



## The impact of maritime activities on the leachable heavy metals in the seafloor sediments of Port Tawfiq and Tersana harbours, Gulf of Suez, Egypt

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### ABSTRACT

The bulk sediment samples and the finest sediment group (FSG) including ( $\text{Ø}3$ ,  $\text{Ø}4$  and  $<\text{Ø}4$ ) were used to estimate the leachable forms of Fe, Mn, Zn, Cu, Ni, Pb, Co and Cd at Port Tawfiq and Tersana harbours in the Suez Bay at the northern tip of Suez Gulf using flame atomic absorption spectrophotometer (AAS). FSG was representing the essential constituents of the seafloor sediments with averages of 71.68% from the total sediments at Port Tawfiq Harbour and 69.47% at Tersana Harbour indicating the deposition under calm conditions. Leachable Fe was the metal carrier for the different heavy metals, the average leachable forms of Fe, Mn and Pb in FSG (53382.81, 60048.81  $\mu\text{g/g}$ ), (625.68, 662.54  $\mu\text{g/g}$ ) and (55.191, 67.23  $\mu\text{g/g}$ ) about two folds in the bulk sediment (26397.11, 27761.07  $\mu\text{g/g}$ ), (219.05, 224.22  $\mu\text{g/g}$ ) and (26.62, 30.47  $\mu\text{g/g}$ ) at both Port Tawfiq and Tersana harbours respectively. Zn in FSG (594.40  $\mu\text{g/g}$ ) about two folds in the bulk sediments (236.34  $\mu\text{g/g}$ ) at Port Tawfiq Harbour, meanwhile at Tersana Harbour Zn in FSG (968.58  $\mu\text{g/g}$ ) about four folds in the bulk sediments (265.25  $\mu\text{g/g}$ ) respectively. The average leachable of Cu at Port Tawfiq Harbour in FSG (303.50  $\mu\text{g/g}$ ) recorded about three folds in the bulk sediments (98.01  $\mu\text{g/g}$ ), while at Tersana Harbour (1020.33  $\mu\text{g/g}$ ) recorded about five folds in the bulk sediments (98.01  $\mu\text{g/g}$ ). At Port Tawfiq Harbour in the FSG, the average leachable Ni (211.47  $\mu\text{g/g}$ ) exceeds more than four folds in the bulk sediments (50.13), meanwhile at Tersana Harbour in FSG (507.75  $\mu\text{g/g}$ ) about eight folds in the bulk sediments (62.08  $\mu\text{g/g}$ ). In the same Manner, the averages of leachable Co in FSG were about one time and half in the bulk sediments at the two studied harbours.

### INTRODUCTION

The overseas maritime trades of Egypt were concentrated mainly in the Gulf of Suez and Suez Canal. The significance of the Suez Canal Suez is not limited to Egypt; it extends to all other world countries because of the size of this channel for international trade. The volume of global trade that passes through this channel ranges between 8% and 12% of total world trade. Suez Canal for Egypt is a very excellent source of income. The revenues of this channel in 2014 were about 39 billion pounds. The volume of trade passing by the Suez Canal in 2016 is about 998.654 about 1000 net ton, (SCA, 2016; Elgendy *et al.* 2018).

Fine sediment forms are the most effective on changes of the geological and geochemical characteristics of the sediments at these harbours as the result of Maritime activities. The Gulf of Suez is extended for about 255 km with a width between 17 and 45 km and maximum depth of 83m (UNEP, 1997). Throughout its geological history, the Gulf of Suez has always been a site of immense sediment accumulations (Behairy *et al.*, 1992) from the flash flood wadis throughout its eastern and western banks. Accordingly, the Gulf of Suez has simple and gentle bottom morphological features with likewise gentle submarine coastal slopes.

This excessive sedimentation has also restrained the development of coral reefs (Behairy *et al.*, 1992; Fouda and Gerges, 1994). The form or “chemical speciation” of metals varies widely depending on the environmental conditions. Such differences in chemical speciation affect the bioavailability, environmental risk, and environmental fate of these heavy metals (Martínez-Sánchez *et al.*, 2008; Hassaan *et al.*, 2016 ; Hassaan *et al.*, 2017; El-Rayis *et al.*, 2014) depending upon the chemistry and sediment structure, metal mobility, solubility, toxicity and reachability (Garcia *et al.*, 2007). The mobile forms of heavy metals are the exchangeable phases of these metals that represent the bio-available toxic hazards in the marine environment. The exchange from one phase to another in the marine environment is controlled by the continuity of reworking operations in the surface of marine sediments (Dar *et al.*, 2016a). The fine fraction sediments are also has a high capacity to retain heavy metals compared to other fractions (Abraham *et al.* 2007; Nobil *et al.* 2010). The retention of heavy metals in the marine sediments is probably controlled by the rates of finest fractions accumulation, the organic matter decomposition and Fe and Mn concentrations. In anoxic conditions, hydroxides and sulphate reduction produce metal sulfides which are the more stable phase. Conversely, metal recycling in these ecosystems is attributed to oxic conditions prevailing (Dar and El Saharty, 2006; Hassaan and El-Rayis 2018; Hassaan and Ali, 2017; Hassaan *et al.*, 2017b).

The present study aims to evaluate the effects of maritime activities on the geological and geochemical characteristics of the bottom sediments inside the navigation harbours of the two studied harbours (Port Tawfiq and Terrassa harbours) through estimation the concentrations of some leachable heavy metals such as Fe, Mn, Zn, Cu, Ni, Pb, Co and Cd.

## MATERIALS AND METHODS

The main activity of Port Tawfiq and Tersana harbors (29° 56' N - 32° 34' E) is the cargo and passenger hunch. These harbours are located on the northern end of the Gulf of Suez at the lateral entrance of the Suez Canal. The area includes the northern coast to the entrance of the Suez Canal and the floor area is 2.3 km<sup>2</sup>. The maximum design capacity is 3.5 million tons per year (General cargo 6.5 million tons per year and 2.5 million passengers annually) (GARSP, 2017).

Twenty seafloor sediments samples were collected from Port Tawfiq and nine samples from Tersana Harbours (Fig. 1). After washing and dried the samples sieved using mechanical shaker every one Ø interval to estimate the main sediment constituents according to (Folk, 1974).

Carbonate content (expressed as CO<sub>3</sub>%) was determined in the bulk samples. Accurately weighed powdered samples (1gm) were shaken with appropriate volume of diluted glacial acetic acid (25 ml) over night.

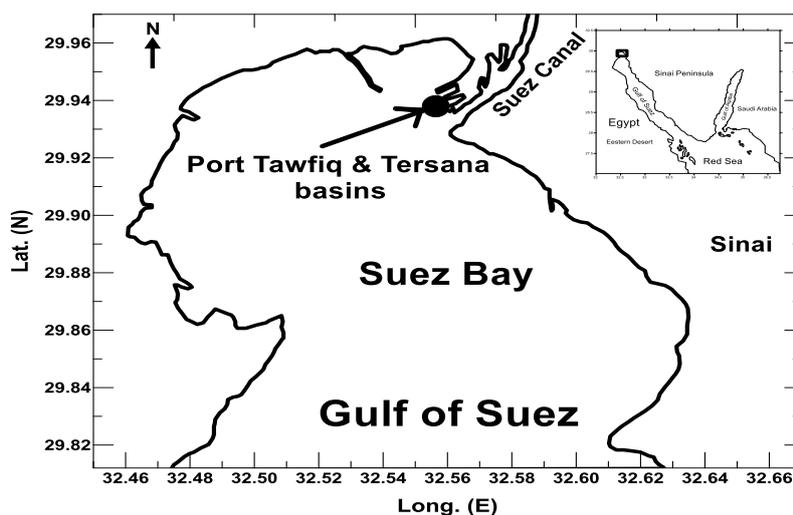


Fig. 1: A map of the two studied areas (Port Tawfiq and Tersana harbours).

The residues were then dried and the weight loss was considered as representing the carbonate content, given as percentage of the total weight (Basaham and El-Sayed, 1998; Dar *et al.*, 2016a). Carbonate percentage was calculated according to the following equation:

$$\text{CO}_3\% = \frac{\text{wt. of sample} - \text{wt. of residue}}{\text{wt. of sample}} \times 100$$

One gram of each bulk sample was burned to ash at 550°C for about two hours. The organic matter content of the sediments was calculated from sequential weight loss (Dean, 1974; Flannery *et al.*, 1982 & Brenner and Binford, 1988). Total organic matter content was estimated according to the following equation:

$$\text{TOM}\% = \frac{\text{wt. of sample} - \text{wt. of ash}}{\text{wt. of sample}} \times 10$$

The leachable forms of; Fe, Mn, Zn, Cu, Ni, Pb, Co and Cd were also measured using the flame AAS technique in both bulk and FSG samples according to (Chester *et al.*, 1994 and Hassaan, 2010). Heavy metal concentrations (in  $\mu\text{g/g}$ ) were measured by complete digestion. Before digestion to analyze heavy metals, each sample was dried at 65 °C for 48 h then, 0.5 gm of well grinded and dried samples (0.125, 0.063 and pan fractions) and ( $\emptyset 3$ ,  $\emptyset 4$  &  $<\emptyset 4$ ) were immersed in 10 ml of  $\text{HNO}_3/\text{HClO}_4$  acid mixture (70 % purity), to investigate the effect of the maritime activities in the selected harbours, this approach were done according to (Chester *et al.*, 1994), All treatments were performed in triplicate for each sample. The distribution patterns of heavy metal contents inside the Harbour were drawn by golden software surfer Ver. 13. The estimated correlation coefficient relationships were computed and figured using Excel 10, Graph Prism 6.0 and Wingraph 10.0.

## RESULTS

### Port Tawfiq Harbour:

Carbonate percentage ( $\text{CO}_3\%$ ) and total organic matter percentage (TOM%) were investigated in the bulk samples only. Carbonate percentage at Port Tawfiq Harbor was changed between 14.95% and 69.79% with an average of 44.24%, while the percentage of the TOM percentage was ranged between 10.74% and 20.75% with average of 15.86% (Table 1).

**Table 1: The average values of heavy metals ( $\mu\text{g/g}$ ) in the bulk sediments and FSG and Carbonate content ( $\text{CO}_3\%$ ) and total organic matter (TOM%) in the bulk sediments only at Port Tawfiq and Tersana harbours.**

Bulk	Fe	Mn	Zn	Cu	Ni	Pb	Co	Cd	$\text{CO}_3\%$	TOM %
Port Tawfiq	26397.11	219.05	236.34	98.01	50.13	26.62	8.58	0.05	44.24	15.86
Tersana	27761.07	224.22	265.25	209.30	62.08	30.47	6.50	0.16	44.93	21.70
FSG	Fe	Mn	Zn	Cu	Ni	Pb	Co	Cd	$\text{CO}_3\%$	TOM %
Port Tawfiq	53382.81	625.68	594.40	303.50	211.47	55.19	11.49	0.87	ND*	ND
Tersana	60048.82	662.55	968.58	1020.33	507.75	67.24	9.47	1.97	ND	ND

ND = Not Determined

The leachable Fe in the bulk sediments was ranged between 10105.80 $\mu\text{g/g}$  and 43351.26 $\mu\text{g/g}$  with an average of 26397.11 $\mu\text{g/g}$ , meanwhile, FSG showed the variation from 38099.54 $\mu\text{g/g}$  to 73240.93 $\mu\text{g/g}$  with an average of 53382.81 $\mu\text{g/g}$ . In the bulk sediments leachable Mn was increased from 74.98 $\mu\text{g/g}$  to 434.58 $\mu\text{g/g}$  with average of 219.05 $\mu\text{g/g}$ , while in the FSG, it was increased from 446.93 $\mu\text{g/g}$  to 941.26 $\mu\text{g/g}$  with an average of 625.68 $\mu\text{g/g}$ . Leachable Zn in the bulk sediments was fluctuated between (64.95 $\mu\text{g/g}$ ) and (642.67 $\mu\text{g/g}$ ) with an average of 236.34 $\mu\text{g/g}$  and in the FSG, Zn was fluctuated between 173.61 $\mu\text{g/g}$  and 1127.20 $\mu\text{g/g}$  with an average of 594.40 $\mu\text{g/g}$ . Leachable Cu in the bulk sediments showed variation from 14.49 $\mu\text{g/g}$  to 253.75 $\mu\text{g/g}$  with an average of 98.01 $\mu\text{g/g}$  and in the FSG, Cu was varied between 51.41 $\mu\text{g/g}$  and 552.54 $\mu\text{g/g}$  averaging of 303.50 $\mu\text{g/g}$ . Leachable Ni in the bulk sediments was changed between 17.73 $\mu\text{g/g}$  and 41.93 $\mu\text{g/g}$  with an average of 26.62 $\mu\text{g/g}$ ; in the FSG, Ni was fluctuated between 24.30 $\mu\text{g/g}$  and 84.69 $\mu\text{g/g}$  with an average of 55.19 $\mu\text{g/g}$ . Leachable Pb in the bulk sediments was declined from 118.06 $\mu\text{g/g}$  to 1.51 $\mu\text{g/g}$  with an average of 51.13 $\mu\text{g/g}$ , meanwhile in the FSG, Pb was declined from 509.14 $\mu\text{g/g}$  to 61.45 $\mu\text{g/g}$  averaging of 211.47 $\mu\text{g/g}$ . Leachable Co in the bulk sediments was ranged between below the detection limit to 15.93 $\mu\text{g/g}$  averaging of 8.58 $\mu\text{g/g}$ , while in the FSG, Co was fluctuated between 4.57 $\mu\text{g/g}$  and 22.73  $\mu\text{g/g}$  with average of 11.49 $\mu\text{g/g}$ . Leachable Cd in the bulk sediments was insignificant, meanwhile in the FSG Cd was increased from below the detection limit to 4.12 $\mu\text{g/g}$  averaging of 0.87 $\mu\text{g/g}$  (Table 1).

#### **Tersana Harbour:**

The percentage of  $\text{CO}_3\%$  in the bulk sediments at Tersana Harbor was fluctuated between 37.10% and 61.77% with an average 44.93%, while the percentage of TOM showed the variation from 14.57% to 25.36% and the average of 21.70% (Table 1).

The leachable Fe in the bulk sediments at Tersana Harbor was varied from 14345.04 $\mu\text{g/g}$  to 41713.42 $\mu\text{g/g}$  with an average of 31173.07 $\mu\text{g/g}$ , meanwhile, in the FSG, Fe was varied from 42157.88 $\mu\text{g/g}$  to 73718.20 $\mu\text{g/g}$  with an average of 60048.82 $\mu\text{g/g}$ . The leachable Mn in the bulk sediments was declined from 291.05 $\mu\text{g/g}$  to 138.44 $\mu\text{g/g}$  with an average of 229.50 $\mu\text{g/g}$ , meanwhile, in the FSG, Mn was declined from 500.83 $\mu\text{g/g}$  to 757.21 $\mu\text{g/g}$  with an average of (662.55 $\mu\text{g/g}$ ). Zn leachable in the bulk sediments was changed between 127.53 $\mu\text{g/g}$  and 450.64 $\mu\text{g/g}$  with an average of 313.02 $\mu\text{g/g}$ , while in the FSG; Zn was fluctuated between 480.76 $\mu\text{g/g}$  and 1662.90 $\mu\text{g/g}$  with an average of 968.58 $\mu\text{g/g}$ . In the bulk sediments, the leachable Cu was changed between 23.55 $\mu\text{g/g}$  and 1053.65 $\mu\text{g/g}$  with an average of 485.70 $\mu\text{g/g}$  and in the FSG; Cu was increased from 46.04 $\mu\text{g/g}$  to 2209.40 $\mu\text{g/g}$  with an average of 1020.33 $\mu\text{g/g}$ . In the same affair, the leachable Ni was changed between 20.93 $\mu\text{g/g}$  and 99.41 $\mu\text{g/g}$  with an average of 39.59 $\mu\text{g/g}$  in the bulk sediments, meanwhile in the FSG, Ni was fluctuated between 20.37 $\mu\text{g/g}$  and 106.66 $\mu\text{g/g}$  with an average of 67.24 $\mu\text{g/g}$ . The leachable Pb in the bulk sediments

was ranged between 26.51 $\mu\text{g/g}$  and 143.57 $\mu\text{g/g}$  with an average of 90.49 $\mu\text{g/g}$ , however in the FSG, the leachable Pb was increased from 20.37 $\mu\text{g/g}$  to 106.66 $\mu\text{g/g}$  with an average of 67.24 $\mu\text{g/g}$ . Cd leachable in the bulk sediments was insignificant, while in the FSG, Cd leachable was ranged from 0.74 $\mu\text{g/g}$  to 2.60 $\mu\text{g/g}$  averaging of 1.97 $\mu\text{g/g}$ . Leachable Co in the bulk sediments was increased from below the detection limit to 7.70 $\mu\text{g/g}$  averaging of 1.33 $\mu\text{g/g}$  and in the FSG, leachable Co was fluctuated between 3.84 $\mu\text{g/g}$  and 18.66 $\mu\text{g/g}$  with an average of 9.47 $\mu\text{g/g}$  (Table 1).

## DISCUSSION

The variability of carbonates at the studied basins; Port Tawfiq & Tersana, 44.24% and 44.93% indicating to high contributions of the biological activities around and inside these basins including the calcareous debris of corals, other marine shells, shell fragments as well as the anthropogenic activities (precipitation of dust from the quarrying activities of carbonate rocks and loading and unloading operations). Tersana Basin showed high average percentage of total organic matter (TOM%) (21.70%) attributed to anthropogenic activities (contamination by the hydrocarbons from the boats and domestic waste and sewage).

The recorded averages at Port Tawfiq (15.85 %) are mainly attributed to the domestic sewage, the hydrocarbons from the boats, petroleum spilled from the tanks and the boats.

In general, the leachable Fe in the studied basins showed significantly high occurrences in the FSG group than in the bulk sediment. In the FSG group, Tersana Basin showed the high average content of leachable Fe. The significantly high leachable Fe at the basins of Port Tawfiq and Tersana may due to the corrosion of constructions and pipes and high organic matter contents that formed high reducing conditions. At the studied harbours; the leachable Fe accompanied with the high FSG distribution (Figs. 2A & 3A). The average of heavy metals in the bulk sediments and FSG at the studied harbours in comparison with the other studies in Egypt and worldwide were tabulated in (Table 2).

At Port Tawfiq and Tersana basins the high averages of leachable Mn indicating to the effect of the anthropogenic inputs within these basins (boats mooring and repairing, corrosion of constructions and pipes) as well as the reducing conditions inside these basins due to the high percentages of fine sediments and organic matter. Mn patterns at Port Tawfiq and Tersana basins were increased beside the wharf due to the navigation activities, (Figs. 2B & 3B).

The leachable Zn showed significantly higher contents in the FSG group than in the bulk sediments at Port Tawfiq and Tersana harbours. At Port Tawfiq and Tersana basins, the leachable Zn increased below the navigation wharfs indicating to the essential source from the maritime activities (Figs. 2C & 3C).

The leachable Cu at the studied basins showed significantly higher occurrences in the FSG group than in the bulk sediments. Tersana Basin showed the higher average content of leachable Cu in FSG than in Port Tawfiq Basin. The distribution patterns of the leachable Cu showed an increasing beside the wharfs of the navigation basins at Port Tawfiq and Tersana, attributed to the variable maritime activities (Figs. 2D & 3D).

The leachable Ni showed higher contents in the FSG group than in the bulk sediment at the studied basins. The distribution patterns of the leachable Ni at Port Tawfiq and Tersana basins showed the highest contents toward the wharfs indicating to the maritime activities (Figs. 2E & 3E).

Table 2: The average values of heavy metals in the bulk and FSG sediments the studied harbours in comparison with the other studies in worldwide.

Location	Heavy metals concentration ( $\mu\text{g/g}$ )								Sediment type	References
	Fe	Mn	Zn	Cu	Pb	Ni	Co	Cd		
Port Tawfiq Harbour	26397.11	219.05	236.34	98.01	50.13	26.62	8.58	0.05	Bulk sediments	Present study
	53382.81	625.68	594.40	303.50	211.47	55.19	11.49	0.87	FSG	
Tersana Harbour	27761.07	224.22	265.25	209.30	62.08	30.47	6.50	0.16	Bulk sediments	
	60048.82	662.55	968.58	1020.33	507.75	67.24	9.47	1.97	FSG	
Worldwide harbors										
Bremen Seehausen, northern German	-	-	53	9.3	12	<0.05	4.2	0.9	Sandy fraction	Lager <i>et al.</i> , (2005)
	-	-	490	65	75	41	20	4.1	Fine fraction	
Vagen, Bergen harbour, Norway	-	-	2,900	1,090	1,920	-	-	-	Pan fraction	Paetzel <i>et al.</i> , (2003)
Dutch marine harbor sediments	-	-	510	95	130	43	-	4.5	Bulk sediment	Stronkhorst <i>et al.</i> , (2003)
Sydney Estuary, Australia	-	-	11300	1060	1932	118	-	52	Bulk sediment	Birch <i>et al.</i> , (2009)
	-	-	8446.5	1229.5	3842	119.5	-	24	(<62.5 lm)	
Guanabara Bay: Rio de Janeiro, Brazil	4622.8	-	377577	9421	9671	20683	1758.25	-	Bulk sediment	Neto <i>et al.</i> , (2006)
Haengam Bay, South Korea	34.1	-	159	-	66.7	-	-	-	Bulk sediment	Yoo <i>et al.</i> , (2015)
Gowatr bay-Iran	2.87	-	58.72	24.18	1666	80.16	14.99	-	<0.063 mm	Moore <i>et al.</i> , (2015)
Sardinia, Western Mediterranean	68.33	76.094	95.682	29.626	32.195	6.721	-	0.681	Bulk sediment	Schintu <i>et al.</i> , (2015) Schintu,
English Channel	-	-	1.12	68.4	-	31.1	113.6	3.3		
Tema Harbour, Ghana	-	210	260	100	88	75	-	8.1		
Quseir Harbour	12003.17	736.77	79.62	35.83	48.24	50.99	10.74	2.10	Bulk sediment	El-Taher <i>et al.</i> , (2018)
Abu- Tartour Harbour	15333.33	3.33	91.67	46.6	63.33	61.67	16.17	2.50		
Touristic Harbour	15433.33	322.33	47.67	21.33	39.00	32.00	20.00	2.97		
Hurghada Harbour	7500.00	383.3	458.33	108.33	75.00	65.00	11.67	3.83		
Batticaloa lagoon, Sri Lanka	65400	-	86.9	33.5	20.6	18.3	-	-	Bulk sediment	Adikaram <i>et al.</i> , (2017)
Adabiya Harbour	27153.91	182.43	180.47	67.02	19.01	62.81	6.91	0.02	Bulk sediment	Elgendy <i>et al.</i> , (2018)
El Zaitiya Harbour	50924.94	532.15	377.61	195.38	54.61	145.95	7.72	0.78	FSG	
Adabiya Harbour	17777.75	155.56	134.62	35.15	15.78	20.27	12.37	0.14	Bulk sediment	
	43965.42	476.88	456.94	109.42	47.35	67.12	5.65	1.01	FSG	

The leachable Pb showed significantly higher occurrences in the FSG group than in the bulk sediment at the studied basins. The distribution pattern at Port Tawfiq Basin showed increasing toward the wharf, meanwhile Tersana basin showed hot spot in the inner part of the Basin (Figs. 2F & 3F).

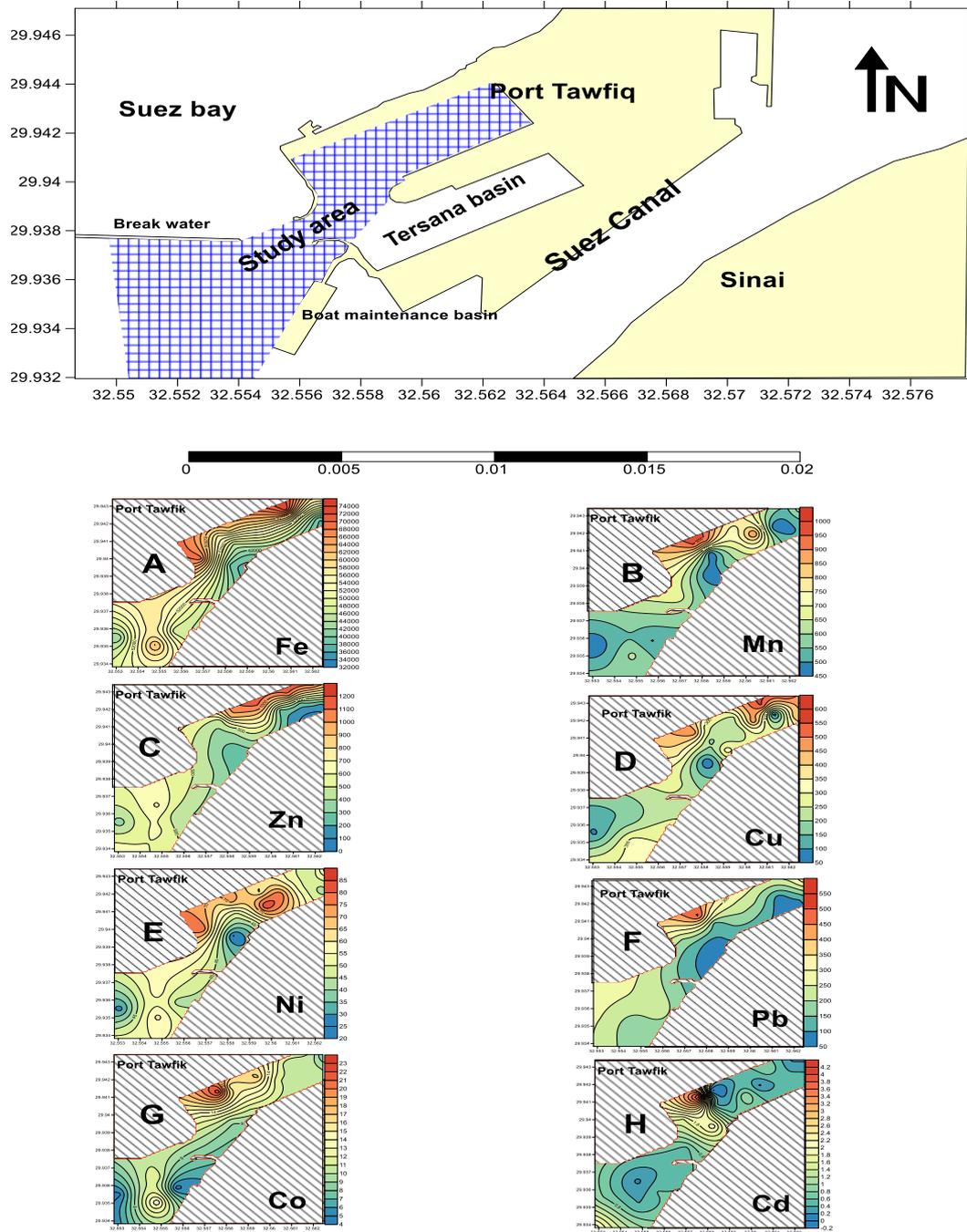
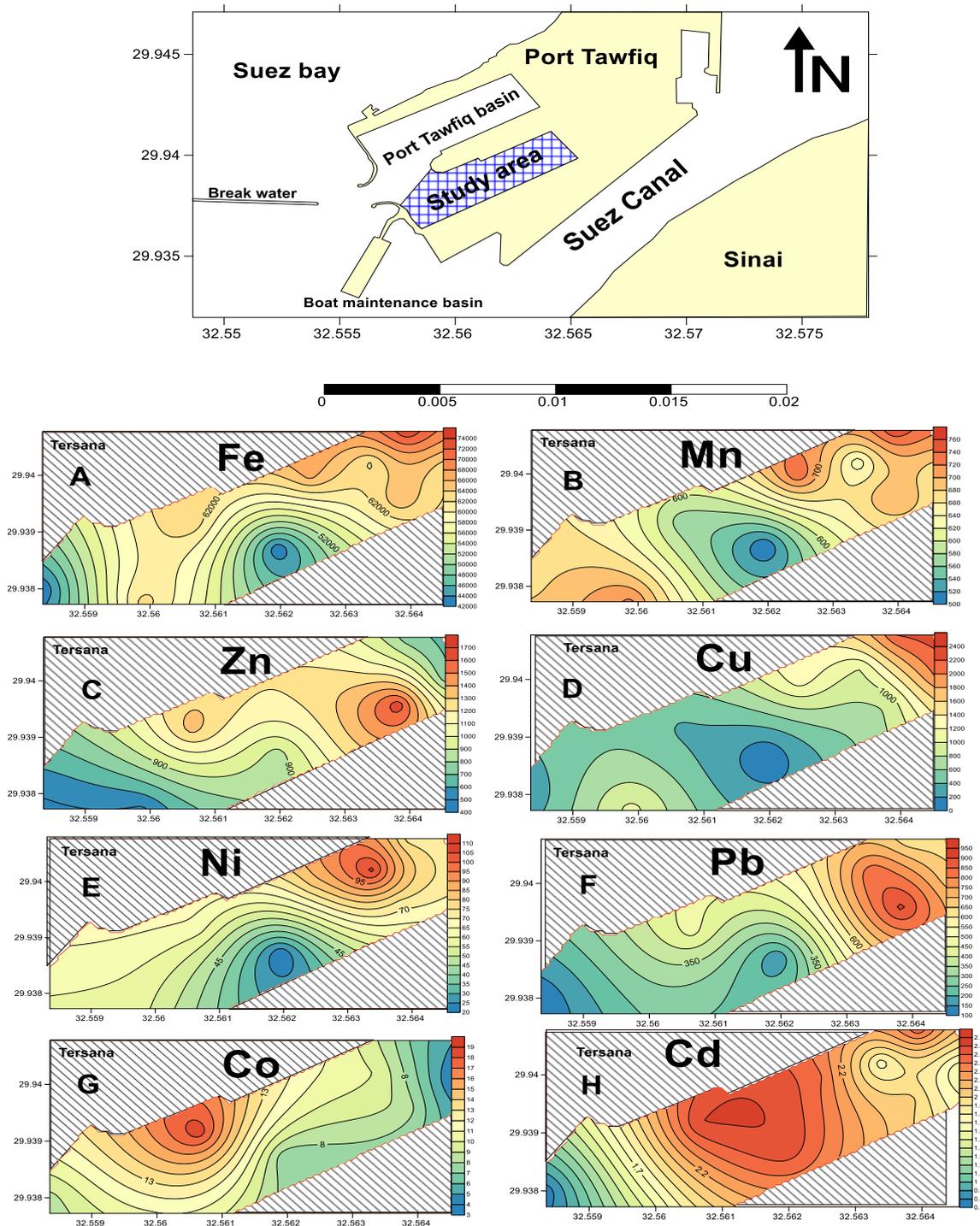


Fig. 2: The distribution pattern of heavy metal contents (FSG) in Port Tawfiq Harbour.

The leachable Co showed significantly higher occurrences in the FSG group than in the bulk sediment at the studied basins. The leachable Co at Port Tawfiq was concentrated in the middle part of the Basin beside the western wharf due to the anthropogenic activities and water movements (waves) within the basin (Fig. 2G).

The leachable Co at Tersana basin increased patterns inside the basins beside the wharfs due to the maritime activities (Fig. 3G).



**Fig. 3: The distribution pattern of heavy metal contents (FSG) in Tersana Harbour**

The leachable Cd showed significantly higher occurrences in the FSG group than in the bulk sediment at the studied basins. Port Tawfiq Basin recorded significant low leachable Cd values. The FSG showed the highest average of leachable Cd at Tersana Basin relative to at Port Tawfiq Basin (Table 1).

### Correlation coefficients and the uncertainty

At Port Tawfiq Harbor, Fe showed fair positive correlation with Mn (Fig. 4), strong positive with Zn (Fig. 4) and Ni (Fig. 4) indicating to that Mn, Zn and Ni tend to accumulate with Fe as oxides. The very strong positive correlation of Fe with FSG% ( $r = 0.78$ ) indicating to most of Fe were accumulated in the particulate sediments from anthropogenic sources, meanwhile the positive fair correlation between Fe and TOM% ( $r = 0.51$ ) indicating to the partial accumulation of Fe as sulfide under the highly reducing conditions. Mn showed the same Fe behavior whereas, the very strong positive correlations of Mn with Ni (Fig. 4), fair positive with Pb ( $r = 0.59$ ) and strong positive with Co ( $r = 0.61$ ) indicating to oxidation phases for these metals. The fair negative correlation between Ni and  $\text{CO}_3\%$  (Fig. 4) assured the Ni tendency to accumulate in different forms rather than carbonates. Finally the logic strong positive correlation was found between FSG% and TOM% ( $r = 0.60$ ).

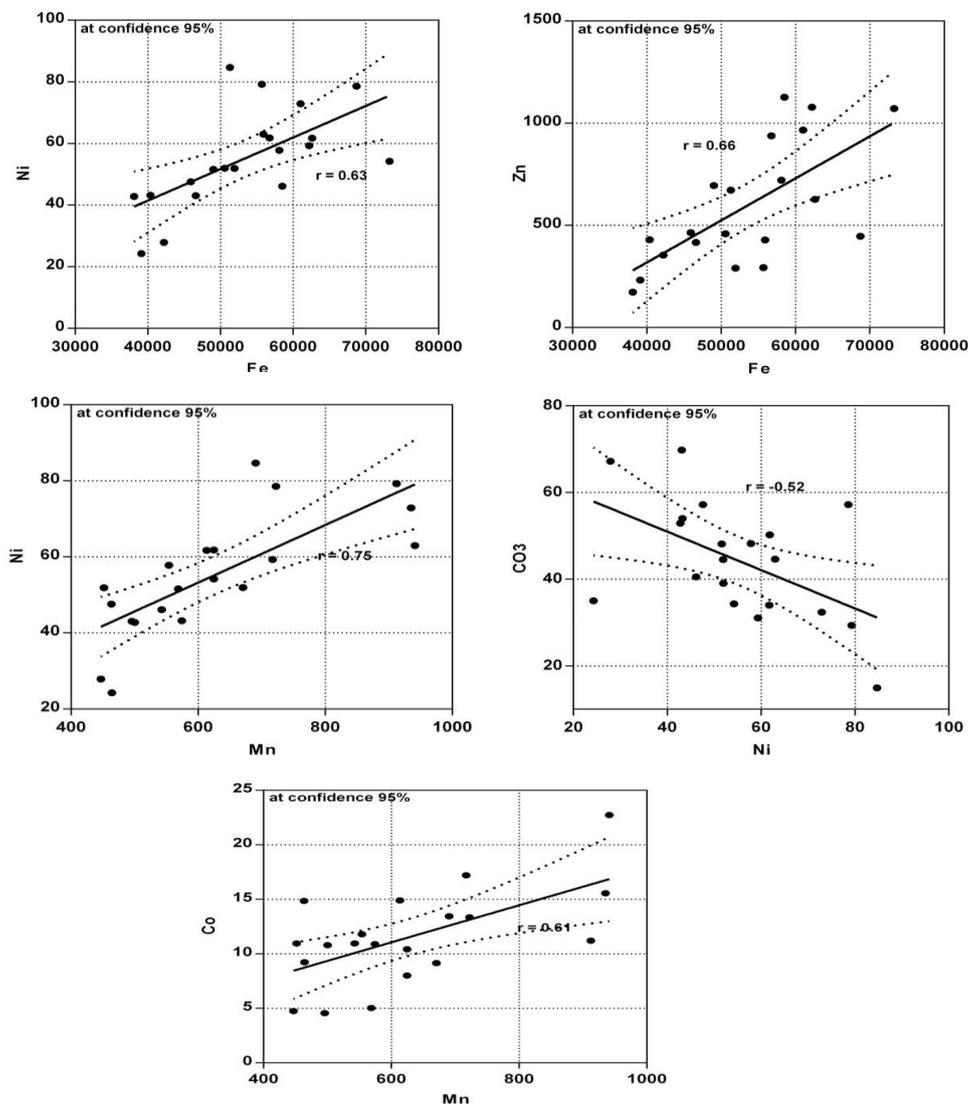


Fig. 4: The Uncertainty relationships of Fe and Mn with Ni, Zn, Co and  $\text{CO}_3$  (at 95% confidence) at Port Tawfiq Harbour.

As shown in (Fig. 5), at Tersana Harbor, Fe showed strong positive correlation with Mn (Fig. 5), very strong positive with Cu ( $r = 0.74$ ), fair positive with Ni ( $r =$

0.59) and strong positive with Pb (Fig. 5) indicating to that the Mn and Pb have the tendency to accumulate with Fe as oxides indicating to most of Fe were from anthropogenic sources mainly the maritime activities. The excellent positive correlation between Fe and TOM% ( $r = 0.88$ ) indicating to the partial accumulation of Fe as sulfide under the highly reducing conditions supported by strong positive correlation between Fe and FSG% ( $r = 0.65$ ). Mn showed the same Fe behavior whereas, the strong positive correlations of Mn with Cu ( $r = 0.69$ ) indicating to association in oxidation phase, the fair positive correlations Mn with TOM% ( $r = 0.55$ ) indicating to Mn accumulate as sulfide.

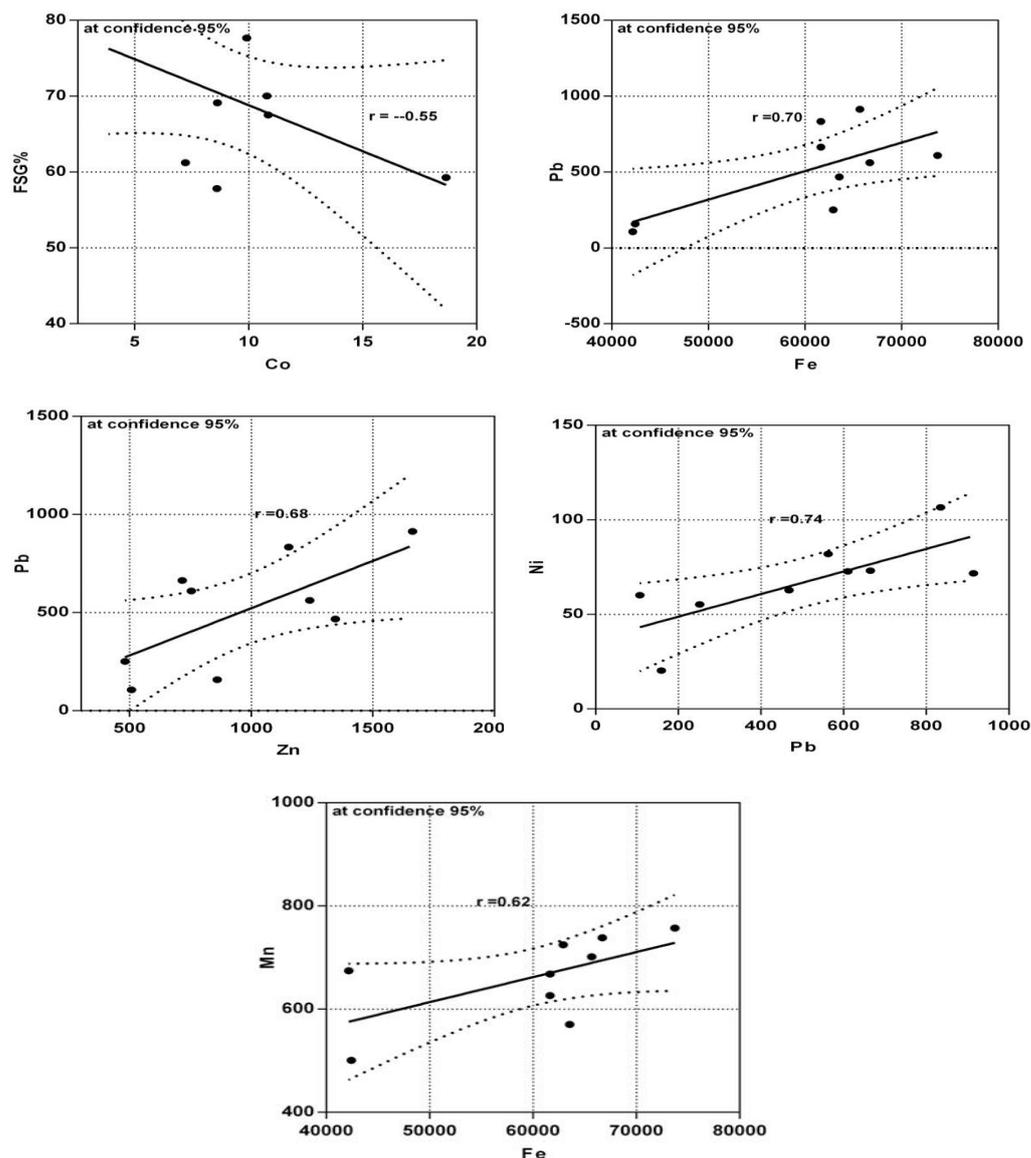


Fig. 5: The Uncertainty relationships of Fe, Cu, Pb and Co with Ni, Mn and FSG (at 95% confidence) at Tersana Harbour.

The strong positive correlation of Zn with Pb (Fig. 5) and fair positive with Cd ( $r = 0.53$ ) indicating to these metals accumulated from anthropogenic sources, however the fair positive correlation of Zn with TOM% ( $r = 0.53$ ) indicating to Zn accumulated as sulfides. The fair positive correlation of Cu with Pb ( $r = 0.51$ ) indicating to the navigation sources, meanwhile the excellent positive correlation of

Cu with FSG% ( $r = 0.91$ ) indicating to the maritime sources and the strong positive correlation of Cu with TOM% ( $r = 0.66$ ) indicating to Cu accumulated as sulfides. The very strong positive correlation of Ni with Pb (Fig. 5) indicating to the anthropogenic sources, however the fair positive correlation of Ni with FSG% ( $r = 0.60$ ) indicating to the maritime sources and the excellent positive correlation of Ni with TOM% ( $r = 0.81$ ) indicating Ni accumulated as sulfides. The strong positive correlation of Pb with FSG% ( $r = 0.68$ ) indicating to navigation sources, however the excellent positive correlation of Pb with TOM% ( $r = 0.85$ ) indicating to Pb accumulated as sulfides in the reducing environment. The fair negative correlation of Co with FSG% (Fig. 5) indicating to Co accumulated with another phase. All metals have mis-correlation or negative correlation with  $\text{CO}_3\%$  assured the heavy metals tendency to accumulate in different forms rather than carbonates and transported by maritime activities. Finally the logic strong positive correlation was found between FSG% and TOM% ( $r = 0.64$ ).

## CONCLUSION

Port Tawfiq and Tersana Harbours were intensively used in maritime activities; transport of goods and passengers. The heavy metal contaminations in the bottom sediments are derived from different navigation activities (repairing, maintaining and shipyard). These conditions are causing acrimonious ecological risk on the marine ecosystem components such as; sediment nature inside these harbours. The concentration of heavy metals in fine sediment group FSG ( $\phi 3$ ,  $\phi 4$  and  $<\phi 4$ ) were higher than in the bulk sediments. The FSG are considerably effective in accumulation of the contaminants and transfer to the marine ecosystem. Tersana Harbour recorded higher leachable averages of Fe, Mn, Zn, Cu, Ni, Pb and Cd than Port Tawfiq Harbour mainly due to the different of maritime activities (maintaining, repairing and shipyard) and the calm conditions. These conditions provide suitable conditions for the metals accumulation under the highly reducing conditions. The distribution patterns of different metals in both basins showed the highest occurrences below the western and northern wharfs of these harbours indicating to that these metals were accumulated mainly from the maritime activities and at the centers due to the eddy currents from the ships motion. Fe showed positive correlation with Mn, Cu, Zn and Ni indicating to that these metals tend to accumulate with Fe as oxides and indicating to most of Fe were from anthropogenic sources mainly the maritime activities. At Tersana Basin the positive correlation of TOM% with Fe, Mn, Zn, Cu, Ni and Pb indicating to these metals accumulated as sulfides in the reducing environment. All metals have mis-correlation or negative correlation at both harbours with  $\text{CO}_3\%$  assured the heavy metals tendency to accumulate in different forms rather than carbonates and transported by maritime activities. Fe and Mn have nearly showed the same distribution patterns. Most of the heavy metals increased beside or below the wharfs due to the effect of the maritime activities.

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### ARABIC SUMMARY

تأثيرات الانشطة الملاحية على العناصر الثقيلة في رواسب القاع بموانئ بور توفيق والترسانه - خليج السويس - مصر

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تم تحليل عينات رواسب FSG وعينات رواسب Bulk لتقدير كل من Fe و Mn و Zn و Cu و Ni و Pb و Co في موانئ بور توفيق والترسانه في الطرف الشمالي لخليج السويس باستخدام مقياس الطيف الامتصاصي الذري باللهب (AAS). كانت FSG تمثل المكونات الأساسية لرسوبيات قاع البحر بمتوسط 71,68% من اجمالي الرواسب في ميناء بور توفيق وتمثل 69,47% من اجمالي الرواسب في ميناء الترسانه مما يشير الى الترسيب تحت الظروف البيئية الهادئه. كان الحديد الناقل الرئيسي للمعادن الثقيلة المختلفة ، وكان متوسط تركيز كل من Fe و Mn في FSG ( 53382.81 ؛ 625.68 ميكروغرام / غرام) حوالي مرتين ضعف تركيزه في bulk ( 28397.11 ؛ 219.05 ميكروغرام / غرام) في ميناء بور توفيق وبالمثل ايضا حوالي مرتين تركيزه في FSG ( 60048.82 ؛ 662.55 ميكروغرام / غرام) أكثر من bulk ( 27761.07 ؛ 224.22 ميكروغرام / غرام) في ميناء الترسانه.