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Use of green alga *Ulva lactuca* (L.) as an indicator to heavy metal pollution at intertidal waters in Suez Gulf, Aqaba Gulf and Suez Canal, Egypt

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ABSTRACT
Metal pollution in the marine coastal line environment is an important topical issue in the context of ecological disturbance. The concentration of nine trace elements: Cu, Co, Ni, Cr, Mn, Zn, Cd, Pb, and Fe was determined in water, sediments and the green alga *Ulva lactuca* (L.), which collected from several sites at three main area (Suez Gulf, Aqaba Gulf and Suez Canal). The abundance of metal concentrations in algae samples was in the following order: Fe> Zn> Mn> Pb> Cu> Ni> Co> Cr> Cd, Fe> Mn>Zn> Pb> Cu> Ni> Co> Cr> Cd, and Fe> Mn>Zn> Cu> Pb> Ni> Co> Cr> Cd in Suez Gulf, Aqaba Gulf, and Suez Canal respectively. The variations at this order of abundance were according to the different in activities and metal sources in these different areas. The high uptake of metals in green alga *Ulva lactuca* suggested that this alga may be used as potential biomonitors for heavy metal pollution. The BCF value of metals in the algae/water was significantly higher than those of algae /sediments. The pollution indicator of Contamination Factor (BCF) was calculated to determine the degree of metal pollution in the marine coastline and the contribution of anthropogenic influence. Significant ($p \leq 0.05$) inter-elemental positive-correlations were observed between most studied metals, as well as negative-correlations between a few of them. Overall, the comparison of heavy metal contents with seawater and sediment samples in the *Ulva* species showed that *U. lactuca* is a suitable plant for biomonitoring studies.

INTRODUCTION

The use of bioindicators provides information on the quantities of pollutants that have been sequestered in the organisms and corresponding affects induced (**Okuku and Peter, 2012**). Some organisms are considered as biomonitors or bioindicators to evaluate certain characteristics of the environment (**Wolterbeek, 2002**). Using biological species in biomonitoring aquatic systems could allow for evaluation of the presence of contaminants and their effects on nearby living ecosystems. In addition, analysis of aquatic components such as water or sediment by relevant biomonitors could provide an overall perception about the contaminants rather than only a small fraction of eco-toxicological indications. Therefore, it considerably reduces or eliminates the requirement of complex investigations on chemical speciation of contaminants (**Akcali and Kucuksezgin, 2011**). According to **Phillips** (**1990**) good indicator should be wide spread, show significant tolerance to high concentrations of contamination. It should be easy to identify and collect. The metals concentration recorded in the organisms should show simple correlation with the concentration of these metals in the environment. It is preferred to measure heavy metal levels in bioindicators organisms rather than measuring the concentrations in water and/or sediment samples (**Stengel, 2004 and Al-Homaidan *et al*. 2011**). Along the worldwide industrial development, the production of heavy metals has increased rapidly. The presence of these heavy metals affects numerous metabolic and/or developmental processes in all living organisms. The presence of these heavy metals affects numerous metabolic or developmental processes in all living organisms (**Verma *et al.* 2008**) because of its toxicity, non-biodegradability, bioaccumulation and persistence in nature. Unlike organic contaminants, heavy metals cannot be broken down by chemical or biological processes. Hence, they can only be transformed into less toxic species (**Ayangbenro and Babalola, 2017**). The toxicity and bioaccumulation tendency of heavy metals in the environment is a serious threat to the health of living organisms. Macroalgae have been used extensively to measure heavy metal pollution in freshwater and marine environments throughout the world (**Conti and Cecchetti, 2003**). This fact has made marine macroalgae to be used extensively in many coastal waters around the world as biomonitors of metal contamination in (**Okuku and Peter, 2012**). An important assumption underlying use of seaweeds as biomonitor is that metal concentrations in the seaweeds are directly proportional to the bioavailable metal concentrations in environment. Also, macroalgae are the most complex and reliable organisms in studies of heavy metal pollution due to their rapid rate of metal accumulation from aqueous solutions and they show the high degree of accumulation of dissolved metals in their cell walls (**Salgado *et al.* 2005**). Macroalgae can accumulate heavy metals, either essential or non–essential, from their living environments (**Salt *et al*. 1995**). They are used as bioindicators because of their distribution, size, longevity, presence at pollution sites, ability to accumulate metals to a satisfactory degree and ease of identification (**Stengel, 2004**). Macroalgae are excellent agents of filtering the metals from seawater. They remove the toxic materials from the environment and accumulate in the body cell. Marine algae accumulate heavy metal by means two stages process, consisting first of rapid and reversible physico-chemical process of adsorption on algae surface and slower metabolically arranged intracellular uptake. The absorption of metals present in the seaweed depends on the surface reaction in which metals absorbed through electrostatic attraction to negatives sites (**Guitouni *et al.* 2016**). This is independent of factors influencing metabolism such as pH, temperature, light or age of the plant, but it is inclined by the virtual abundance of elements in water (**Sanchez-Rodriguez *et al*. 2001**). Determination of heavy metal concentrations in marine algae samples is usually preferred in the seawater and sediment samples. Heavy metal concentrations in seawater are very low and show wide fluctuation. At the same time, heavy metal levels in the sediment samples can be changed by organic matter content, grain size composition, pH and oxidation-reduction potential, etc. (**Topcuoğlu *et al.* 2010**). On the other hand, marine organisms can be used as monitors to give information on concentrations of heavy metals in the surrounding environment. Especially, marine algae species are usually used to indicate heavy metal levels in both estuarine and coastal waters throughout the world. In benthic food webs, marine algae are key links and they act time-integrators of pollutants. Biological monitoring of marine water primarily focuses on the brown algae, red algae and green algae. The uptake of heavy metals by these algae proceeds as follows: Chlorophyta > Phaeophyta > Rhodophyta (**Al-Shwafi and Rushdi, 2008; Rybak *et al.* 2012)**. Thus, green algae, particularly from the genus *Ulva* (Ulvophyce, Ulvaceae), are very common as biomonitoring species (**Akcali and Kucuksezgin, 2011; Rybak**

***et al.* 2013**). However, in the most studies on the accumulation of heavy metals by *Ulva* showed that only concentrations of these elements characterized in the organisms (more than water and sediments). *Ulva lactuca* is a widespread macro alga occurring at all levels of the intertidal zone, in calm and protected harbors as deep as 10 meters and in northern climates. *Ulva lactuca* grows along rocky or sandy coasts of oceans and estuaries (**Aslan *et al*. 2010**). The analysis of the heavy metal concentrations in the entire natural environment from organisms are sampled, may provide information on the extent of contamination and shall reveal possible applications of using *Ulva* as bioindicator (**Villares *et al*. 2002**). *Ulva* appears as a valuable biosentinel of water quality due to its massive developments and wide distribution. *Ulva* species have shown to be particularly promising in monitoring trace metal contamination (**El-Adl, 2009**). Among the seaweeds, *U. lactuca* was the most abundant marine algae along the coastal regions. Indeed, it has the ability to reflect the levels of trace elements; thereby it can serve as a useful bioindicator for pollution in marine environment (**Saleh, 2015**). The present study aims to provide information on the *Ulva lactuca* to act as an efficient bioindicator of metals in Suez Gulf, Aqaba Gulf and Suez Canal coastal environments. We described the spatial variation in Cu, Co, Ni, Cr, Mn, Zn, Cd, Pb, and Fe concentrations in *Ulva lactuca* in these coastal areas. We investigated the variation in metal contents in this macroalga reflects the variation in their ambient abundances and if it is significantly affected by certain variables. Provided that metal contents in seaweeds often indicate their ambient bioavailability. We predicted that *Ulva lactuca* would reflect the ambient abundances of the metals analyzed, i.e. that it satisfies the basic prerequisite for its use as bioindicator of these elements in Suez Gulf, Aqaba Gulf and Suez Canal coastal environments.

MATERIALS AND METHODS

The study area

The far northern end of the Red Sea is divided into two parts (gulfs) by the Sinai Peninsula. The west is the Gulf of Suez, and the east is the Gulf of Aqaba. The Gulf of Suez, an important shipping route for oil and other products, lies along the edges of the African country of Egypt and the Sinai Peninsula. The Gulf of Suez is approximately 195 miles (314 km) in length. The width runs from 12 to 27 miles (19 to 43 km). The Gulf of Aqaba is an elongated basin (~180 × 20 km) with depths reaching 1850 m. It represents the southern. Gulf that is a branch of the Red Sea, running to the east of the Sinai Peninsula. The gulf is 160 km long, and has a maximum width of 24 km. The gulf passes through the Straits of Tiran at its junction with the Red Sea proper. In the north, the manmade Suez Canal provides access to the Mediterranean Sea. The Suez Canal is considered to be the shortest link between the east and the west due to its unique geographic location. It is an important international navigation canal linking between the Mediterranean Sea at Port Said and the Red Sea at Suez .The unique geographical position of the Suez Canal makes it of special importance to the world and to Egypt as well Fig. 1.

Sampling and laboratory analytical procedures

Sampling: Water, sediment and *Ulva lactuca* (L.), collected from several sites at three mean areas (Suez Gulf, Aqaba Gulf and Suez Canal). Surface water samples were collected, in cleaned and acid washed polypropylene bottles and then they were filtered in Millipore filter paper [mesh size 0.45µ]. All the samples were collected in sterile polythene bags and kept in the laboratory deep freezer (-20ºC) to prevent deterioration untill further analysis.

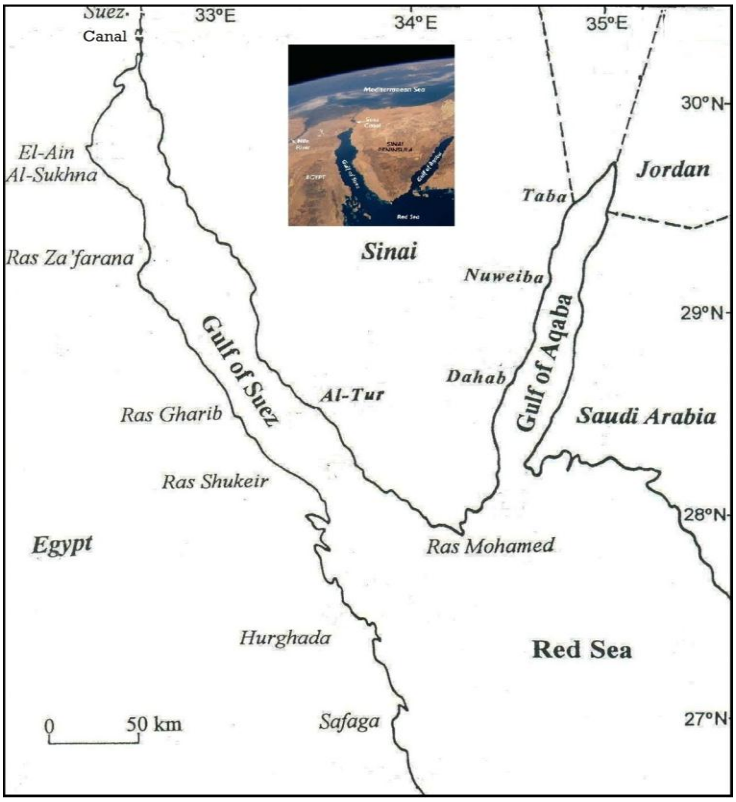

Fig. 1: Locations of different samples collected from the study area (Suez Gulf, Aqaba Gulf and Suez Canal).

The algal samples were carefully washed with distilled water, dried in a forced air oven at 50±1 ◦C to constant weight, crushed in a mortar and stored in plastic bags until analyzed. Sediment samples were air dried at room temperature. Bulk sediment samples were ground to pass through 250 μm sieve to facilitate sample dissolution before subsequent analysis. All reagents of analytical grade; glassware were soaked in 10% nitric acid and later rinsed with distilled water prior to use in order to avoid metal contamination.

Heavy metal analysis

Water samples were preconcentrated with APDC – MIBK extraction procedure according to the standard methods (**APHA, 1989**). The resulting solution was aspirated to the flame Atomic Absorption Spectrophotometer. The obtained data expressed as μg/L.

Sediment samples 0.5 g of each sample was weighed into a screw capped teflon beaker and digested with 10 ml of a mixture of concentrated HNO_3, $HClO_4$ and HF acids (3: 2: 1) then left overnight (12 h). The samples were then digested at 120°C for 1 - 2 h on a hot plate. The residue of each sample was dissolved into 2 ml of 12 N HCl, diluted to 25 ml with distilled water and filtered using a filter paper (**Oregioni and Aston, 1984**).

***Ulva lactuca* samples** Each dried sample (1 gm on dry weight basis) was digested with a mixture of nitric acid and hydrogen peroxide followed by addition of hydrochloric acid (**Kumar *et al.* 2012**). The extracts were made up to 50 ml with distilled water. The digested samples were analyzed for Cu, Co, Ni, Cr, Mn, Zn, Cd, Pb, and Fe against standard concentration of each metal on a Perkin Elmer Atomic

Absorption Spectrophotometer (Model A Analyst 100). The obtained data were expressed as μg/g dry wt. Blank correction was done to bring accuracy to the results.

Data analysis

Statistical analyses: Pearson Correlation Matrix was used to evaluate the inter-specific significance between algal metal accumulation and between metal levels in different sites with p= 0.05. All statistical analyses of data were conducted using computer program: Stat Plus LE Analyst Soft Inc 6.3.0.0

Calculations: The bioconcentration factor (BCF) is a ratio, which gives information about the ability of the plants or algae to accumulate metal in their tissue from the aquatic ecosystem, by comparing the concentrations in the biota (algal biomass) and an external medium (e.g. water and sediments).

The BCFs, was calculated according to **Kalfakakour and Akrida-Demertzi** (**2000**) and **Rashed** (**2001**) as follows:

$$BCF = \frac{M_{algae\ tissue}}{M_{water\ or\ sediment}}$$

Where, $\mathbf{M}_{\text{algae tissue}}$ (μg/g dry wt) is the metal concentration in algae tissue and $\mathbf{M}_{\text{sediment or water}}$ the metal concentration in sediment (μg/g) or in water (μg/mL). Some parameters affecting the performance of this parameter are: 1) the physiological state of the seaweed, 2) the age of the cells, 3) the availability of micronutrients during their growth and finally 4) the environmental conditions during uptake dependent on pH, temperature, and light intensity etcetera. Accumulation factor based on the described "seaweed battery" principle is new and applied for the first time (**Van Ginneken and de Vries, 2018**).

RESULTS AND DISCUSSION

Species of macroalgae of the genera *Ulva* are regarded as good bioindicators of heavy metal contamination in sea water (**Ustunada *et al.* 2010; Rybak *et al*. 2012**). However, the legitimacy of using these organisms for monitoring contaminated waters requires having complete information about metal concentrations in the macroalgae habitat. Such information is obtained through the analysis of sediment and water samples. It was also noticed that reliable monitoring of heavy metal pollution requires *Ulva* to cover a large area.

Heavy metal concentration in seawater

The concentration of nine trace elements: Cu, Co, Ni, Cr, Mn, Zn, Cd, Pb, and Fe were determined in the water from several sites at three mean areas (Suez Gulf, Aqaba Gulf and Suez Canal). It's showed significant temporal variations and are presented in (Table 1, and Fig. 2). Mean metal concentrations in the water decreased in the order Fe> Zn> Pb> Ni> Cu> Cr> Co> Cd> Mn at Suez and Aqaba Gulfs sites and Fe> Zn> Cu> Ni> Pb> Cd> Co> Cr> Mn at Suez Canal site. The difference in the distribution of metals amongst the three locations was attributed to the differences in inflow of effluents from industries, anthropogenic wastes, ship unloading and welding activities, which are the probable source of heavy metals in this region. The concentrations of dissolved heavy metals in seawater are affected by a number of processes, namely biological uptake, scavenging by particulate matter, release from bottom sediments, advection and mixing of water masses and aeolian transport of terrestrial materials etc. regulates the concentration of dissolved metals in the sea water (**Hasan *et al.* 2016**).

Table 1. Mean concentrations of heavy metals in seawater, sediments and *Ulva lactuca* samples from three areas (Suez Gulf, Aqaba Gulf and Suez Canal)

	Seawater (µg/L)			**Sediments (µg/g)**			***Ulva lactuca* (µg/g)**		
Metals	**Suez Gulf**	**Aqaba Gulf**	**Suez Canal**	**Suez Gulf**	**Aqaba Gulf**	**Suez Canal**	**Suez Gulf**	**Aqaba Gulf**	**Suez Canal**
Cu	0.829	0.825	2.041	6.063	4.753	10.62	5.701	5.333	8.915
Co	0.592	0.517	0.310	8.847	7.523	7.332	1.388	1.746	2.042
Ni	0.949	0.929	1.430	23.14	21.98	14.54	5.654	4.285	4.479
Cr	0.664	0.603	0.200	16.59	12.87	14.11	1.342	1.419	1.276
Mn	0.226	0.189	0.161	91.21	68.69	48.74	16.15	25.23	49.80
Zn	8.325	6.135	5.471	25.63	14.01	10.42	22.35	13.52	13.90
Cd	0.477	0.439	0.351	4.872	3.436	3.061	0.657	0.531	0.593
Pb	1.339	1.197	0.941	19.08	15.39	13.13	8.686	8.112	7.186
Fe	13.98	17.07	14.50	2464	2923	2275	464.1	724.7	628.0
Max	13.98	17.07	14.50	2464	2923	2275	464.1	724.7	628.0
Min	0.226	0.189	0.161	4.872	3.436	3.061	0.657	0.531	0.593

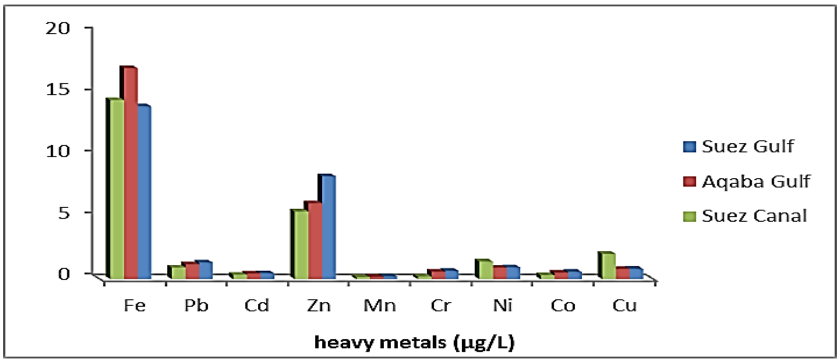

Fig. 2. Concentration of heavy metals (µg/L) from three mean areas (Suez Gulf, Aqaba Gulf and Suez Canal)

Cu, Ni, at Suez Canal and Fe at Gulf of Aqaba, Suez Gulf only recorded the highest heavy metals concentrations in water. This may attributed to Suez gulf environments receive either locally or more widely, a variety of stresses as a result of human activities, including mixed sources of industrial pollution as wastewater discharges from oil refineries which associated with harbours disposals (**Abd El-Azim, 1996; Mansour *et al.* 2005; Mehanna and Abd El-Azim, 2018**). The different anthropogenic activities included recreational resorts, urban agglomeration, marine shipping, and activities of phosphate industry, fishing ports, as well as limited freshwater and sewage sources (**El-Shenawy and Farag, 2005**). Cu and Ni recorded high levels at Suez Canal. It was attributed to antifouling paints found in the area; beside of Ni, copper and cupric oxide released from the antifouling and anticorrosive paints that protect the hulls of marine vessels (**Abd El-Azim, 2002; Soliman *et al.* 2010; Olusola and Festus, 2015**).

Heavy metal concentration in sediments

Heavy metal concentrations measured in sediments in the different areas are presented in Table 1. Metal concentrations in sediment decreased in the following order: Fe> Mn> Zn> Ni> Pb> Cr> Co> Cu> Cd, Fe> Mn> Ni> Pb> Zn>Cr> Co> Cu> Cd and Fe> Mn> Ni> Cr>Pb>Cu> Zn> Co> Cd at Suez, Aqaba Gulfs and Suez Canal respectively (Fig., 3). The metal qualities, soil or sediment qualities, and environment factors are as important as total concentration metals on heavy metals mobility (**Weng *et al*. 2003; Tavakoly Sany *et al*. 2011**). Sediments represent the most important sink of metals in estuarine and coastal waters due to their strong metal-adsorbing capacity (**Pan and Wang, 2011**). The majority of suspended particles in seawater have a strong affinity for binding to metals, and metals in the formation of complexes with suspended particles are subsequently precipitated into bottom sediments, causing metal accumulation in sediments (**Duman and Kar, 2012**).

Cu, (Suez Canal) and Fe (Gulf of Aqaba and Suez Gulf) recorded the highest concentrations in sediments from the studied areas (Fig. 3). This shows that heavy metals are originated from many sources such as runoff due to rainfall and anthropogenic activities in the study area. The average concentration of metals in sediment in is probably due to run off and industrial outlets. High levels of industrialization and urbanization and oil spillages, which are taken place in the Suez Gulf region, are probably responsible for the elevated levels of pollutants in this area (**Al-Homaidan, 2007**).

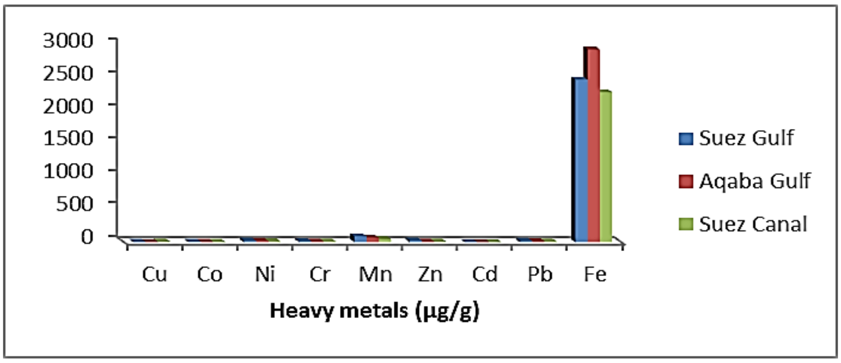

Fig. 3: Concentration of heavy metals (µg/g) at sediments from three mean areas (Suez Gulf, Aqaba Gulf and Suez Canal).

These sources cause disturbance in environment and change geochemical concentrations ratio of metals and increase metals concentration from their standard or typical level. **Wang and Qin** (**2006**) studied about stability and relative concentration of metals in sediment. Generally they have stated that, when geochemical metals concentration are suffered from disturbance due to potential change in environmental, the relative concentration ratio of metals goes beyond their standard variation levels in sediment. The existing balance between suspended metals and metals present on the sediments was in many cases broken by human activity which caused a wholesale increase in the concentration levels of metals through uncontrolled discharges, especially in highly industrialized areas. In chronically polluted areas, algae and sea plants tend to accumulate metals in very high and dangerous levels (**Volterra and Conti, 2000**). According to (**Gopinath *et al.* 2011**) who showed that most trace elements which are bio accumulated in algal species have a common source ambient sediment, which explains similar trends of metal accumulation in algae and sediment. The concentrations of the heavy metals in seawater and sediment were not evenly distributed among the three sampling areas. The difference in the distribution of metals amongst the three areas was attributed to the differences in in flow of effluents from industries, anthropogenic wastes, ship unloading and welding activities, which are the probable source of heavy metals in this region.

Contents of heavy metals accumulated in the *Ulva lactuca*

The values of heavy metal contents (µg /g dry weight) characterized in algae samples are illustrated in Table 1 and Fig. 4. The average concentrations of metals in the algae decreases in the following order: Fe> Zn> Mn> Pb> Cu> Ni> Co> Cr> Cd, Fe> Mn>Zn> Pb> Cu> Ni> Co> Cr> Cd, and Fe> Mn>Zn> Cu> Pb> Ni> Co> Cr> Cd at the algae from Suez Gulf, Aqaba Gulf, and Suez Canal respectively. The metals Cu, Co, Ni, Cr, Mn, Zn, Cd, Pb, and Fe are present in the algae samples but at different levels of contamination, depending on the sampling area (**Benabdallah *et al.* 2017**). Therefore, the interaction between the site and significantly affect the contents and the metal accumulation in the *Ulva lactuca*.

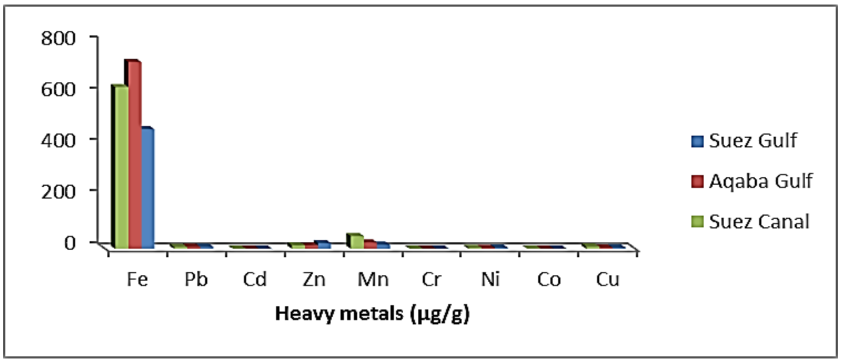

Fig. 4: Concentration of heavy metals (μg/g) at *Ulva lactuca* from three mean areas (Suez Gulf, Aqaba Gulf and Suez Canal)

Seaweeds have the highest potency to be used as biomonitors for metal pollution in the marine environment because they have fundamental prerequisites for use as bioindicators. They are easy to identify and to collect, available all the year round in almost all coastal areas. One way to assess the suitability of *Ulva lactuca* as a bioindicator for trace metals is to find out whether the alga in known areas of metal discharge has its tissue accumulated with high levels of the metals. Concentrations of heavy metals accumulated in algae depend, for instance, on the characteristic (different, frequently changeable) contamination of waters and benthic sediments with heavy metals, their bio accessibility for the elements of biota, algae sorption properties and the concentration of other, outside analytes in the aquatic area (**Rajfur, 2013**). From the data presented in Table 4, *Ulva lactuca* is able to accumulate appreciable amounts of metals in urban sites where industrial and/or domestic discharge occur. The highest metals accumulation in *Ulva lactuca* species was: Ni, Zn, Cd and Pb at Suez Gulf, Cu, Co and Mn at Suez Canal and Cr and Fe at Aqaba Gulf. High levels of metals were found in the algae at the studied areas in the following order: Suez Gulf> Suez Canal> Aqaba Gulf. Anthropogenic discharges, including domestic, industrial and agricultural discharges are probably responsible for this problem (**Al-Homaidan *et al.* 2011**).

Data analysis

Bioconcentration factor (*BCF*)

Table (2) and Fig. (5) Show the values of the *BCF* factor showing the accumulative properties of the analysed algae at the different investigated areas in relation to the analysed heavy metals. The determination of the values of bioconcentration factors reveals very good sorption properties of the analysed algae. A varied bioaccessibility of the determined heavy metals in relation to *Ulva lactuca* may be influenced by, for instance, the form of analyte existence, concentration and the time of exposure of a plant to its activity, cellular distribution of metal, forms of storing and detoxication of metal, interactions with other compounds present in the cell and the specific features (*eg* adaptive capacity) (**Hédouin *et al.* 2008; Rajfur, 2013**). In order to assess the bioaccumulation capacity of heavy metals by the algae elements, a bioconcentration factor (*BCF*) is determined (**Nguyen *et al.* 2005**). The values of the factor *BCF* > 1000 reveal very good sorption properties of the algae (**Rajfur, 2013**), and suggest the possibility of their application in biomonitoring and effective phytoremediation.

Table 2: Mean bioconcentration factors* (BCF) x10^3 for algae from water and sediments from three mean areas (Suez Gulf, Aqaba Gulf and Suez Canal)

Areas	**Suez Gulf**		**Aqaba Gulf**		**Suez Canal**	
Metals	**BCFw**	**BCFs**	**BCFw**	**BCFs**	**BCFw**	**BCFs**
Cu	6.873	1.199	6.464	0.879	1.384	0.266
Co	2.712	0.184	2.924	0.197	6.589	0.171
Ni	6.654	0.257	4.609	0.185	3.133	0.308
Cr	2.021	0.104	2.351	0.085	8.882	0.125
Mn	71.46	0.235	133.2	0.276	138.3	1.022
Zn	2.685	1.595	2.204	0.527	4.371	2.298
Cd	1.743	0.135	1.211	0.154	5.982	0.684
Pb	6.483	0.455	6.772	0.527	7.644	0.356
Fe	33.19	0.188	42.44	0.247	43.31	0.276

*Calculated by dividing the mean metal contents in the algae by the mean metal concentration in seawater, and expressed in µg /g dry wt algae per µg / ml $^{-1}$ seawater (w) and µg /g dry wt for sediments (w).

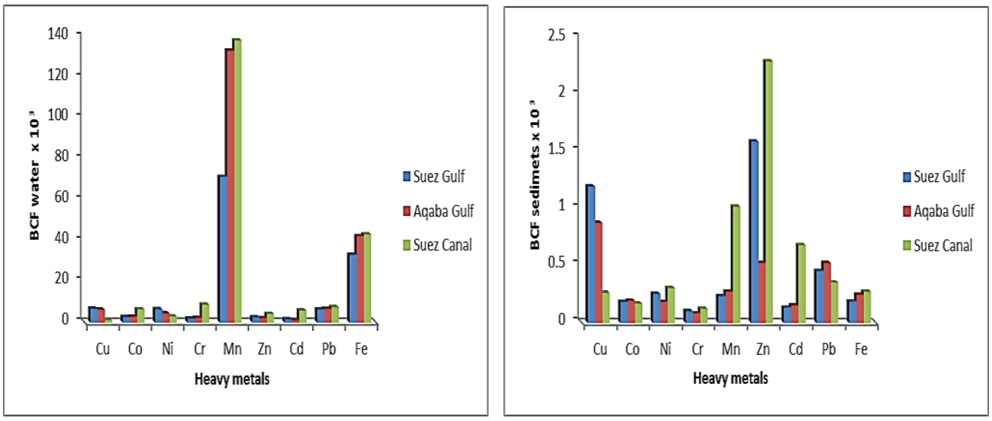

Fig. 5: Mean bioconcentration factors* (BCF) x10^3 for algae from water and sediments from three mean areas (Suez Gulf, Aqaba Gulf and Suez Canal)

The BCF value of metals in the algae/water was significantly higher than those of algae /sediments. These results suggested that the water may offer great potential for accumulation and transportation of metals in aquatic environments and had implications for understanding the biogeochemical cycling of different metals in eutrophic water ecosystems. Based on this criterion, the present results showed that *U. lactuca* is a good accumulator of metals from water with high BCF values.

Useful tool to check the possibility of using species as a bioindicator is bioconcentration factor (BCF). This ratio describes the relation between the concentration of metals in algae, water and sediment (**Rybak *et al.* 2013**). Analysis of obtained result allows determining "hiperaccumulators" – species, for which value of bioconcetration factor is more than 1000. Bioconcentration factor between the concentration of metals in algae and water is presented in Table 2. In this study, BCFt-w refers to the concentration of heavy metals in algae per content of these metals the water. The high values (> 1000) of bioconcentration factor for water populations of *Ulva* were noted for all metals. BCFs for Cu, Zn and Mn, Zn at Suez Gulf and Suez Canal respectively, were higher than 1000, probably because of anthropogenic available of these metal in photosynthesis (**Chaudhuri *et al.* 2007**).

Correlation coefficients

Correlation coefficients between the metals in the alga are shown in Table 3. Significant correlations were found between many of the metals in *Ulva lactuca*. However, few metals were the exception in that it correlated (negatively). Significant ($p \leq 0.05$) inter-elemental positive-correlations were observed between most studied metals, as well as negative-correlations between a few of them. The specific macroalgal responses to heavy metal accumulation were significant.

Table 3: Correlation matrices of trace metal contents accumulated in the alga *Ulva lactuca*.

	Cu	**Co**	**Ni**	**Cr**	**Mn**	**Zn**	**Cd**	**Pb**	**Fe**
Cu	1								
Co	0.765*	1							
Ni	0.095	0.400	1						
Cr	-0.333	0.398	0.458*	1					
Mn	0.908*	0.087	0.758*	0.200	1				
Zn	0.728*	0.865*	0.557*	0.298	0.506*	1			
Cd	0.265	0.331	0.223	0.257	-0.099	-0.557*	1		
Pb	0.236	0.277	0.408	-0.267	0.377	0.522	-0.056	1	
Fe	0.240	0.297	0.468	0.589*	0.440	0.593*	-0.116	0.912*	1

*Significance at $p \leq 0.05$.

High correlation **v**alues between metals may indicate that those metals originate from the same or similar sources. While in case of relatively low correlation coefficients, the metals may be present in different amounts and proportions in the various effluent outfalls**.** When concentrations in the water body are particularly high, the various metals can present interference phenomena (synergy and antagonism effects). Metal concentrations in algae depend on external factors and involving the interaction between metal and cell wall (pH, salinity, inorganic and organic compounds) and also, on the physico-chemical parameters, such as temperature, light, oxygen and nutrients (**Barreiro *et al.* 2002**). **Wan *et al.*** (**2017**) stated that, the metal compositions and concentrations found in *Ulva* were site dependent. Overall, the comparison of heavy metal contents with seawater and sediment samples in the *Ulva* species showed that *U. lactuca* is a suitable plant for biomonitoring studies. Insight to metal bioaccumulation factor of the algal species provides a scope for decontamination, thereby reducing the pollution load of aquatic as well as terrestrial ecosystems**.**

CONCLUSION

This study indicates that Suez Gulf, Suez Canal, and Aqaba Gulf ecosystems are actively accumulating heavy metals in the environment in the following order: Suez Gulf> Suez Canal> Aqaba Gulf, and that *Ulva lactuca* have the potential to accumulate Cu, Co, Ni, Cr, Mn, Zn, Cd, Pb, and Fe. Concentrations of heavy metals in algal biomass reflect the metal load in the marine environment. Significant correlations of heavy metal concentrations in *Ulva lactuca* and its ability to accumulate these heavy metals showed that we can use it as a good bio-monitor of Cu, Co, Ni, Cr, Mn, Zn, Cd, Pb, and Fe. Calculated bio-concentration factor was > 1000, but with low concentration thresholds in each element, suggesting that algal biomass was a very good heavy metal accumulator. In conclusion, algae can be a promising aquatic bio-filter plant for bio-monitoring of polluted urban stream ecosystems and wastewater.

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