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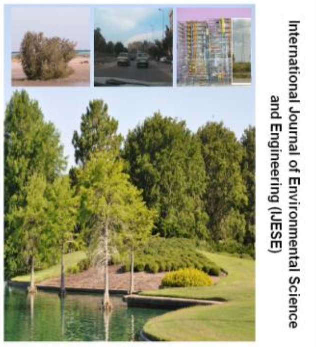

Comparative study on some heavy metals in water, sediments and fish along the Suez Canal, Egypt

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ABSTRACT

Concentration of Pb, Cd, Cu, Zn and Fe were determined in water, sediments and some organs of fish collected from Suez Canal during 2013-2014. The canal was divided into three sectors (Port Said, Ismailia and Suez) including 12 stations. 7 different fish species were collected from four landing sites (Port Said, Lake Timsah, Bitter Lakes and Suez). The highest means of investigated metals in water (μg/l) were Pb (2.90±1.49), Cd (0.91±0.23), Cu (29.74±25.53 (μg/g),), Zn (16.56±9.30) and Fe (265.63±25.14). While in sediments were 11.77±7.62, 0.75±0.82, 11.52±3.35, 14.29±10.69 and 3863.0±93.72 respectively. In fish muscles, Cd recorded the lowest concentration among the studied metals (0.01-0.88 μg/g), while the highest one was Fe (6.36-19.07 μg/g). High concentrations of the studied metals were observed in liver and gills comparing to those found in muscles. The present concentrations of metals in fish muscles are acceptable by the international legislation limits and are safe for human consumption.

1. INTRODUCTION

Water pollution is one of the most serious of all environmental problems and possesses a major threat to the health and well-being of people and ecosystems which caused the loss of biodiversity through the extinction of many species (Alloways and Ayres, 1993). Living organisms require trace amounts of some heavy metals, including cobalt, copper, iron, manganese, molybdenum, vanadium, strontium and zinc. Excessive levels of essential metals, however, can be detrimental to the organism. Non-essential heavy metals of particular concern to surface water systems are cadmium, chromium, mercury, lead, arsenic and antimony (Kennish, 1992). There are many biological and environmental factors affecting the accumulation of heavy metals such as water temperature, sexual state of the fish and metals concentration in the surrounding medium (Dallinger *et al.*, 1987; Nicoletto and Hendricks, 1988).

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The metal concentrations in water and sediments fluctuate drastically depending on water flow, intermittence (Rainbow, 1995; Morillo *et al*., 2005), and environmental conditions (Zauke *et al*., 1998).

Many studies were conducted to discuss the relationships between metals level and factors affecting their accumulation in the fish tissues (El-Moselhy, 1993, 1996 & 2000; Kock *et al.*, 1996; Lemus and Chung, 1999; Abd El-Azim 2002; El-Moselhy and El-Boray, 2004). Studies concerned to the determination of heavy metals concentration in water, sediments and aquatic organisms from the Egyptian waters were carried out by many authors (El-Moselhy and Gabal, 2004; El-Moselhy *et al*., 2005, 2006 and 2014; El-Moselhy and Abd El-Azim, 2005; El-Moselhy and Yassin, 2005; Hamed, 2005; Soliman, 2006; Hamed and Emara, 2006; Shakweer *et al*., 2006; Aboulela *et al*., 2007 Hamed *et al*., 2012).

The present study aimed to evaluate Suez Canal state in relation to heavy metals pollution in water, sediments and fish collected along the canal from Port Said to Suez, passed through Lake Timsah and Bitter Lakes.

2. MATERIAL AND METHODS

2.1 Study area

The Suez Canal is located in Egypt between 29^o 55′ N at Suez on the Gulf of Suez and 31^o 15′ N at Port Said on the Mediterranean Sea, and stretches between 32^o 17′ E and 32^o 35′ E, with an average length along the major axis of 101 mile (164 km) which extending between north of Port Said and south of Port Tawfiq through a series of lakes with different ecological conditions, from north to south. The cross - sectional area of the canal however varies between 3900 and 4200 m^2. The canal depth ranges from 20.5 to 25.5 m (UNEP, 1997). At the northern end, the canal receives polluted brackish water from Lake Manzala, which is the largest among them, connected the Mediterranean Sea and Suez Canal; it is essential source of fish in Egypt and affected by various external factors, industrial and agricultural wastewater discharge. The middle part of the canal is affected by polluted brackish water from Lake Timsah in the north at km 76 from Port Said; this lake receives agricultural, industrial fishing, employ local citizen and domestic wastes; and Great and Little Bitter Lakes in the southern part (between km 97.5 at Defersoir and km 134.5 at Ginefa) with saline water.

In the present work, the Suez Canal was divided into 3 sectors which are selected to cover the area under investigation (Fig. 1).

2.1.1 Sector A (Port Said):

2.1.1.1 Station 1 (Port Said): the northern entrance of the canal, and affected by Port Said Harbour.

2.1.1.2 Station 2 (El-Raswa): located infront Lake Manzala-Suez Canal connection, and affected by polluted water flowing from the lake.

2.1.1.3 Station 3 (El-Qantara): its water is affected by the dominant water current in the canal.

2.1.2 Sector B (Ismailia):

2.1.2.1 Stations 4 and 5 (Lake Timsah): there are characterized by different water currents caused by the passage of ships, receive some sewage effluents as well as fresh water from Ismailia sweet channel, and represent brackish water due to land drainage.

2.1.2.2 Station 6 (Abo Sultan): this is characterized by the presence of electrical power station.

2.1.2.3 Station 7 (Fanara): this considered as the biggest fish landing site in the Bitter Lakes. Occupied by tourist villages, agricultural land and Fanara fish landing site.

2.1.2.4 Station 8 (Elsail bridge): is characterized by agriculture drain.

2.1.3 Sector C (Suez):

2.1.3.1 Station 9 (Kabreit) and Station 10 (Shandora): arranged along the two Bitter Lakes. These stations also, represent a huge water body of high salinity and separating Suez Canal into two main parts.

2.1.3.2 Station 11 (Suez Kornysh) and Station 12 (NIOF shore): southern entrance of the canal, connection between the Suez Canal and Suez Bay, its water is usually drained from the Gulf of Suez most of the year.

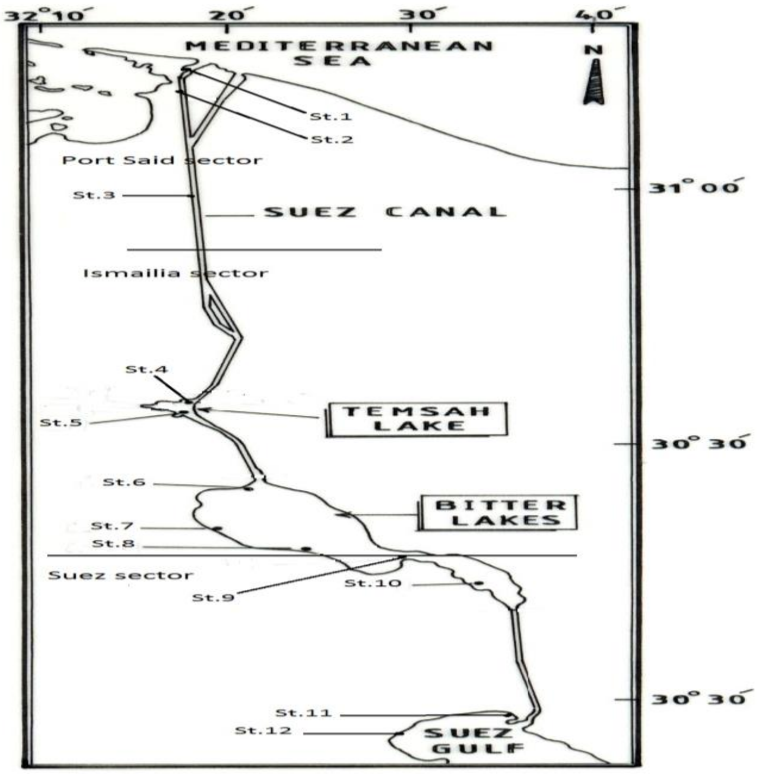

Fig. 1: A map showing Suez Canal and different studying stations.

2.2 Sampling and metals analysis

2.2.1 Water

Five liters of surface water samples were collected seasonally during 2013-2014 from the different stations using a poly Vinyl Chloride Van Dorn water sampler bottle. The precautions recommended by Kremling (1983) to minimize risk of sampling contamination were followed during collection, treatment and filtration of samples.

The water samples were filtered in a dust-free clean Lab through 0.45µm fiberglass paper. The metals in the filtrate were extracted using APDC-MIBK procedure *(*Brewer *et al*., 1969 and APHA, 1989*).* Metals in the extracted organic layer were determined by atomic adsorption spectrometry, Model Perkin Elmer AAnalyst 100. The results were expressed in µg/l.

2.2.2 Sediments

Sediment samples were collected once from each station along the canal by using Van-Veen grab coated with polyethylene (Amini Ranjbar, 1998). Sediments were kept in self-sealed acid pre-cleaned plastic bags, rinsed with metal-free water then transferred to the laboratory. Before sample extraction, the samples were air dried and kept until analyzed. 0.5 g of sediment samples was digested according to the method described by Oreigioni and Aston (1984). The extracted solutions were finally kept in polyethylene bottles for determination of the metals by Atomic Absorption Spectrophotometer (AAS) Perkin Elmer model A Analyst 100. Metals concentrations were expressed in µg/g.

2.3 Fish

Seven different fish species were collected once from the four landing sites: Port Said (*Liza carinata* and *Sardinilla gibbosa*), Ismailia, Lake Timsah (*Liza carinata* and *Pomadaysis stridense*), Bitter Lakes, Fanarah (*Liza carinata*, *Pomadaysis stridense* and *Rhabdosaragus haffara*), and Suez (*Saurida undosquamus, Rhabdosaragus haffara, Pomadaysis stridense, Nemipetrus japonicas* and *Trachurus indicus*). The samples were stored in plastic bags and transferred to the laboratory in an ice box. Muscles, gills and liver of fish were digested in Teflon vessels with 4 ml HNO_3 and 2 ml $HClO_4$ for 12 h at room temperature and heated subsequently at 100^{o}C for 2 hr. After cooling, solutions were then made up to 25 ml with double distilled water (Denton and Burdon-Jones, 1986). Metals concentrations were expressed in μg/g wet weight.

The precision and accuracy of the methods of metals determination in water, sediments and fish was checked by replicate measurements of studied metals in each. Precisions were found satisfactory which were in the ranges of 9.1–18.5, 5.3-19.2 and 7.5-16.8 % respectively for all studied metals. Reference material (Marine sediments—MESS-2) was used to check method accuracy for sediments analysis. The recovery values of metals analysis were between 85% and 92%.

3. RESULTS AND DISSCUTION

3.1Heavy metals in water

Seasonal variations and annual means of the studied metals (Pb, Cd, Cu, Zn and Fe) in water collected along the Suez Canal are represented in Tables (1 and 2). The obtained results revealed that lead concentrations were ranged from 1.16 (in autumn) to 1.69 μg/l (in spring), 1.01 (winter) - 2.90 μg/l (spring) and 1.33 (spring) - 1.79 μg/l (summer) in Port Said, Ismailia and Suez sectors respectively. Stations 1, 5 and 11 recorded the highest lead concentration, which may be attributed to the presence of municipal pollutions in these sites.

The concentration of cadmium in Port Said, Ismailia and Suez sectors recorded the ranges of 0.16 - 0.69, 0.12 - 0.86 and 0.23 - 0.91 μg/l, respectively. Annually, stations 1, 8 and 12 recorded the highest Cd concentration in each sector. The low levels of cadmium mainly reflect the absence of direct source of Cd at the present study area.

Through different sectors of the Suez Canal, stations 1, 7 and 9 recorded the absolute highest values of Cu during spring season (47.30, 56.96 and 28.91 μg/l respectively). As well as, seasonal Cu concentrations varied from 0.49 - 29.07, 0.34 - 29.74 and 0.69 - 19.17 μg/l in Port Said, Ismailia and Suez sectors respectively.

The concentration of zinc in Port Said sector ranged from 4.55 (winter) - 14.20 μg/l (spring), while Ismailia and Suez sectors showed the ranges of 2.22 - 16.56 and 3.28 - 15.14 μg/l. Stations 3,7 and 9 recorded the highest levels of Zn in comparing to each sector. Concentration of copper and zinc in Suez Canal stations was greatly affected by municipal and industrial activities.

Fe in water collected from Port Said, Ismailia and Suez sectors recorded the ranges of 15.86- 244.93, 22.22 - 265.63 and 23.63 - 232.53 μg/l respectively. The highest annual means of Fe were 95.02, 128.72 and 153.68 μg/l at stations 2, 6 and 9.

Generally, spring season showed the highest level of the studied metals in Suez Canal water, as well as stations affected directly by pollution sources and land-based activities revealed maximum metals concentration. These results were in agreement with those of Abd El-Azim (2002), El-Moselhy *et al*. (2005) and Soliman *et al*. (2015).

Suez Canal is suffered from considerable sources of land based activities; waste discharging from tankers passing across the canal, domestic wastes, industrial effluents and fish processing activities. Port Said sector is the most industrialized area in the Suez Canal, the middle sectors are affected mainly by agriculture effluents, and the southern part was affected by invaded water coming from the Suez Bay, which is loaded by oil and industrial effluents (El-Moselhy *et al*., 1998). The principal process dominating the ecosystem are the mean sea level, the velocity and direction of current which are responsible for the distribution of pollutants along Suez Canal (El Samra *et al*., 1983).

By comparing levels of the present studied metals with those reported for the other Egyptian waters (El-Moselhy *et al.*, 2005; Hamed, 2005; El-Moselhy and Hamed, 2006; Abou Hend, 2013; El-Metwally, 2014 and Zaghloul, 2015), it can be observed that the present study is comparable with that reported in other works. On the other hand, the metals level in Suez Canal water obtained in the present study were higher than the previous concentrations in the Open Ocean and coastal water reported by Johnston *et al.* (2002). However, Zn concentration was only higher than the open ocean level but lies within the range of coastal water concentration (0.30 – 70.0 μg/l) recorded by Bryan & Langston (1992) and UNEP (1993). In contrast, the present levels of metals were lower than the recommended values for water quality (EPA, 2001).

3.2 Heavy metals in sediments

Tables (1 and 2) show the concentrations of heavy metals (Pb, Cd, Cu, Zn and Fe) in sediments collected from different stations along the Suez Canal, and its mean at Port Said, Ismailia and Suez sectors which were 11.77±7.62, 0.26±0.24, 11.52±3.35, 13.13±8.47 and 3863.0±93.72 μg/g, 10.02±6.95, 0.50±0.32, 9.19±5.87, 14.29±10.69 and 3242.6±1213.5 μg/g and 9.77±11.48, 0.75±0.82, 6.20±2.25, 7.22±3.95 and 3281.6±523.3 μg/g respectively. The obtained results revealed that Port Said sector recorded the highest mean of Pb, Cu and Fe, which may be attributed to the presence of polluted water discharged from Manzala Lake, harbour and others human activities. Zn exhibited its highest mean at Ismailia sector mainly due to sewage and agriculture wastes discharged into this area through different drains in addition to industrial activities in Lake Timsah. While Cd recorded the highest level in Suez sector due to the oil refineries and processing. Generally, stations 2, 8 and 12 recorded highest values of the most studied metals, which reflect the direct effect of pollution sources on these stations.

Table 1: Seasonal variation of lead, cadmium, copper, zinc and iron in water of Port Said, Ismailia and Suez sectors and their levels in the sediments

	spring	**summer**	**autumn**	**winter**
		Water (μg/l)		
Sectors			**Pb**	
Port Said	1.69±0.77	1.45±0.66	1.16±0.66	1.46±0.21
Ismailia	2.90±1.49	1.03±0.26	1.21±0.48	1.01±0.19
Suez	1.33±0.80	1.79±0.61	1.34±0.44	1.40±0.40
			Cd	
Port Said	0.69±0.02	0.19±0.12	0.16±0.07	0.16±0.04
Ismailia	0.86±0.38	0.12±0.04	0.22±0.08	0.17±0.07
Suez	0.91±0.23	0.29±0.21	0.34±0.11	0.23±0.08
			Cu	
Port Said	29.07±15.81	0.89±0.41	0.49±0.56	0.84±0.77
Ismailia	29.74±25.53	0.73±0.24	0.82±0.40	0.34±0.36
Suez	19.17±11.03	1.12±0.42	0.69±0.54	0.88±0.64
			Zn	
Port Said	14.20±5.55	6.02±2.27	5.08±1.06	4.55±0.59
Ismailia	16.56±9.30	2.22±1.14	3.02±0.91	3.81±2.21
Suez	15.14±13.00	4.52±0.96	3.28±2.30	8.14±3.10
			Fe	
Port Said	244.93±20.75	15.86±0.51	17.84±3.56	50.35±39.85
Ismailia	265.63±25.14	22.22±32.53	77.80±88.94	49.60±19.18
Suez	232.53±15.31	56.31±64.36	23.63±8.78	35.55±10.50

			Sediments (μg/g)		
	Pb	Cd	Cu	Zn	Fe
Port Said	11.77±7.62	0.26±0.24	11.52±3.35	13.13±8.47	3863.0±93.72
Ismailia	10.02±6.95	0.50±0.32	9.19±5.87	14.29±10.69	3242.6±1213.5
Suez	9.77±11.48	0.75±0.82	6.20±2.25	7.22±3.95	3281.6±523.3

Table 2: Annual mean of lead, cadmium, copper, zinc and iron in water from different stations along Suez Canal and their levels in the sediments

Sector	Stations	Pb	Cd	Cu	Zn	Fe
				Water (µg/l)		
Port Said	**St. 1**	1.70±0.43	0.31±0.26	12.25±23.37	7.32±2.73	80.74±120.84
	St. 2	1.54±0.78	0.30±0.27	5.83±8.91	6.56±3.33	95.02±90.43
	St. 3	1.07±0.27	0.29±0.28	5.39±10.22	8.50±8.10	77.57±115.89
Ismailia	**St. 4**	0.86±0.20	0.26±0.22	3.99±6.65	3.50±2.81	80.35±122.47
	St. 5	1.73±1.60	0.35±0.40	3.02±4.34	7.01±9.08	100.01±102.82
	St. 6	1.18±0.40	0.26±0.16	2.01±3.01	3.95±2.47	128.72±124.62
	St. 7	1.60±0.80	0.34±0.22	14.64±28.21	8.76±12.06	94.68±139.40
	St. 8	1.63±1.52	0.43±0.61	11.96±22.69	5.89±5.31	91.83±109.07
Suez	**St. 9**	1.37±0.59	0.31±0.13	7.89±14.02	11.68±15.14	153.68±117.81
	St. 10	1.44±0.50	0.45±0.48	4.14±5.55	6.63±4.90	104.88±100.56
	St. 11	1.67±0.51	0.39±0.32	2.25±3.28	6.17±3.86	74.79±113.93
	St.12	1.37±0.79	0.49±0.18	7.58±13.73	6.59±1.76	81.35±89.82
				Sediments (µg/g)		
Port Said	**St. 1**	9.88	0.10	14.23	17.87	3768.2
	St. 2	20.15	0.54	12.57	18.17	3955.6
	St. 3	5.27	0.14	7.77	3.36	3865.3
	St. 4	4.19	0.18	5.18	7.58	1988.5
Ismailia	**St. 5**	13.62	0.47	12.84	17.65	4887.9
	St. 6	5.98	0.44	5.38	7.50	2802.2
	St. 7	5.72	0.35	4.74	7.05	2426.1
	St. 8	20.59	1.04	17.79	31.68	4108.3
Suez	**St. 9**	1.96	0.22	5.36	3.87	3688.7
	St. 10	2.61	0.19	3.53	4.33	2945.5
	St. 11	7.98	0.66	8.74	8.33	3765.8
	St.12	26.51	1.93	7.16	12.33	2726.2

The present levels of heavy metals in Suez Canal sediments were comparable with those recorded in other Egyptian coastal areas (Hamed and El-Moselhy, 2000; El-Moselhy and Gabal, 2004; Hamed and Emara, 2006; Kaiser *et al*., 2009; Abou Hend, 2013; Zaghloul, 2015), and still lower than the values of Lake Manzala sediments (Hamed *et al*., 2013). Comparing available data with the background concentrations and typical levels of metals in sediments (Bryan, 1985) and unpolluted sediments (GESAMP, 1993), it can be concluded that the levels of metals in the present study showed lower concentrations, except Cd in sediments of Ismailia and Suez sectors which was higher than the previous concentration (0.30) recorded by Bryan (1985).

3.3 Heavy metals in fish

Concentrations of heavy metals (Pb, Cd, Cu, Zn and Fe) in the organs (muscles, liver and gills) of different fish species collected along Suez Canal are presented in Table (3). Generally, cadmium showed the lowest metal concentration while iron recorded the highest one.

The present investigation revealed that the lowest concentration of cadmium in muscles of the studied fish was in the Bitter Lakes fish, which ranged from 0.01 to 0.033 µg/g followed by Port Said and Lake Timsah fish (0.07-0.13 and 0.10-0.11 µg/g respectively), while the highest value was found in Suez fish (0.07 -0.88 µg/g). The level of cadmium in liver and gills had the same trend in its concentration. The study area (Suez Canal) has not a remarkable source of cadmium except sewage drain run off, and water flow from the Suez Bay which is affected by oil refineries.

Level of lead in muscles of Port Said fish ranged from 0.74 to 0.75 µg/g, Lake Timsah fish (0.43-0.45 µg/g), Bitter Lakes fish (0.37 -0.44 µg/g) and Suez fish (0.81-2.30 µg/g). Liver and gills recorded high level of Pb showing similar pattern.

Table 3: Levels of Pb, Cd, Cu, Zn and Fe (μg/g) in fish organs (muscles, liver and gills) collected from the Suez Canal.

(a) Port Said fish

Species	organs	Pb	Cd	Cu	Zn	Fe
L. carinata	**muscles**	0.75± 0.08	0.07 ±0.02	1.36± 0.30	2.58± 0.13	12.12± 2.04
S. gibbosa	**muscles**	0.74± 0.46	0.13 ±0.01	2.81± 0.75	5.30 ±3.74	16.27± 4.43
L. carinata	**liver**	2.71± 1.09	0.15 ±0.07	33.72± 3.14	65.83±25.45	295.8 ±150.6
S. gibbosa	**liver**	10.51±5.56	1.23± 1.19	18.94± 4.36	47.36±23.89	372.3± 193.2
L. carinata	**gills**	1.62± 0.38	0.16± 0.01	1.43 ±0.80	9.86± 0.22	36.62 ±3.42
S. gibbosa	**gills**	17.9±24.01	0.53± 0.22	8.49 ±3.61	50.33±29.48	121.8± 69.28

(b) Lake Timsah fish

Species	organs	Pb	Cd	Cu	Zn	Fe
L. carinata	**muscles**	0.43 ± 0.18	0.11± 0.03	1.88 ± 0.36	3.90 ± 0.90	19.07± 7.94
P. stridens	**muscles**	0.45 ± 0.33	0.10 ±0.06	2.59 ± 0.93	4.61 ± 1.41	12.13 ±1.38
L. carinata	**liver**	1.24 ± 0.35	0.11 ± 0.03	1.97 ± 0.60	8.10 ± 2.99	52.82 ± 23.54
P. stridens	**liver**	5.48 ± 5.81	0.46 ± 0.66	9.78 ± 8.94	28.30 ± 10.18	98.08 ± 51.72
L. carinata	**gills**	1.24 ± 0.35	0.11 ± 0.03	1.97 ± 0.60	8.10 ± 2.99	52.82 ± 23.54
P. stridens	**gills**	4.10 ± 7.30	0.13 ± 0.05	2.04 ± 0.16	6.74 ± 2.45	26.31 ± 7.64

(c) Bitter Lakes fish

species	organ	Pb	Cd	Cu	Zn	Fe
L. carinata	**muscles**	0.37±0.12	0.01±0.01	1.71±0.43	3.50±0.39	18.20±11.95
R. haffara	**muscles**	0.41±0.20	0.03±0.02	0.86±0.03	3.49±0.40	14.44±5.32
P. stridens	**muscles**	0.44±0.23	0.033±0.001	0.88±0.49	3.07±1.71	11.79±8.45
L. carinata	**liver**	0.85±0.72	0.02±0.01	4.33±2.60	11.00±7.10	71.59±20.36
R. haffara	**liver**	5.75±3.37	0.042±0.03	10.26±3.42	46.21±12.00	143.57±61.54
P. stridens	**liver**	0.45±0.42	0.02±0.001	5.13±0.87	11.67±2.64	34.67±4.49
L. carinata	**gills**	2.35±0.73	0.19±0.03	3.71±0.85	10.48±1.84	110.90±41.80
R. haffara	**gills**	2.81±0.40	0.30±0.02	5.30±1.34	15.02±4.42	103.39±30.05
P. stridens	**gills**	2.75±0.77	0.25±0.04	1.14±0.61	14.93±4.78	52.62±37.42

(d) Suez fish

Species	Organ	Pb	Cd	Cu	Zn	Fe
S. undosqamus	**muscles**	1.23±0.33	0.27±0.07	1.69±0.36	1.88±0.30	9.80±1.26
R. haffara	**muscles**	1.18±0.11	0.22±0.02	2.17±0.63	2.40±0.65	11.76±3.16
N. japonicus	**muscles**	1.04±0.56	0.88±1.22	1.05±0.40	1.66±0.55	7.31±3.81
P. stridens	**muscles**	2.30±1.60	0.47±0.28	2.00±0.14	2.63±0.52	14.09±3.14
T. indicus	**muscles**	0.81±0.06	0.07±0.05	0.91±0.26	3.30±0.83	6.36±1.64
S. undosqamus	**liver**	8.42±5.10	0.59±0.39	13.42±4.85	28.10±6.87	157.97±22.1
R. haffara	**liver**	3.34±1.18	0.17±0.06	3.28±0.60	22.68±7.07	78.64±6.56
N. japonicus	**liver**	7.99±4.40	0.10±0.04	5.80±2.34	81.43±46.85	79.68±40.30
P. stridens	**liver**	12.59±4.79	0.09±0.04	6.39±6.72	27.53±7.50	146.63±49.08
T. indicus	**liver**	7.41±3.31	0.19±0.08	7.33±2.22	23.21±2.38	127.32±57.55
S. undosqamus	**gills**	5.32±1.65	0.31±0.09	1.84±0.72	23.06±4.98	41.62±14.54
R. haffara	**gills**	2.97±0.84	0.19±0.05	2.04±1.24	16.73±3.15	68.44±39.33
N. japonicus	**gills**	4.49±0.27	0.26±0.04	3.31±0.83	14.46±0.39	44.85±15.36
P. stridens	**gills**	4.42±0.91	0.18±0.07	2.09±1.02	10.09±0.31	37.77±10.57
T. indicus	**gills**	5.94±1.84	0.36±0.07	4.56±1.06	19.78±2.51	80.17± 8.50

Lead in Suez Canal come from different sources such as effluents of Lake Manzala at Port Said, Al Mahsama drain at Lake Timsah, and drain of Kobry Al-Sail discharged in Bitter Lakes.

Copper and zinc in muscles exhibited their highest concentrations in fish collected from Port Said and Lake Timsah with a range of 1.36-2.81 and 1.88-2.59 μg/g (Cu), 2.58-5.30 and 3.90-4.60 μg/g (Zn) respectively. While Bitter Lakes fish recorded the lowest copper level in muscles (0.86-1.71 μg/g) with zinc value of 3.07-3.50 μg/g. Suez fish recorded the lowest zinc

(1.66-3.30 µg/g) with copper content of 0.91-2.17 µg/g. The same concentration trend was recorded for copper and zinc in liver and gills of the present studied fish. The recorded levels of copper and zinc in fish collected from different fishing sites along Suez Canal were attributed to many sources of industrial and municipal wastes as well as antifouling paints and ships activities, which cause elevation of heavy metal levels in aquatic environment and consequently increases its contents in fish.

Fish muscles had Fe ranges of 6.36-14.09, 11.79-18.20, 12.13-19.07 and 12.12-16.27 µg/g for Suez, Bitter Lakes, Lake Timsah and Port Said, respectively. Liver and gills recorded higher content of iron compared to muscles. Concentrations of the present heavy metals were in the order Cd<Pb<Cu<Zn<Fe in all fish organs.

El-Moselhy *et al.* (2014) observed the concentrations of heavy metals in different fish species collected from the Red Sea (from Suez to Shalateen), and they concluded that the levels of heavy metals varied significantly among fish species and organs. Muscles always possessed the lowest concentrations of all metals in most studied fish; the liver was the target organ for Cu, Zn and Fe accumulation. Pb and Mn, however, exhibited their highest concentrations in the gills.

The concentrations of the present studied metals are in the range or lower than those recorded in other previous studies on the fish from different Egyptian waters (El-Moselhy, 1996, 2000; Soliman, 2006; Abdallah, 2008; Hamed *et al.*, 2012 and El-Metwally, 2014). In addition, metals in the present species were less than the maximum permissible levels (MPLs) of 5, 2, 10 and 100 µg/g for Pb, Cd Cu, and Zn, respectively (WHO, 1982 & 2006; FAO, 1983 and FAO/WHO, 1987) and limit for zinc in sea food (50 µg/g, MAFF, 1995). Therefore, the fish of Suez Canal analyzed in the present study were found to be safe for consumption and do not pose a significant threat to the health of human consumers.

4. CONCLUSION

Generally, it can be concluded that levels of the present studied metals (Pb, Cd, Cu, Zn and Fe) in water, sediments and fish species of the Suez Canal are affected directly by land-based activities and pollution sources. The obtained results showed that metals accumulation in fish varied between organs and species depending on species-specific factors like feeding behavior, swimming patterns and genetic tendency, and/or other factors like age, geographical distribution and ambient concentration of metals that caused variation in metals accumulations between fish even from the same species. Finally, the internal organs of the studied fish contain metals higher than those of muscle tissues (edible parts) and the later is safe for human consumption according to international criteria.

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