AB and the MSS) are presented in Table 2. The pH and DO values showed no differences compared to

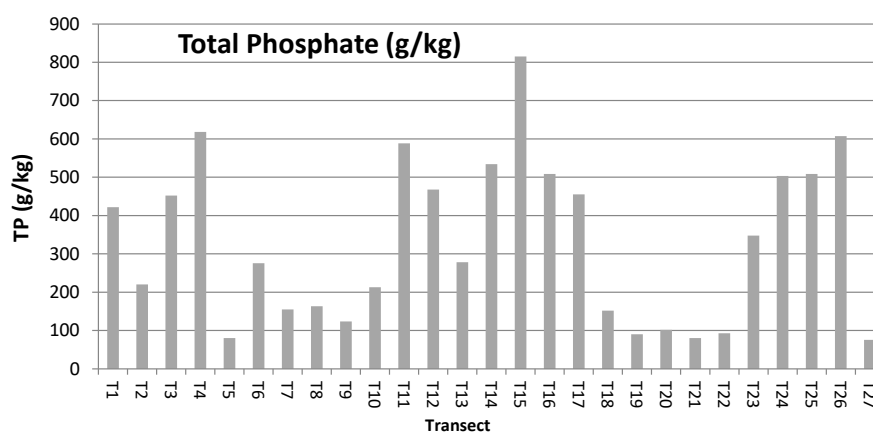
the values of the reference MSS water. Oxygen values represent a saturated condition. Nutrients (ammonium, nitrate, nitrite, phosphate and silicate) values at OPP and MSS were almost the same, which are comparable with the baseline values of the Gulf of Aqaba<sup>[12]</sup>. The slight difference might be due to the sensitivity of the used method<sup>[12]</sup>. Chlorophyll  $a$  values from the OPP-AB were similar to those recorded from the reference site. All chlorophyll  $a$  values were below  $1 \text{ ug/L}$  which is the limiting concentration for eutrophication in oligotrophic water as reported by several researchers<sup>[12,24]</sup>.

### Total inorganic phosphate distribution along OPP

Total inorganic phosphate (TIP) contents ( $\text{g.kg}^{-1}$ ) in all collected cores in the OPP-AB area are represented in Figure 2. The middle area (T11-T17) contains generally higher concentrations than those at the edges of our study. The maximum value of approximately  $800 \text{ g/kg}$  was found to be at transect T15, and the lowest was determined at T5 with a very low value ( $80 \text{ g/kg}$ ). The average value of approximately  $340 \text{ g/kg}$  was recorded which shows that one third of the sediment at the OPP is raw phosphate. The values at the OOP was much higher than the TIP values at MSS (Approx.  $0.3 \text{ g/kg}$ ) as reported by Al-Rousan et al.<sup>[7]</sup>. This large difference may be due to the loss during transportation<sup>[18]</sup>.

**Table 2. Chemical properties of seawater samples collected from OPP (AB) and Marine Science Station (MSS). Duplicate samples were taken; averages and standard deviations are presented.**

Location	pH	DO (mg/L)	$\text{NH}_4^+$ ( $\mu\text{M}$ )	$\text{NO}_3^-$ ( $\mu\text{M}$ )	$\text{NO}_2^-$ ( $\mu\text{M}$ )	$\text{PO}_4^{3-}$ ( $\mu\text{M}$ )	$\text{SiO}_2$ ( $\mu\text{M}$ )	Chl $a$ ( $\mu\text{g/L}$ )
OPP-AB	$8.24 \pm 0.10$	$6.78 \pm 0.10$	$0.56 \pm 0.12$	$0.78 \pm 0.15$	$0.08 \pm 0.01$	$0.08 \pm 0.01$	$1.53 \pm 0.20$	$0.33 \pm 0.03$
MSS	$8.27 \pm 0.11$	$6.75 \pm 0.12$	$0.56 \pm 0.11$	$0.74 \pm 0.12$	$0.09 \pm 0.01$	$0.10 \pm 0.01$	$1.65 \pm 0.20$	$0.30 \pm 0.02$

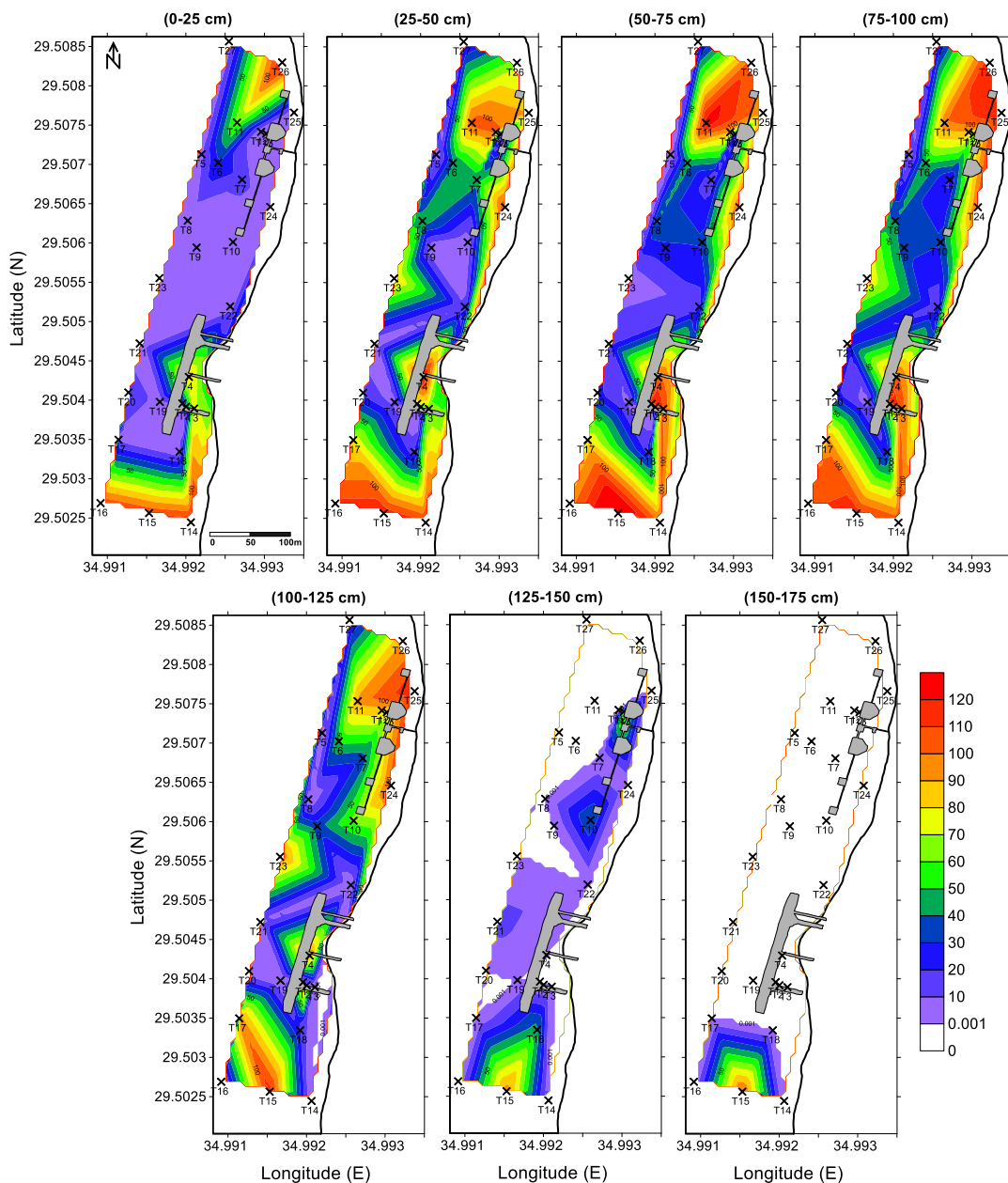


**Figure 2. TIP in the whole collected cores from the two areas A and B (OPP-AB) in the northern Gulf of Aqaba (for transect location, see Fig 1).**

**Total Inorganic Phosphorus Quantity at Different Sediment Layers**

The distribution of TIP in each layer in OPP-AB (Fig. 3, Table 3) revealed that the highest amount was found in the layer 75–100 cm (24% more than the upper layer 50–75 and 48% more than the deep layer 100–125). Apparently, there was a clear gradual increase from 0–25 cm layer to 75–100 cm layer, indicating the high sedimentation rates of the lost transported phosphate in the last years before the translocation of the port to the southern coast of the Jordanian Gulf. The concentrations started to decrease from the 75–100 cm layer to the last

layer (150–175 cm). Obviously, phosphate concentrations decreased in the layer of 150–175 cm. However, phosphate in this layer clearly still existed in the southern part of this area. According to the estimation used in Equation 1, the total mass of phosphate was approximately 11.78 million kg (Table 3). The distribution of TIP in the sediment layers indicates that the transportation of phosphate using this port was in small quantities in the first years and was starting to increase after then to reach a maximum before port relocation to the south. This was confirmed by Jordan Phosphate Mines Company (personal communications).



**Figure 3. Distribution of phosphate concentration ( $\text{g kg}^{-1}$ ) at each layer (25 cm thick) in collected cores from the OPP (AB) area at Aqaba Main Port (AMP) in the northern Gulf of Aqaba.**

The relatively small quantity in the top 25 cm compared to the middle layers (50–125 cm) indicates that TIP will decrease gradually with time because normal sediments (without raw

phosphate) were precipitated in the last years after port relocation with an average sedimentation rate of about  $1.5 \text{ g/cm}^2/\text{year}$ <sup>[7]</sup>.

**Table 3. Total Mass of phosphate (kg) in OPP (AB) and northern inner basin areas in the northern Gulf of Aqaba.**

Layer (cm)	Phosphate mass (kg)
0–25 cm	1 369 722
25–50 cm	2 352 445
50–75 cm	2 399 565
75–100 cm	2 971 897
100–125 cm	2 021 325
125–150 cm	481 649
150–175 cm	189 725
TOTAL MASS (Approx.)	11.78 millions

## Conclusion

In conclusion, the total mass of the estimated TIP is around  $11.5 \times 10^6 \text{ kg}$  at the OPP. However, the final recommendation to the decision maker in Aqaba is that there is no need to remove the existing phosphate, because, in general, it has no direct negative influence on the biological, geological, chemical and physical properties, since the solubility of TIP is very little in seawater<sup>[9]</sup>. In contrast, the removal of this large quantity may induce negative impacts

on the marine environment due to intensive turbidity and abrupt change to the ecosystem habitat structure that will be caused by the dredging and constructions during the removal process which may affect the wealthy environment.

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