JJEES

JJEES (2023) 14 (3): 222-231
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

Transportation, Accumulation and Pollution by Lost Raw Phosphate Dust Particles from a Phosphate Loading Berth in Coastal Water of the Gulf of Aqaba-Red Sea

Rawajfh, M. M.[1], Rasheed, M. Y.[*2], Al-Rousan, S. A.[3], Manasrah, R. S.[4], Abu-Hilal A.H.[1]

[a] Department of Earth and Environmental Science, Faculty of Science, Yarmouk University, Irbid 21163, Jordan
[b] School of Science, Department of Chemistry, University of Jordan, Amman,11942 Amman, Jordan
[c] School of Science, Department of Geology, University of Jordan, Amman,11942 Amman, Jordan
[d] Department of Coastal Environment, Faculty of Marine Sciences, The University of Jordan-Aqaba Branch, Jordan

Received 23th March 2022; Accepted 10th May 2023

Abstract

The present study was carried out to investigate the accumulation pattern, magnitude and distribution of the phosphate rock dust particles that reach the coastal seawater of the Jordanian Gulf of Aqaba during ship-loading at the Phosphate Loading Berth (PLB). The concentration of phosphate- phosphorus was measured in water, sediment and trap-sediments. The speed and direction of currents in the area of the PLB were also measured to assess its effect on the transportation, sedimentation and distributions of phosphate dust particles within the study area. The analysis and examination of the results indicate that phosphate pollution is located mainly near the phosphate loading berth. The results show that the concentrations of phosphorus (total phosphorus (TP), inorganic (IP), and organic (OP) in trap-sediments were higher than their concentrations in sediments and IP was the major species of phosphorus in the study area. The statistical analysis showed that TP, IP, OP in trap-sediments and sediments of PLB differ significantly from those of all other sites. The concentration of TP, IP and OP were higher in the power station north (PSN) and central power station (PS) located to the south of PLB compared to the concentrations at stations located to the north of PLB and thus reflecting the effect of prevailing southward current. The increase in dissolved inorganic phosphorus (DIP) concentration in the water of the PLB area is not high to cause significant increase in the DIP in the water of the Gulf of Aqaba to abnormal or hazardous levels.

Keywords: *Phosphate, Pollution, Gulf of Aqaba, Sediments, Trap-sediments, Prevailing currents*

1. Introduction

Jordan has the fifth largest reserve and the second largest exporter of phosphate in the world (Jordan Phosphate Mines Company, 2020). The phosphate port in Aqaba is used for exporting phosphate powder. Phosphate dust generated during storage and loading is considered an important environmental problem in Aqaba because of the substantial quantities of the phosphate that is lost and settled to the water of the Gulf of Aqaba during the loading process (Abed, 2012; Abu-Hilal, 1999).

The concentrations of dissolved inorganic phosphate in the coastal water of the Gulf of Aqaba range between 0.02 to 0.2 µM (Rasheed et al., 2018). Phosphate-phosphorous and other nutrients concentration in the sediment pore water is higher than those in the water overlying these sediments, which under very calm condition resulted in fluxes of 0.1 and 0.01 µmol m^{-2} d^{-1} for dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP), respectively (Al-Rousan, 1998; Rasheed et al., 2002; Al-Rousan et al., 2004). The bottom sediments of the Jordanian coast water contain 0.07 % total phosphorous and the phosphate concentration in the interstitial water is about 50 times higher than those of the overlying water (Al-Rousan, 1998; Al-Rousan et al., 2004). Other estimate for the total phosphorous concentration in the bottom sediments is in the range of 0.04 to 0.25% was recorded (Al-Rousan et al. 2006; MSS Report 2020). However, values up to 50 folds was recorded in sediments from the Phosphate Loading Terminal (Badran and Al Zibdeh, 2005; MSS Report, 2020). It has been reported that some of the raw phosphate (flouroapatite) does dissolve in the sea- water and therefore it contributes to the level of the inorganic phosphate nutrient in the ecosystem [10] (Abu-Hilal et al., 2008). It has been reported that phosphate levels in PLB area is nearly three to four times higher than that of the water in the adjacent areas (Abu-Hilal, 1985).

The environmental effects of the phosphate dust include increasing of suspended solids and water turbidity, reduction of water clarity and light penetration, and siltation on the coral reef and depression of coral growth. Other potential impact includes increasing the levels of dissolved phosphate nutrients and other toxic heavy metal such as Cd, As, and Zn (Abu-Hilal, 1999; Al-Rousan et al., 2016).

The physical characteristics of sea water of the Gulf of Aqaba that may affect phosphate dust distribution, abundance and dissolution in the environment of the Gulf of Aqaba have been investigated, particularly the effect of

* Corresponding author e-mail: m.rasheed@ju.edu.jo

the prevailing currents and the distance from the phosphate loading berth which has been considered the main source of sedimentary phosphorus in the Jordanian (northeastern) sector of the Gulf of Aqaba.

The main goal of the present study was to investigate the accumulation rate, magnitude and distribution of the phosphate rock dust particles that reach the coastal seawater of the Jordanian Gulf of Aqaba during ship loading at the Phosphate Loading Berth (PLB), which is located on the most northeastern side of the Gulf of Aqaba. The results of this work would help decision makers to estimate the necessity to remove the accumulated phosphate dust when rehabilitation is needed for the old phosphate Port area.

2. Materials and Methods

2.1 Study sites

The present study was carried out in the north and northeastern coasts (Fig. 1). The sampling sites covered the sector from the Hotel Area (HA) in the north to the Marine Science Station (MSS) in the south. Water, sediment, and trap-sediment samples were collected four times during the study period. Sample processing and pretreatment were carried out immediately after collection.

2.2 Sampling process

Water samples were collected from near surface and near bottom levels, then sorted in pre–labelled acid washed polyethylene bottles of one litre (1 L) capacity. Immediately after collection the bottles were put in an ice box and transported to the laboratories of Marine Science Station. Water samples were sorted in a deep Freezer at -20 ^{O}C until future analysis. The sediment and trap-sediment samples were collected at different depths from eleven selected sites (Fig. 1). Settling sediments particles were collected using bottom sediment traps that were placed 1m above sea bottom. Each trap was made of two cylindrical jars. Each jar was 9.9 cm in diameter, and 30 cm in height. The sedimentation jars were collected at regular time intervals of about four weeks and replaced again for another stage collection. Sedimentation rates were determined using sedimentation traps. The near-bottom water, sediment and trap-sediment samples were collected by SCUBA divers. Sediment samples from the top 5 cm of surface sediment were collected in pre-cleaned acid washed plastic bags from each site at the same time of traps collection.

2.3 Current measurements

Acoustic Doppler Current Profiler (ADCP) Workhorse 300 kHz (RD Instruments) was deployed at the seabed (35 m depth) of a shelf area in close vicinity of the Phosphate Loading Berth (PLB). Horizontal and vertical current components were measured. The time interval between ensembles was 10 minutes and the number of pings per ensemble was 300 at each 2-m bin length.

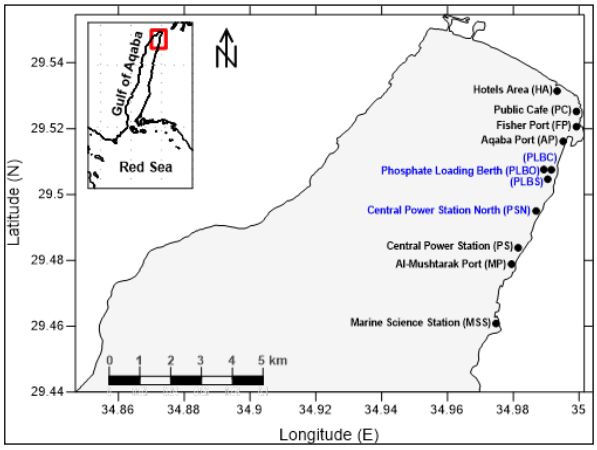

Figure 1. Map of the study area showing the locations of the sampling sites.

2.4 Laboratory work

The single solution method of Murphy and Riley (1962) for the determination of DIP in sea water as described by Grasshoff et al. (1999) with minor modification was used in the present work.

Aliquot of 0.1 g of the sediments was treated with concentrated HNO_3 and evaporated to near dryness. The residue was digested with 4 ml of concentrated $HClO_4$ until the white fumes of $HClO_4$ were not observed (APHA, 1971). The digested samples were dissolved in 2 ml of 6 M HCl and 10 ml of deionized water and filtered into a100 ml polypropylene volumetric flask through Whatman filter paper No 1. Filtrate in the flask was made up to 100 ml with deionized water. Aliquot of the digest was used for the determination of total phosphorus, as dissolved inorganic phosphorus (DIP) using the same method of determination of DIP in water.

Inorganic phosphorus (IP) was determined by the addition of 25 ml of 1 M HCl to an aliquot of 0.1 g of trap-sediment sample in a Teflon beaker. The samples were kept at room temperature for 24 hours. The samples were filtered through pre-weighed, pre-ignited 24 mm GF/C Whatman glass fibre filter into a 100 ml polypropylene vlometric flask. The filtrate in the flask was completed to the 100 ml mark by the addition distilled water. Inorganic phosphorus was determined as DIP using the same method of determination of DIP in water. Organic phosphorus was determined by the difference between total phosphorus (TP) and inorganic phosphorus (IP) of each sample (Aspila et al., 1976). Sediment samples were washed with deionized water and dried at 80 ^{O}C for at least 36 hours. The dried samples were physically freed from visible shells and coarse shell fragment. Samples were ground, powdered and homogenized by the use of an agate pestle and mortar. Phosphorus species (TP, IP, OP) were analysed by the use of the same methods that have been described under the trap-sediment samples. Total sedimentation rate was measured following the method of English et al . (1994).

In order to test the significance in differences between the different concentrations of phosphorus species at different sites of the study area, the “one-way ANOVA test” has been used to calculate the P-values while, significance has been tested using 95% confidence interval.

3. Results and discussions

3.1 Dissolved inorganic (reactive) phosphorus (DIP) in the water of the Gulf of Aqaba

The results of DIP in surface (Sw) and near-bottom (Bw) water from the eleven sites (Fig. 2a) show that the highest concentration was recorded at PLBS whereas the lowest was at HA in the north. DIP concentrations show a general increase in winter (November and January). It is obvious that the concentrations of DIP are slightly higher around PLB and tend to decrease with increasing distance from this site.

The statistical analysis for DIP in the surface and near-bottom water showed significant differences between the sites adjacent to the Phosphate Loading Berth (phosphate loading berth center (PLBC); phosphate loading berth offshore (PLBO); and phosphate loading berth south (PLBS) and the other seven sites (Aqaba port (AP); Fisher port (FP); Hotels Area (HA); Al-Mushtarak Port (MP); Marine Science Station (MSS); Central Power Station north (PSN); and Public cafés (PC)). In contrast, the differences between the three adjacent sites which are close to the Phosphate Loading Berth (PLB) were not significant. The slight increase in DIP concentration in the close vicinity of this area can be attributed to the dissolution of the lost raw phosphate particles in the water of this site (Hulings and Abu-Hilal, 1984; Al-Moghrabi and Horani, 1998). The available evidence indicate that the increase of DIP due to the partial dissolution of the raw phosphate reaching the water of the Gulf of Aqaba would not cause a substantial or significant increase in the prevailing levels of DIP in water (Abu-Hilal et al., 2008; Rasheed et al., 2005; Rasheed et al.2018).

3.2 Total phosphorus

The results of TP in the trap-sediment and sediments from the eleven sites (Fig. 2b) show that the highest concentration was obtained from the sediment traps which are located at the PLBS while the highest concentration in sediment was measured at PLBC. The lowest concentration was obtained from the trap- sediment and sediment which are located at the Hotel Area in the north and at Marine Science Station in the south. The concentrations of TP are higher around the Phosphate Loading Berth with TP concentrations are relatively high in the stations located to the south of PLB (PSN and PS) compared to the concentrations at stations located to the north of PLB (AP, PC and HA). The concentrations of TP and IP in the trap-sediments are higher than the concentrations in the sediments. The statistical analysis of the results for TP in trap-sediments showed significant differences between the sites located within the PLB area and other sites, while the differences between the sites located within the PLB were not significant. The statistical analysis for TP in sediments showed also the same result; significant differences between the three sites which are located within the PLB area and all other sites.

3.3 Inorganic phosphorus

The results (Fig. 2c) show that the highest mean concentrations of IP in the trap-sediments of PLBS, while the highest concentration in sediments was measured at the PLBC. The lowest IP concentrations in both sediment and trap-sediment were recorded at HA in the north. It is clear that the concentrations of IP are higher around the Phosphate Loading Berth and in the stations located to the south compared to those located to the north. The statistical analysis of the IP results in trap-sediments and sediments revealed significant differences between the sites that are located within or close to the PLB and all other sites, while the differences between the sites that are located within the PLB area are not significant.

3.4 Organic Phosphorus

The examination of the results of OP in trap-sediments from the eleven sites (Fig. 2d) shows that the highest concentration was measured at PLBC while the highest concentration in sediments was measured at PLBS while the lowest in trap-sediment and sediment were at MSS. This trend of OP in trap-sediments and sediments is similar to that of TP and IP in sediments and trap-sediments; the relatively higher concentration of all phosphorus species tends to decrease with increasing distance from the PLB area whether to the north or the south. The statistical analysis of OP in sediments and trap-sediments reveals significant difference between the sites that near PLB and all other sites, while the differences between the sites near PLB were not significant.

3.5 Sedimentation Rate

The total sedimentation rate (mg cm^{-2} d^{-1}) in the near-bottom sediment traps (Fig. 2f) was highest at the HA in the north, whereas the lowest was measured at the PLBO. The statistical analysis for the total sedimentation rate in the near-bottom sediment traps showed significant differences between the site of PLBC and the other sites in the south. Significant differences have been also found between the highest sedimentation rates at HA in the north and seven other sites in the south. Significant differences were observed also between the lowest sedimentation rate at PLBO and the sites HA, PLBC, PLBS, AP, FP, and PC. The high sedimentation rate at Hotel Area might be attributed to many factors that include but not restricted to the constructions and infrastructure work that take place in the northern tip of the Gulf. Similar results were also recorded by the MSS (MSS Report, 2020). The higher sedimentation rate at the PLB area is expected to be related to ship loading and due to the high rate of sedimentation from the air borne dust which has been reported at this site (Schuhmacher et al., 1982; Badran and Zibdah, 2005; Al-Rousan et al., 2016). The lowest sedimentation rate was recorded in the PLBO at a distance of about (200 m) to the west of the PLB site. This might be attributed to the depth of sedimentation trap at this site (nearly 20 m) and also due to relatively long distance (200m) between this site and the Phosphate Loading Berth (PLB) site which is receiving most of the lost raw phosphate particle. Al-Rousan (2016) has found that the sedimentation rate is decreasing with increasing depth of the water column due to the limited effect of the currents and waves factors in eroding the subsurface sediments at deep site. The higher sedimentation rates at the sites located within the PLB area are still much lower than the rates reported by other authors (Al-Rousan, 1998; Hamdan, 1999; Bani-Awwad, 2002; MSS report, 2020). These relatively low sedimentation rates (present study) can be attributed to the improved management of phosphate handling during trucks and trains

unloading, storage, and ship loading processes that include the use of chalk feeders, better training and environmental awareness of the workers and operators working in the Phosphate Loading Berth sites (MSS Report, 2020).

3.6 Phosphate-phosphorus as phosphorus pentoxide (P_2O_5) and tricalcium phosphate (TCP) in trap-sediments and sediments

The results in table 1 indicate that IP is an important phosphorus species as it constitutes 82.50 - 97.54 % of the TP in trap-sediments, while OP constitutes 2.44 - 17.50 %. TP in the trap-sediments ranged between 0.32 - 23.45% when calculated as P_2O_5 and between 0.70 - 49.28% when calculated as TCP. By comparison, IP ranged between 0.26 - 22.23% when calculated as P_2O_5 and 1.08 - 45.93% when calculated as TCP.

The results of sediments analysis (Table 2) are similar to those of trap-sediments. IP is an important phosphorus species and represents 77.01-94.53 % of the TP concentrations in the sediments, while OP constitutes 5.4 - 23.11 %. The concentrations of TP in the sediments represent 0.16-21.74% as P_2O_5 and 0.34 - 47.50% as TCP, while those of IP represent 0.14-20.55% as P_2O_5 and 0.31-44.90 % as TCP. The higher percentage of TP and IP are caused mainly by the high apatite phosphorus fraction, which usually constitutes a major fraction of the inorganic form of phosphorus (Abu-Hilal, 1987). The concentrations of phosphorus species (TP, IP, and OP) are highest in the sites which are nearest to PLB and the concentrations tend to decrease with increasing distance from this site. The abnormally high concentrations of the total phosphorus at the sites PLBS, PLBC, and PLBO and dramatic decrease in these concentration with increasing distance (to the south and north) indicated that phosphate pollution is concentrated mainly in the close vicinity of the PLB due to the high specific gravity of the raw phosphate particle that, therefore, settle quickly and deposit onto the bottom causing the high sedimentation rate of phosphate dust around Phosphate Loading Berth. The higher concentrations of TP and IP in trap-sediments as compared to their concentrations in sediments can be attributed to the rapid dilution in the sediments and dissipation of the partially dissolved raw phosphate particles in the water of the Aqaba Gulf. Phosphorus as P_2O_5 constitutes 0.32-23.45 %, 0.16-21.74 % of the total phosphorus concentrations in trap-sediments and sediments respectively, compared to the phosphate rock which contain about 32% phosphorus as P_2O_5.

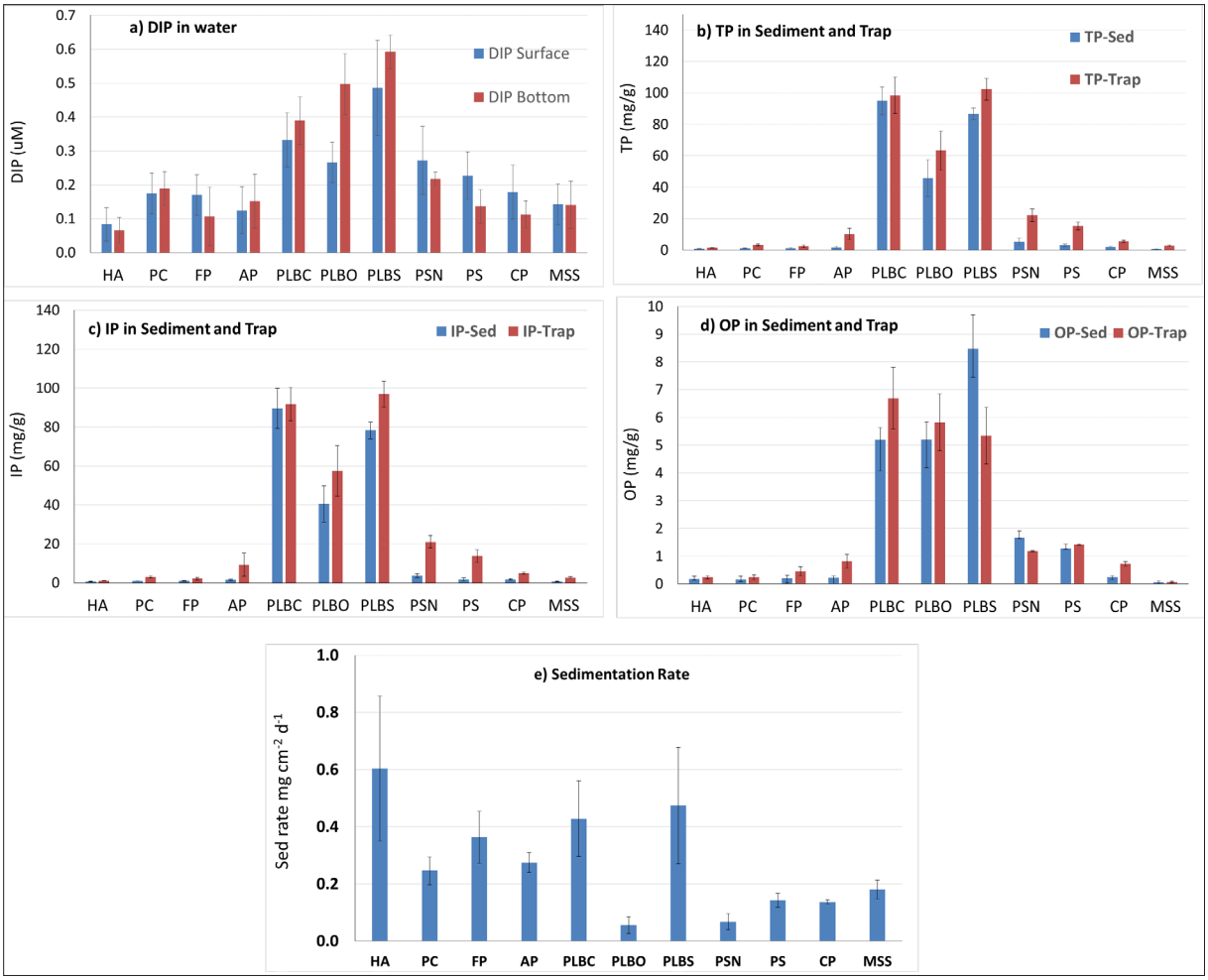

Figure 2. Sampling sites with (a): Mean dissolved inorganic phosphate (DIP) concentrations (µM) in surface and near-bottom water of the Gulf of Aqaba. b): Mean concentrations (mg g -1) of total phosphorus (TP) in trap-sediments and sediments (c): Mean concentrations (mg g-1) of inorganic phosphorus (IP) in trap-sediments and sediments. (d): Mean concentration (mg g -1) of organic phosphorus (OP) in trap-sediments and sediments. (f): Mean sedimentation rate (mg cm-2 d-1) in the near-bottom sediment traps along the Jordanian coast of the Gulf of Aqaba. Error bars in all figures represent the standard deviation of the measured parameter in all measured months. Sampling sites are demonstrated in figure 1 above.

Table 1. Percentage of TP and IP in trap-sediments were calculated as P_2O_5 and TCP.

Site	Mean concentration mg g $^{-1}$			IP/TP	OP/TP	TP as		IP as	
	(TP)	(IP)	(OP)	(%)	(%)	%P_2O_5	%TCP	% P_2O_5	%TCP
HA	1.39	1.15	0.24	82.97	17.03	0.32	0.70	0.26	0.58
PC	3.29	3.05	0.24	92.70	7.30	0.75	1.65	0.70	1.53
FP	2.61	2.15	0.46	82.50	17.50	0.60	1.31	0.49	1.08
AP	10.32	9.34	0.81	90.45	7.84	2.37	5.17	2.14	4.68
PLBC	98.43	91.73	6.70	93.20	6.80	22.56	49.28	21.02	45.93
PLBO	63.33	57.50	5.83	90.80	9.20	14.51	31.71	13.18	28.79
PLBS	102.33	96.99	5.34	94.78	5.22	23.45	51.24	22.23	48.56
PSN	22.21	21.02	1.18	94.67	5.33	5.09	11.12	4.82	10.53
PS	15.22	13.80	1.42	90.65	9.35	3.49	7.62	3.16	6.91
MP	5.69	5.01	0.73	88.08	12.79	1.30	2.85	1.15	2.51
MSS	2.77	2.70	0.07	97.54	2.44	0.64	1.39	0.62	1.35

Table 2. Percentage of TP and IP in sediments when calculated as P_2O_5 and TCP.

Site	Mean concentration mg g $^{-1}$			IP/TP	OP/TP	TP as		IP as	
	(TP)	(IP)	(OP)	(%)	(%)	%P_2O_5	%TCP	% P_2O_5	%TCP
HA	0.81	0.62	0.19	77.01	23.11	0.19	0.41	0.14	0.31
PC	1.18	1.02	0.16	86.00	13.93	0.27	0.59	0.23	0.51
FP	1.26	1.06	0.20	83.90	16.08	0.29	0.63	0.24	0.53
AP	1.79	1.57	0.22	87.76	12.29	0.41	0.90	0.36	0.79
PLBC	94.86	89.67	5.19	94.53	5.47	21.74	47.50	20.55	44.90
PLBO	45.74	40.53	5.21	88.61	11.39	10.48	22.90	9.29	20.29
PLBS	86.78	78.31	8.48	90.23	9.77	19.89	43.45	17.94	39.21
PSN	5.40	3.74	1.66	69.24	30.76	1.24	2.70	0.86	1.87
PS	3.04	1.77	1.26	58.41	41.63	0.70	1.52	0.41	0.89
MP	2.03	1.79	0.24	88.10	11.86	0.47	1.02	0.41	0.90
MSS	0.69	0.64	0.05	92.52	7.73	0.16	0.34	0.15	0.32

The low percentage of P_2O_5 in trap-sediments and sediments as compared with raw phosphate rock is attributed to the dissolution and dilution of phosphate dust in the Gulf of Aqaba before the phosphate dusts are deposited on the bottom. It is worthy to mention that these P_2O_5 percentages in sediments (0.16 - 21.74%) are in general agreement with the values (1.47-18.62%) reported by Abu-Hilal (1999). In the present study however, the average P_2O_5 in sediments (6.82%) is 16 times higher than the mean value (0.42%) reported by Mulqui (1978) and 11 times higher than the highest value (0.65 %) reported by Freemantle et al. (1976) who used 2M HCl at 80°C to extract phosphorus from sediment. The difference between their values and the present values can be attributed in part to the more rigorous perchloric acid method used for the extraction of sedimentary phosphorus in the present study. However, other factors may be also relevant, notably to the sampling sites PLBS, PLBC, and PLBO in this study which are closer to the phosphate loading berth than the corresponding sampling sites of Freemantle et al. (1978). In addition, there has been a major increase in the amount of phosphate exported over the past decade's period compared to the 1978 period. By 2008, more than 3.5 million tons (on average) are exported through Aqaba port each year (Abu-Hilal et al., 2008). The average annual export increased to 4.5 million tons between 2010 and 2018 (Jordan Phosphate Mines Company, 2020).

3.7 Currents

The current was measured in the study area at different depth levels between 3 and 27 m during the study period. The results show (Fig. 3) clearly that the current at 3 and 5m depth was southeastward (147° ± 18.8°) and (181° ± 32.9°) with mean speed of (14.6 ± 13.4 cm s^{-1}) and (7.3 ± 5.1 cm s^{-1}), respectively.

The current at 7 m depth was weak (3.1 ± 4.3 cm s^{-1}) with unstable direction. Below this depth, the current started to change its direction to the northeast, which assumes that the 7 m depth layer is a transition layer between two layers that have different directions. The currents between 9 and 25 m remained northeastward but with a tendency to decrease in magnitude from 4.5 ± 4.0 cm s^{-1} at 9 m to 2.7 ± 2.4 cm s^{-1} at 25 m. Because the sediment samples were collected at about 10 m depth, the current data above this depth has been used to examine the relation between the phosphate-phosphorus distribution (TP, IP, and OP). This suggests that the current which is assumed to affect the distribution of phosphorus concentration was mainly southeastward of the PLB which means that the effect of this prevailing current should be reflected on the distribution of phosphate-phosphorus, and one therefore should find more phosphorus to the south of PLB than to north. Almost all the results of TP, IP concentrations confirm postulation that there are higher concentrations of

TP and IP around PLB, and the concentrations of these two forms of phosphorus are higher in the stations located to the south of the PLB than those located to the north of it, despite the fact that the distances between the PLB and the north sites are less than the distances between the PLB and the south sites, as indicated by (Table 3).

3.8 Correlations between TP and (IP and OP) in trap-sediments and sediments

The results of this analysis (Fig. 4) show that the concentrations of TP in trap-sediments and sediments have high and significant correlation with IP (R^2=0.996) compared with moderate correlation with OP (R^2=0.579 for trap-sediments and 0.659 for sediments).

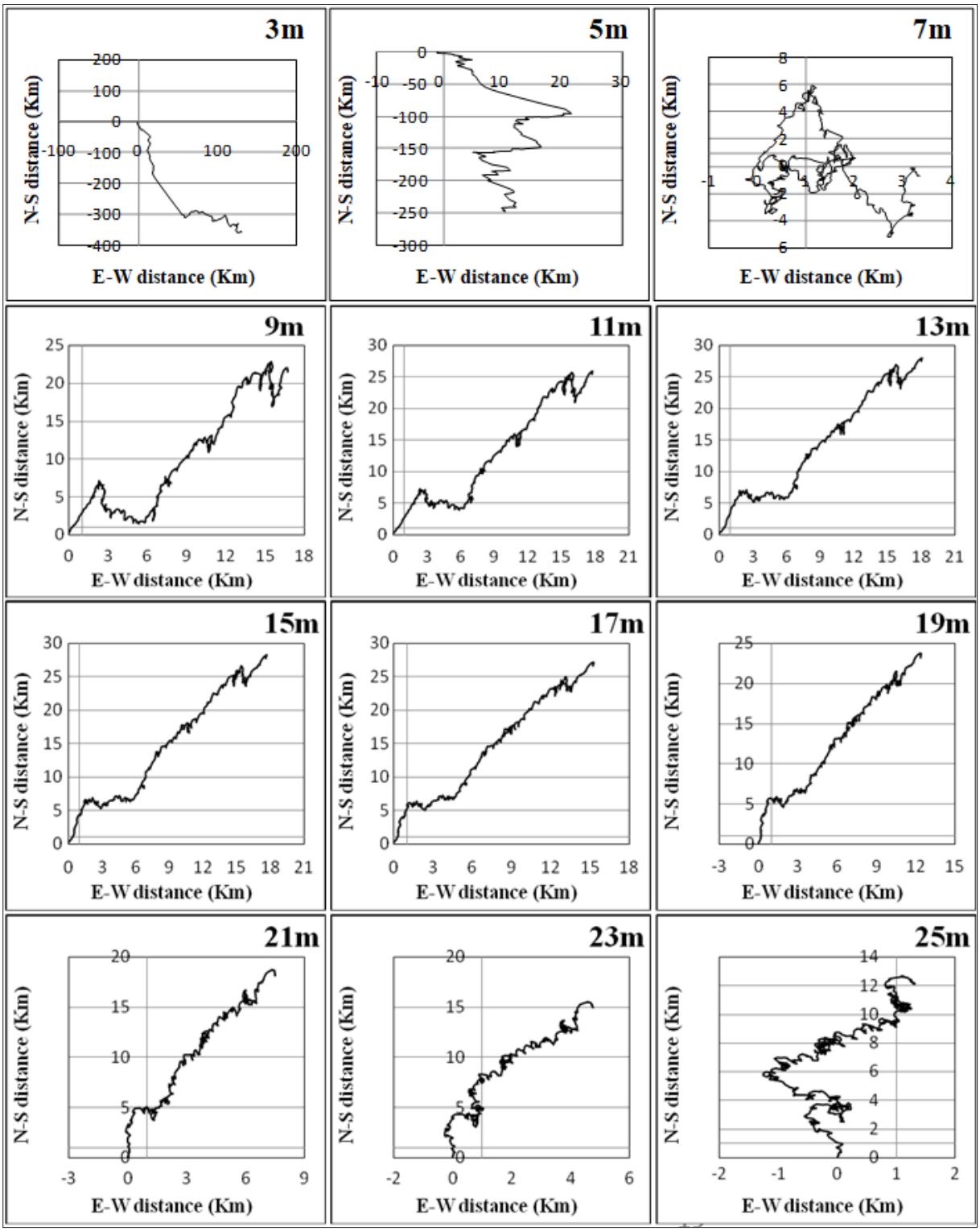

Figure 3. Progressive vector diagram of current at different depth levels in the study area during the study period.

Table 3. Effect of location and distance between the mean of sampling sites and Phosphate Loading Berth center (PLBC) on the distribution and concentration (mean values) of the measured parameter.

Site	Location relative to PLBC	Distance from PLBC (m)	TP mean	IP mean
HA	north	2974	0.81	0.62
PC	north	2515	1.18	1.02
FP	north	1407	1.26	1.06
AP	north	710	1.79	1.57
PLBC	-------	0	94.86	89.67
PLBO	west	50	45.74	40.53
PLBS	south	235	86.78	78.31
PSN	south	1516	5.40	3.74
PS	south	2904	3.04	1.77
MP	south	3537	2.03	1.79
MSS	south	5390	0.69	0.64

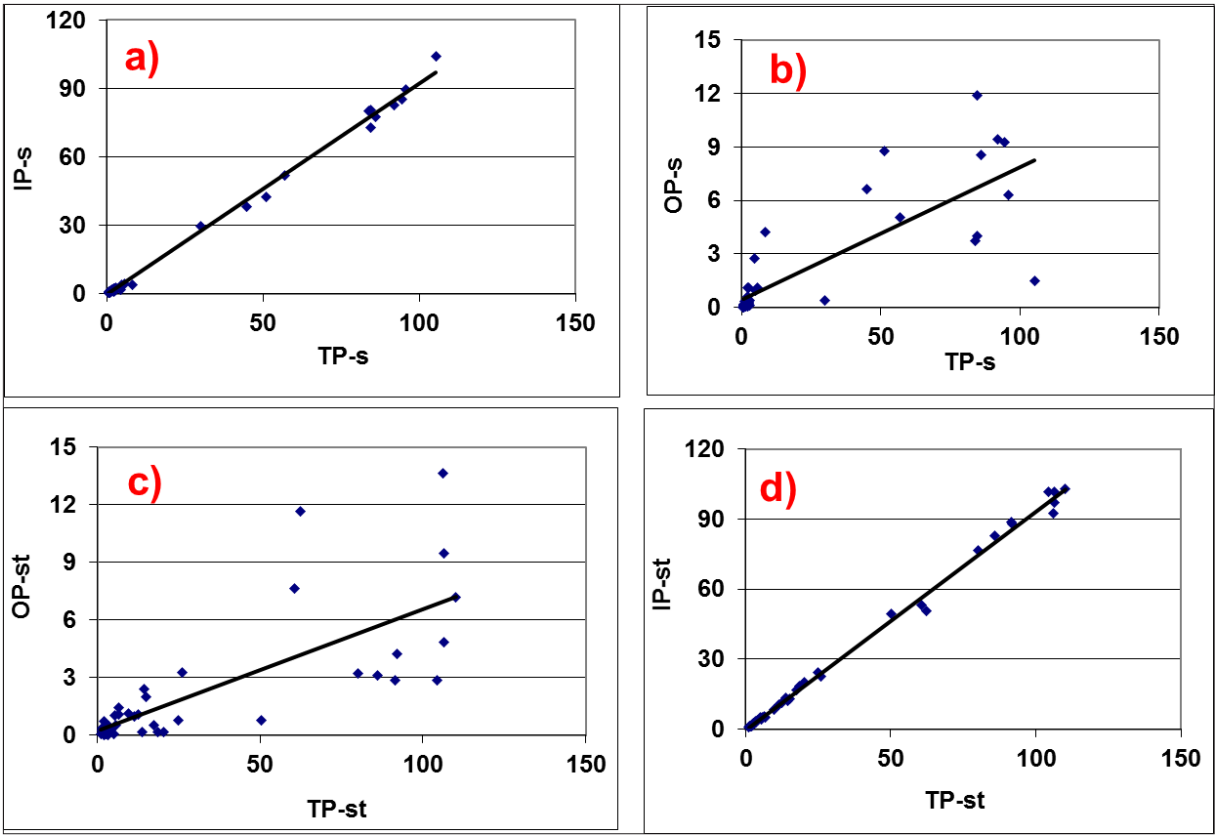

Figure 4. (a) Correlations between total phosphorus (TP) and inorganic phosphorus (IP) in sediments (s); (b) Correlations between total phosphorus (TP) and organic phosphorus (OP) in sediments (s); (c) Correlations between total phosphorus (TP) and inorganic phosphorus (IP) in trap sediments (st) (d) Correlations between total phosphorus (TP) and organic phosphorus (OP) trap sediments (st).

4. Conclusions

Based on the results of the presents study it was possible to conclude that:

1. The sediments of the study area near the Aqaba phosphate loading berth (PLB) are polluted with various species of phosphorus.

2. The concentrations of TP, IP, and OP are highest in the sediments of the sites that are in closer to the PLB area. These high concentrations are mainly attributed to the higher sedimentation rate at the PLB area due to ship loading and due to the high rate of sedimentation from the dust air borne of the heavy (high specific gravity) phosphate particles that settle down onto the bottom sediments during loading of the exported raw phosphate and due to the high rate of sedimentation from the air borne dust. The statistical analysis for these species in trap-sediments and sediments within the PLB area are significantly different from those of all other sites. The abnormally high concentrations of the total phosphorus at the Phsphate Loading Berth sites and the relatively lower concentrations at the other sites indicate that phosphate pollution is located mainly near PLB area and attributed to the high sedimentation rate of phosphate dust particles at this area

3. The concentration of TP, IP and OP are higher in the

stations located to the south of the PLB compared to those located to the north of it. This is because of the eastward and southeastward of prevailing currents and winds.

4. Inorganic Phosphorus (fluorapatite) is the major species of phosphorus in the study area and represents 82.5-97.5 %, 77-94.5 %, of the TP in trap-sediments and sediments, respectively. The concentrations of TP in trap-sediments and sediments have high and significant correlation with IP. The concentrations of TP as P_2O_5 in the sediments represent 0.16-21.74% and 0.34 - 47.50% as TCP, while those of IP represent 0.14-20.55% as P_2O_5 and 0.31-44.90 % as TCP.

5. The low percentage of P_2O_5 in trap-sediments and sediments as compared with raw phosphate rock is attributed to the of the partial dissolution of the inserted raw phosphate (fluorapatite) dust particles in the water of the Gulf of Aqaba and to the effect of the dilution of the deposited phosphate particles by mixing with the sediments. Due to this partial dissolution in the water of the Gulf of Aqaba, highest concentrations DIP in surface (Sw) and near-bottom (Bw) water were recorded at Phosphate Loading Berth Sites. The higher concentrations of DIP around PLB tend to decrease with increasing distance from this site. However, the increase in DIP concentrations in the water is not significant to cause significant increase in the DIP concentrations in the water of the Gulf of Aqaba to abnormal or the hazardous levels.

6. The lowest sedimentation rate in the offshore site (PLBO) at a distance of about 200 m of the PLB is explained by the fact that prevailing currents do not carry phosphate particles in the direction of this site. The deeper position of sedimentation trap (~ 20 m) is another possible reason.

Acknowledgments

The Authors would like to acknowledge the help of the technical staff of the Marine Science Station/Aqaba in the lab and field work. This work was mainly supported by the Deanship of Scientific Research/Yarmouk University.

References

Abed, A. (2012). Review of Uranium in the Jordanian Phosphorites: Distribution,Genesis and Industry. Jordan Journal of Earth and Environmental Sciences 4:35-45.

Abu-Hilal, A. (1985). Phosphate pollution in the Jordan Gulf of Aqaba. Marine Pollution Bulletin 16: 281-285.

Abu-Hilal, A. (1987). Distribution and forms of sedimentary phosphorus near a phosphate-polluted coral reef area in Jordan Gulf of Aqaba, Red Sea. Dirasat 14: 137-150.

Abu-Hilal, A. (1999). Environmental issues in the Gulf of Aqaba: Jordanian perspective. Proceedings; Conference on "The 1999 Maritime Safety Coloquim" Pendragon Applied Research, Nova Scotia, Ca- nada. Aqaba, Jordan. Topic 12: 1-8.

Abu-Hilal, A., Rasheed, M., and Al-Najjar, T. (2008). Potential environmental impact of dissolution of raw phosphate in sea water of the Gulf of Aqaba. Taylor and Francis, Chem. and Ecol. 24: 51-59.

Al-Moghrabi, S.M., and Horani, H.K. (1998). Distribution and seasonal variation on nutrients in the Gulf of Aqaba. Dirasat 25: 226-239.

Al-Rousan, S. (1998). Sediment role in nutrient cycle within the coral reefs of the Gulf of Aqaba, Red Sea. Master Thesis. Yarmouk University. Jordan.

Al-Rousan, S., Rasheed, M., and Badran, M. (2004). Nutrient diffusive fluxes from sediments in the northern Gulf of Aqaba, Red Sea. Scientia Marina 68 (4): 483-490.

Al-Rousan, S., Rasheed, M., Al-Horani, F, and Manasrah, R. (2006). Geochemical and Textural Properties of Carbonate and Terrigenous Sediments along the Jordanian Coast of the Gulf of Aqaba. Journal of Oceanography 62: 839-849.

Al-Rousan, S., Al-Taani, A., and Alrashdan, M. (2016). Effects of pollution on the geochemical properties of marine sediments across the fringing reef of Aqaba, Red Sea, Marine Pollution Bulletin 110, 546–554.

APHA (1971). Standard Methods for the Examination of Water and Wastewater. New York 13: 1-874.

Aspila, K.I., Agemian, H. and Chau, A.S.Y. (1976). A semi-automated meth- od for the determination of inorganic, organic and total phosphate in sediments. Analyst 101: 187-197.

Bani-Awwad, O.M. (2002). The airborne dust and its environmental impact on scle- ractinian coral settlement in the Gulf of Aqaba. Master Thesis. Yarmouk University. Jordan.

Badran, M., and Al Zibdah M (2005). Environmental Quality of Jordanian Coastal Surface Sediment, Gulf of Aqaba, Red Sea. Ambio 34: 615-620.

English, S., Wilkinson, C. and Baker, V. (1994). Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science. Townsville.

Freemantle, M.H., Hulings, N.C., Mulqi, M. and Watton, E.C. (1978). Calcium and phosphate in the Jordan Gulf of Aqaba. Marine Pollution Bulletin 9: 79-80.

Grasshoff, K., K. Kremling and M. Ehrhardt, (1999). Methods of Seawater Analysis. Wiley-Vch, Weinheim, 600 pp.

Hamdan, F.S. (1999). Comparison between the effect of phosphate on the growth and productivity of the branched coral, stylophora pistillata (Esper, 1797) and massive coral, platygyra deadalea (Ellis and Solander, 1786) in the Gulf of Aqaba, Master Thesis. Yarmouk University. Jordan.

Hulings, N.C. and Abu-Hilal, A.H. (1984). The temporal distribution of nutrients in the surface waters of the Jordan Gulf of Aqaba. Dirasat 10: 91-105.

Jordan Phosphate Mines Company, 2020. Personal Communication. Aqaba Office, Aqaba, Jordan.

MSS Report (2020): Environmental appraisal of the Jordanian coast of the Gulf of Aqaba, unpublished report. Marine Science Station, 88p. Aqaba, Jordan.

Mulqui, M.W. (1978). The effect of phosphate rock dust on the calcium, magnesium and phosphate levels in the Jordan Gulf of Aqaba. Master Thesis. Jordan University. Jordan.

Murphy, J. and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. Analaltica Chimica Acta 27: 31-36.

Rasheed, M., Badran, M., Richter, C., and Huettel, M. (2002). Effect of reef frame- work and bottom sediment on nutrient enrichment in coral reef of the Gulf of Aqaba. Marine Ecology Progress Series 239: 277-285.

Rasheed, M., Al-Rousan, S. A., and Badran, M.I. (2005). Phosphate enrichment in the northern Gulf of Aqaba: Regulation by carbonate sediments and impact on nitro- gen elevation. Taylor and Francis, Chemistry and Ecology 114:99–208.

Rasheed, M., Manasrah, R., Al-trabeen, K., and Kellie Dixon

L. (2018). Impact of artificial lagoons on seawater quality: evidence from 7 years of physicochemical seawater monitoring. Environmental Monitoring Assessment 21: 244.

Schuhmacher, H., Koss, H. and Brieda, F. (1982). Report on the environmental imp- act of industrial activities in the southern region. Environmental and development studies for the southern region of Jordan. Ministry of Municipal and Rural Affairs (Jordan), and German Agency for Technical Cooperation (GTZ), PP 1-135.