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ORIGINAL PAPER

Bioremediation of iron from polluted water using marine algae

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Abstract

El-Mex Bay receives huge of toxicants and pollutants that resulted from various anthropogenic activities and different heavy metals. These pollutants adversely affect human's health and the aquatic ecosystem. In this study, iron is selected rather than other heavy metals for bioremediation as it constitutes a large part of the Bay. This work aims to the assessment of the efficiency of six marine algal species as bio-sorbents for iron, which constitutes a large part of El-Umum drain wastewater at El-Mex Bay locality. These species are *Ulva linza, Ulva fasciata* (Chlorophyceae), *Padina pavonia*, *Saragassum hornschuchii* (Phaeophyceae), and *Pterocladia capillacea*, *Corallina officinalis* (Rhodophyceae). Algal nanoparticles and finely powdered algae were evaluated for adsorbing iron in aqueous solutions as a function of contact time, biomass weight, different wastewater concentrations, and pH. Analyzing function groups of the biomass was also assessed. Compared to ordinary ground algal biomass, nanoparticles of dry algal biomass (ground by ball mill) is considered an efficient economic adsorbent for iron removal that occurs at high concentration levels, either dissolved or particulate. Comparing the maximum removal efficiency, it was recorded values of 95.6, 98.8, and 97.6% for *Ulva linza, Sargassum hornschuchii,* and *Corallina officinalis*, respectively, using 0.1 g nano-biomass at pH 9.4, these values were 79.60, 96.33, and 83.41%, for the same algal species using 0.5 g ground powder biomass at the same pH.

Keywords Adsorption · Algae · Iron · Nano-biomass

Introduction

The current pattern of anthropogenic activities imposes novel chemicals into the ecosystem and changes the natural influx of matter (Faisal and Hasnain 2004). Most of the discharged effluents into the environment especially water bodies contain toxic materials mainly heavy metals. Contamination of soil, air, and water with these metals is a great ecosystem problem (Park et al. 2006). The existence of heavy metals in the ecosystem causes a threat to human life and the environment because of their toxicity and bio-accumulating tendency (Horsfall and Spiff 2005). The toxic effects of heavy metals depend on the forms and routes of exposure, interruptions of intracellular homeostasis include damage to lipids, proteins, enzymes, and DNA via the production of free radicals (Jan et al. 2015). They act as a pseudo-element of the body while at certain times they may even interfere with metabolic processes, they are among the constant pollutants that are not affected by the bacterial attack or break down degradation processes, few metals such as aluminum can be removed through elimination activities, while some metals get accumulated in the body and food chain, exhibiting a chronic nature (Jaishankar et al. 2014).

Iron is a grayish metal, lustrous, ductile, and malleable. It is the second most abundant metal and fourth most abundant element in the earth's crust forming much of the earth's outer and inner core, but it has a very low concentration in water because of its low solubility (Wei and Guihua 2011). The presence of excess amounts of iron in water causes a bitter or metallic taste in water, the formation of reddish-brown or black color, staining of clothes during laundering, supporting the growth of microorganisms in presence of organic matter, and causes difficulty in water softening processes (Vigneswaran et al. 2009). Also, iron overload (hemochromatosis) causes liver disease,

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cancer, heart attacks, heart failure, diabetes mellitus, and metabolic syndrome (Yutaka et al. 2008).

Biological methods such as bioaccumulation or biosorption may provide an alternative technique to physicochemical methods for the removal of heavy metal ions. The biomass is capable of absorbing and adsorbing metal ions from aqueous media (Gadd and White 1993). This attractive alternative process has been called biosorption, bioremoval, bio-separation, and sometimes phytoremediation (Schiewer and Wong 2000). The biosorption mechanisms involve extracellular and intracellular bonds which depend on the metal type and the biosorbent structure (Davis et al. 2003c). Adsorption is a surface phenomenon that includes the total volume of the adsorbent. It occurs due to physical or van der Waals forces (physisorption) and chemical (chemisorption) force due to chemical bonds between adsorbent and adsorbate (Thakuria and Godboley 2016). In the adsorption process, the atoms, ions, and molecules adhere to the surface of a material which resulted in the formation of a layer of adsorbate on the adsorbent.

Some algae play an important role in the research and development of new biosorption materials due to their high uptake capacities for the accumulation of heavy metals similar to ion-exchange resins. Numerous algae synthesize phytochelatins and metallothioneins to form complexes with heavy metals and translocate them into vacuoles (Suresh and Gokare 2004). The high biomass production of the algae can be considered as an advantage in phytoremediation that leads to high absorption and accumulation of heavy metals (Chekroun and Baghour 2013).

Nanotechnology is a novel branch of science known for the last three decades. Nanomaterials have a larger surface area per unit mass in comparison with traditional materials. Different chemical reactions take place at nanomaterial surfaces, so these materials have faster rates than the larger ones (Gogotsi 2017). The physical properties of these materials can be controlled by altering the dimensions of the particle as a result of the well-known quantum confinement effect (Nagaoka et al. 2014). Nanoscale particles could recover the environment through direct applications of those nanoparticles to detect, prevent, and remove contaminants (Mansoori et al. 2008). At the same time, it presents new challenges in the health and safety of different ecosystems in water purification by using natural nanomaterial to sequestrate heavy metals and hazardous wastes (Salah El Dine 2014).

Alexandria is the second biggest city in Egypt and one of the most important industrial centers including 100 large factories and about 260 smaller ones. Annually, more than 18×10^6 m^3 of contaminated sludge and wastewaters were discharged from large numbers of drains into Alexandria coastal area within the local-sludge system (Mohammed 2015).

The present study aims to the evaluation of algal biomass (natural material) as a biosorbent for the iron that constitutes a large part of El-Umum drain wastewater at El-Mex Bay, Alexandria, Egypt during the period 2016–2017. The work is extended to determine factors affecting the biosorption capacity. The study also compared the biosorption efficiency of algal nanoparticles with that of ground fine powdered algal biomass, to design a model filter using the promising species for iron removal.

Materials and methods

The algae used in this work were 6 species representing 3 different classes: Chlorophyceae, *Ulva linza* Linnaeus, and *Ulva fasciata* Delile; Phaeophyceae *Sargassum hornschuchii* C. Agardh, and *Padina pavonia* (Linnaeus) Gaillon, and Rhodophyceae, *Corallina officinalis* Linnaeus, and *Pterocladia capillacea* (Gmelin) Bornet et Thuret. They were collected from the Mediterranean seashore of Alexandria along Abu-Qir district (Fig. 1), rinsed thoroughly with natural seawater to remove sand particles and epiphytes. The algal biomass was air-dried for 24 h, followed by oven drying at 60 °C till complete dryness, and then they were ground to a fine powder using a coffee mill and kept under dry conditions until used.

Wastewater samples were collected from the surface water of El-Mex Bay during May 2014 (spring) in front of El-Umum Drain. Estimation of dissolved oxygen (DO), salinity, pH, oxidizable organic matter (OOM), chlorophyll-a (Chl-a) were carried out. Nutrient salts were also estimated: ammonium, nitrate and nitrite, dissolved inorganic phosphorus, and reactive silicate. Dissolved iron-chelating resin (chelex-100) and particulate iron were measured. In the field, the temperature (°C) and transparency (m) of the seawater were recorded.

Algae samples were analyzed by Infrared Perkin-Elmer model 1430, Ratio 1430 recording FTIR System Spectrophotometer (USA). Nano-biomass was obtained using PM 100 (Planetary Ball Mill) with ten small balls each of 14 gm for 23 h at (33.3 g-forces). N5 Submicron Particle Size Analyzer (Schimatzu, supplied from Japan) was used to estimate the size of algal nano-biomass. To obtain an accurate image of the surface structure of algal material, scanning electron microscope (SEM), model JSM- 6360LA, JEOL Ltd was used.

To measure the effect of contact times on the adsorption of iron, six Erlenmeyer flasks of 250 ml by adding 100 ml filtered wastewater samples with constant weight (1 g) of dry algal biomass at room temperature (29 ± 2 °C). These mixtures were constantly shaken (0.49 g-force) at different time intervals 1, 3, 5, 7, and 24 h then they were filtrated through filter paper. The filtrates were centrifuged (655.2 g-forces)

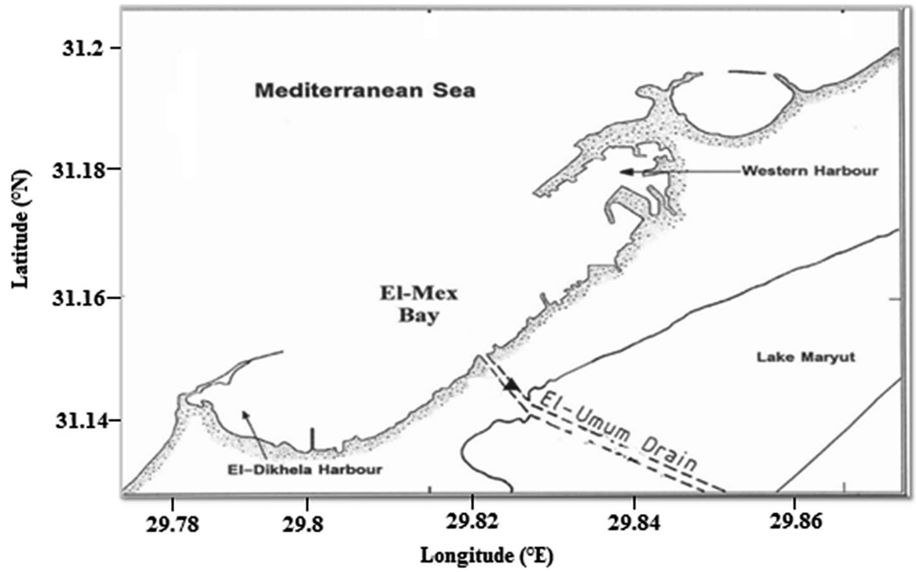


Fig. 1 Study area of El-Mex Bay

for 10 min to obtain extremely clear solutions and finally, further filtration to eliminate any fine remained precipitated particles. These filtrates were analyzed for residual iron concentration via atomic absorption spectroscopy (AAS).

The adsorption efficiency of *Ulva linza, Sargassum hornschuchii,* and *Corallina officinalis* for iron as a function of different weights of algal biomass (0.25, 0.5, 1.0, and 1.5 g) were investigated. Each biomass was mixed with 100 ml filtered wastewater solution in a series of four Erlenmeyer flasks with a similar design as the previous experiment. Finally, these filtrates were analyzed for residual iron concentration. To study the effect of concentrations of wastewater on biosorption of iron, different concentrations of wastewater (25%, 50%, 75%, and 100%) in a series of four Erlenmeyer flasks with the same methodology and the residual iron concentration was analyzed.

The effect of pH on the efficiency of *Ulva linza, Sargassum hornschuchii,* and *Corallina officinalis* dry biomass for iron uptake was performed by varying pH values (3.2, 4.1, 6.1, and 9.4). The experiment was carried out by preparing 100 ml filtered wastewater (100%) with constant algal weight (0.5 g) in a series of four Erlenmeyer flasks of different pH values with a similar design as the previous experiments and the residual iron concentration was analyzed.

Nano-biomass studies

To study the effect of dry algal nano-biomass dosage on biosorption of iron, a similar design of the previous experiment was carried out using different dry nano-biomass weights (0.1, 0.3, and 0.5 g). These weights were mixed with 50 ml filtrated wastewater solutions in three Erlenmeyer flasks at the same conditions and methodology and the residual iron concentration was analyzed. For the effect of wastewater concentrations on biosorption of iron by algal nano-biomass, 50 ml of different concentrations (25, 50, 75, and 100%) and constant weight (0.1 g) of algal nanoparticles were used at the same conditions, methodology, and the residual iron concentration was analyzed. Also for the effect of pH on biosorption of iron by algal nano-biomass, a similar design of the experiment using different pH values (3.2, 4.1, 6.1, and 9.4) was constructed in a series of 50 ml filtered wastewater (100%) with constant weight (0.1 g) at the same conditions, methodology, and the residual iron concentration was analyzed.

Note: All experiments were repeated three times with five replicates each.

Results and discussion

Analysis of El-Mex Bay wastewater to study its physico-chemical properties of the area under investigation (Table 1). The recorded temperature was 19.60 °C which depends on the weathering condition. The pH value was slightly alkaline (7.75) which may be due to the increase in photosynthetic activity. Transparency recorded 0.43 m, due to the influence of domestic, agriculture effluents, and suspended matter. Salinity recorded 10.30 ‰, which is considered a low value compared to seawater due to the amount of brackish water discharged from El-Umum drain. Oxidizable organic matter was 8.7 mgO_2l^{-1} that was affected by contamination with organic wastes. Dissolved oxygen recorded 1.2 mgO_2l^{-1} and was greatly affected by the amount of biological oxygen demand. Chlorophyll-a content was 2.20 μgl^{-1} that indicates the growth of phytoplankton. Also, the nutrient salts were measured and the estimated concentrations were as follow: ammonia (NH_4–N): 197.55 µM, nitrate (NO_3–N):

Table 1 Physicochemical parameters of surface water of El-Mex Bay

Temperature (°C)	pH	Transparency (m)	Salinity (‰)	Oxidizable organic matter (mgO_2l^{-1})	Dissolved oxygen (mgO_2l^{-1})	Chlorophyll-a (μgl^{-1})
19.60	7.75	0.43	10.30	8.7	1.2	2.20

Table 2 Water quality standard limits of iron concentration (µg/l) in surface water

LAW 48/1982	FAO 1985	CWQGS 1987	LAW 4/1994	USEPA 2000	Present data
< 1000	2000	1500	1500	1000	7000

LAW 48/1982 (Egypt): for protection of the River Nile and waterways from pollution, *FAO* Food and Agriculture Organization Guidelines, *CWQGS* Canadian Water Quality Guidelines for the protection of aquatic life, LAW 4/1994 (Egypt): Law promulgating the environment law for criteria and specification of certain substances when discharged into the marine environment, *USEPA* United States Environmental Protection Agency

11.91 µM, nitrite (NO_2–N): 11.52 µM, reactive orthophosphate (PO_4–P): 18.41 µM, reactive silicate (SiO_4–Si): 197.55 µM. The total concentration of dissolved-Fe and particulate-Fe was 7 mg/l, which is considered very high according to many standards (Table 2).

Fourier transform infrared spectroscopy (FTIR)

It is widely used to determine and identify spectral characteristics of various algal species found in the transmission region between 500 and 4000 cm^{-1}. It has been widely used to supply information of vibrational active functional groups of algae, which are responsible for adsorption of iron on its surface that involve residual water (–OH), lipid (–CH2–CH3), cellulose (–C=O), protein amide (=C–N–H), nucleic acid (> P=O), and starch (–C–O–C) in different biological samples (Dean et al. 2008a) (Fig. 2).

IR spectra of algae under investigation showed broadband within the range 3100–3600 cm^{-1} assigned for O–H stretching vibration of H_2O and N–H stretching vibration of protein amide. A weak band within the range of 2800–2950 cm^{-1} is characteristic for asymmetric and symmetric CH_2 stretching vibration of lipid and carbohydrate molecules. The samples give a weak stretching C=O band within the range 1500–1700 cm^{-1} characterized for the protein amide band (Benning et al. 2004). Meanwhile, at range 1350–1500 cm^{-1} a rough weak band was assigned for asymmetric bending CH_2 and CH_3 of the methyl group of protein and asymmetric bending CH_2 of the methyl of lipid except for *Corallina officinalis*, a sharp band at this range. The samples give weak stretching vibration bands within the range of1072-1092 cm^{-1}, ν(C–O–C) is characteristic for the absorption of carbohydrate of polysaccharide nucleic acid and stretching vibration ν(> P=O) of phosphodiester compounds. The bands within the range of 600–1072 cm^{-1} represent stretching vibration ν(C–O–C) for the absorption of polysaccharides of carbohydrates (Dean et al. 2007).

Effect of contact time on biosorption of iron

Adsorption of iron by the studied algal species dry biomass with different time intervals is given in Fig. 3. The results indicated that the sorption of metal ions increased with the increase of contact time to 24 h which attributed

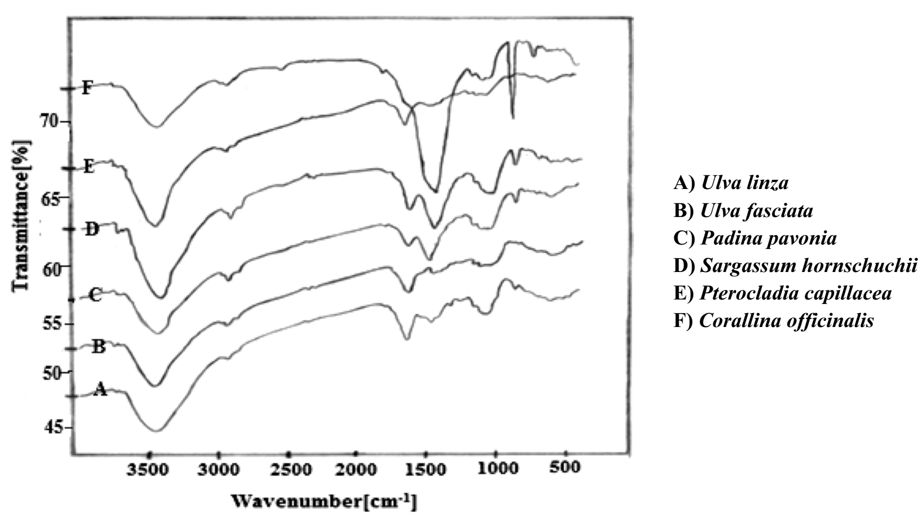


Fig. 2 Infrared of algal samples

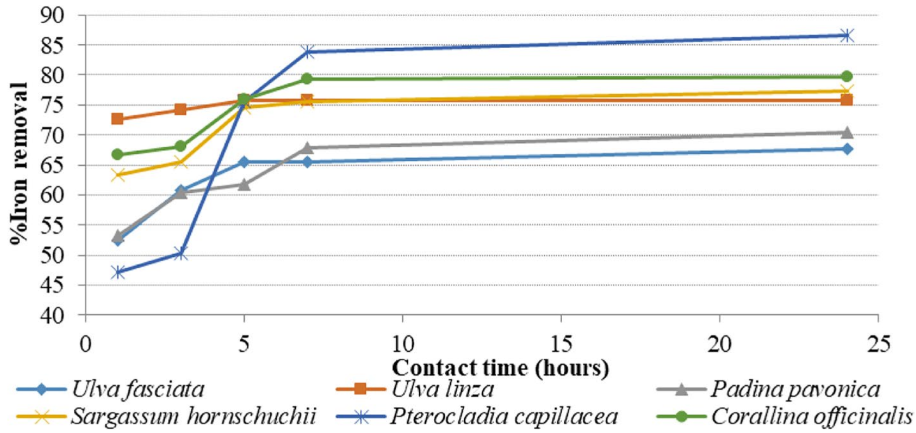


Fig. 3 Percentage iron removal by *Ulva linza, Ulva fasciata* (Chlorophyceae)*, Padina pavonia, Sargassum hornschuchii* (Phaeophyceae)*, Pterocladia capillacea,* and *Corallina officinalis* (Rhodophyceae) dry biomass at different time intervals (1, 3, 5, 7, and 24) hours

to the availability of binding sites for interaction with increasing time. These results matched with that reported by Devi et al. (2010), where the percentage removal of mercury increased with increasing contact time and the availability of active sites. For most of the tested algae, the biosorption increased significantly up to 5 h, so the contact time of 5 h was set for all the following experiments as the shortest effective time. The algal species *Ulva linza* (Chlorophyceae)*, Sargassum hornschuchii* (Phaeophyceae), and *Corallina officinalis* (Rhodophyceae) were chosen for the next experiments where they showed more significant biosorption for iron than the other species in their corresponding algal class.

Effect of dry biomass dosage on biosorption of iron

Figure 4a shows that the adsorbed concentration of iron by the studied algae increased with increasing the biomass weight loading up to 0.5 g, then this absorbed concentration significantly decreased with increasing algal dry biomass weight more than 0.5 g. This may be due to the equilibrium limitations. At the same time, the number of metal ions being adsorbed to a certain unit surface area of algae was slightly decreased, which attributed to repulsive forces between solute molecules on the algae and bulk phase. In addition to a consequence of partial aggregation of the biomass at a higher concentration that results in lowering the effective surface area for the adsorption (Karthikeyan et al. 2007). Also, it was suggested that the higher biomass concentrations led to the screen effect of the outer dense layer that blocked the binding sites with metal ions leading to lowering metal uptake per unit mass. Therefore, the dry biomass dosage 0.5 g was selected for further adsorption experiments of iron by *Ulva linza, Sargassum hornschuchii*, and *Corallina officinalis* after 5 h.

Effect of concentration of wastewater on biosorption of iron

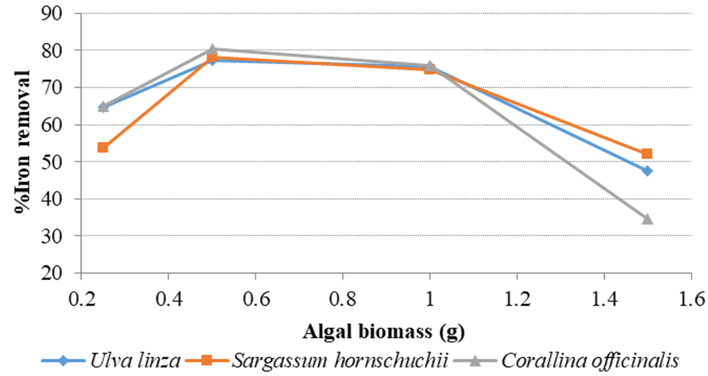
Figure 4b shows that the removal of iron increased with increasing the concentration of wastewater (i.e., increasing iron concentration) for all algal species. This increment was attributed to the increasing number of ions available for competing at higher concentrations to the binding sites of surfaces of algae (Banker et al. 2009). The results were in agreement with the reported data of De Philips and Vincenzini (1998). Therefore, the effective wastewater concentration of 100% was selected for further adsorption experiments of iron by *Ulva linza, Sargassum hornschuchii*, and *Corallina officinalis* using 0.5 g dry biomass and after 5 h.

Effect of pH on biosorption of iron

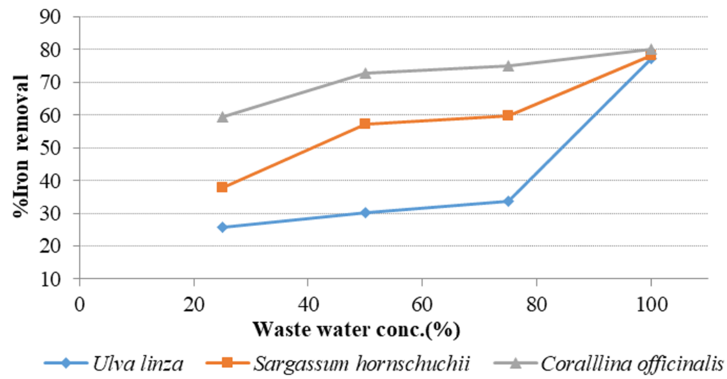
pH is a major factor influencing the adsorption as it affects biosorption surface charge and degree of ionization (Ahmady-Asbchin et al. 2008). The pH of the solution affects both metal binding sites on the cell alginate and the chemistry of metal in solution (Dursan 2006).

Figure 4c shows that sorption for iron at pH value 3.2 was 77.30% for *Ulva linza* that increased with raising the pH value till it reached its maximum uptake (79.60%) at pH 9.4. For *Sargassum hornschuchii* it started with (78.20%) removal at pH 3.2 and increased with raising the pH till 9.4, where it reached its maximum removal (96.33%). For *Corallina officinalis*, the adsorption of iron to its surface started with 80.35% removal at pH 3.2, increased with raising the pH to reach its maximum value (83.41%) at pH 9.4. Earlier studies of surface charge reported that with increasing pH, the surface binding sites of calcium alginate became more negative, so the metal ions uptake increased with raising pH (Crist et al. 1994). These results are in harmony with that reported by Chen

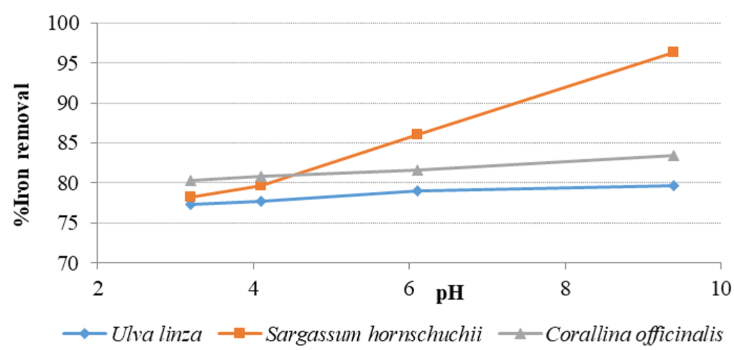
Fig. 4 **a** Effect of different dry biomass dosages (0.25, 0.5, 1.0, and 1.5 g) of *Ulva linza*, *Sargassum hornschuchii*, and *Corallina officinalis* on iron removal after 5 h. **b** Effect of different concentrations of wastewater (25, 50, 75, and 100%) on iron removal by *Ulva linza, Sargassum hornschuchii*, and *Corallina officinalis* dry biomass (0.5 g) after 5 h. **c** Effect of different pH values on iron removal by *Ulva linza*, *Sargassum hornschuchii*, and *Corallina officinalis* dry biomass (0.5 g), after 5 h at 100% wastewater concentration



a Effect of different dry biomass dosages (0.25, 0.5, 1.0, and 1.5g) of *Ulva linza*, *Sargassum hornschuchii,* and *Corallina officinalis* on iron removal after 5 hours



b Effect of different concentrations of wastewater (25, 50, 75, and 100%) on iron removal by *Ulva linza, Sargassum hornschuchii,* and *Corallina officinalis* dry biomass (0.5g) after 5 hours.



c Effect of different pH values on iron removal by *Ulva linza*, *Sargassum hornschuchii,* and *Corallina officinalis* dry biomass (0.5g), after 5 hours at 100% wastewater concentration.

and Johns (1991), where increased pH leads to more negative sites available for copper. It was shown that by increasing pH from an initial value of 3.5 to 6.0, more sites were available for metal ion sorption by *Sargassum fluitans*, so the removal efficiency increased with pH (Schiewer and Volesky 1995).

Nanomaterial studies

After grinding of algae (*Ulva linza*, *Sargassum hornschuchii,* and *Corallina officinalis*) with PM100 (Fig. 5), the size of algal nano-biomass was estimated using N5 Submicron Particle Size Analyzer (Schimatzu, supplied from Japan). From angle 11.1°, the size was about 57.5 nm while from angle

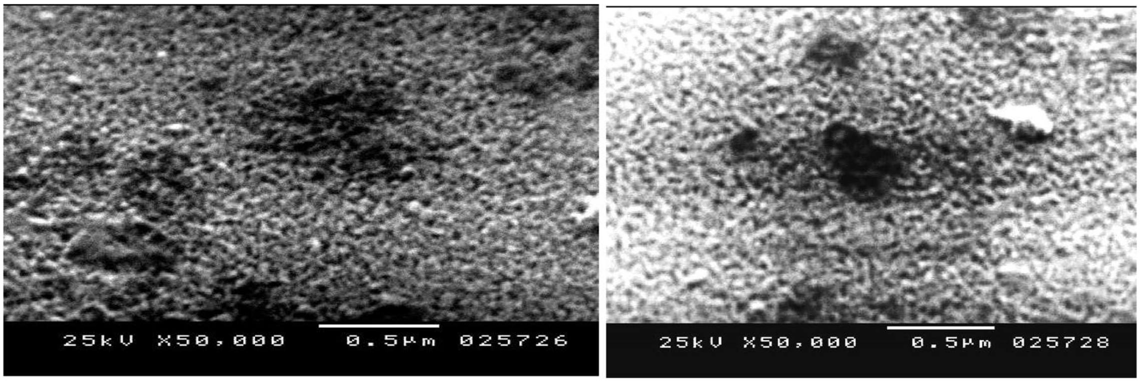


Fig. 5 Scanning electron microscope (SEM) image of nanoparticles of dry algal biomass showing spherical morphology. Left: not aggregated, right: aggregated nanoparticles

90.0° the size was about 295.1 nm due to the aggregation of nanoparticles to each other.

Effect of dry nanoparticles of dry algal biomass dosage on biosorption of iron

Figure 6a shows that residual iron concentration significantly increased with increasing the weight of nanoparticles of dry algal biomass by more than 0.1 g. It was noted that there was a similar trend of biosorption of iron to that of normal grinding algae which attributed to repulsive forces between solute molecules on the algae and bulk phase, in addition to a consequence of partial aggregation of the biomass at a higher concentration that results in lowering the effective surface area for the adsorption. Therefore, the dry algal nano-biomass dosage 0.1 g was selected for further adsorption experiments of iron by *Ulva linza, Sargassum hornschuchii*, and *Corallina officinalis*. Comparing the efficiency of removal, it was recorded values of 82.6, 87.4, and 94.8% for *Ulva linza, Sargassum hornschuchii*, and *Corallina officinalis* using (0.1 g) dry nano-biomass, respectively, these values were 77.3, 78.2, and 80.3% for the same algal species using (0.5 g) normal ground dry biomass. The general feature is a more effective iron removal with a lower weight of nanoparticles of dry algal biomass.

Effect of wastewater concentrations on biosorption of iron by dry algal nano-biomass

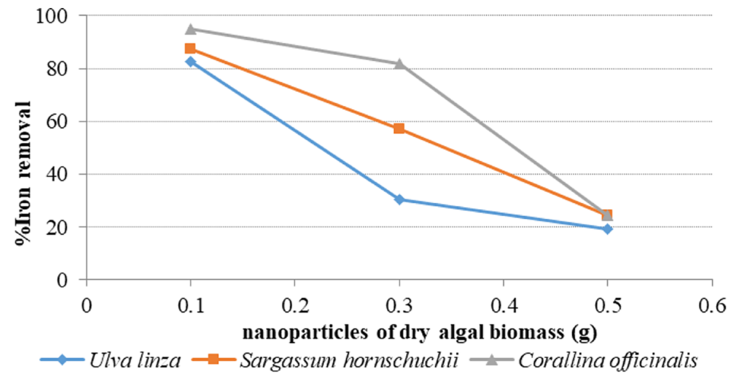
Figure 6b shows that the removal of iron increased with increasing the concentration of wastewater (i.e., increasing iron concentration) for all algal nano-biomass. This was due to the large number of ions available for competing at the higher concentrations at the binding sites of surfaces of nano-biomass. Also, there was a similar trend of biosorption of iron to that of normal ground algae. Therefore, the effective wastewater concentration is 100% was selected for further adsorption experiments of iron by *Ulva linza, Sargassum hornschuchii,* and *Corallina officinalis*.

Effect of pH on biosorption of iron by algal nano-biomass

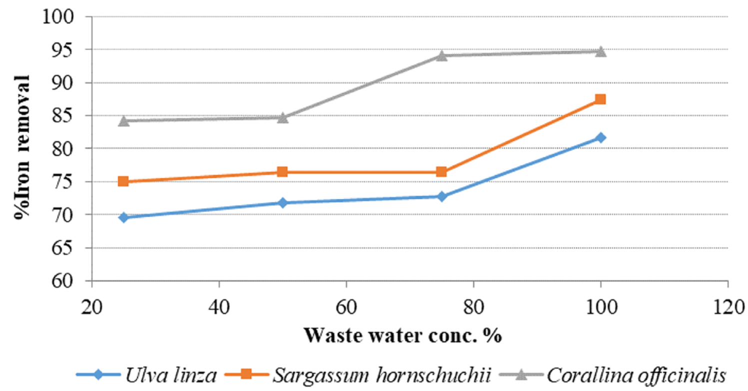
There was a similar trend of biosorption of iron by algal nanoparticles to that of normal grinding algae. Figure 6c shows that sorption for iron at pH value 3.2 was 94.7% for *Ulva linza* nano-biomass then increased with increasing pH value till it reached its maximum uptake (95.6%) at pH 9.4. For *Sargassum hornschuchii*, it started with 87.4% removal for iron at pH 3.2 that increased with raising pH to reach its maximum (98.8%) at pH 9.4. For *Corallina officinalis* nano-biomass, the adsorption of iron started with 94.7% at pH 3.2 that increased with raising pH to reach its maximum value (97.6%) at pH 9.4. This increase of iron adsorption by *Ulva linza*, *Sargassum hornschuchii,* and *Corallina officinalis* was attributed to the increased binding sites at the algae surface. Comparing the maximum removal efficiency, it was recorded values of 95.6, 98.8, and 97.6% for *Ulva linza, Sargassum hornschuchii,* and *Corallina officinalis* respectively, using 0.1 g nano-biomass at pH 9.4, these values were 79.60, 96.33, and 83.41%, for the same algal species using 0.5 g ground powder biomass at the same pH, so the general feature of algal nano-biomass in all experiments is that more effective iron removal with lower algal biomass. Finally, Fig. (7) illustrates a proposed model filter using algal species for iron heavy metal removal.

A) Acidic portion $[H^+]$ from HNO_3 acid is implied to wastewater to prevent the hydrolysis of iron to keep all of its species in dissolved form, B) then wastewater is filtrated using a vacuum pump to remove any suspended species, C) this filtrated wastewater enters the deoxygenated container to prevent oxidation and precipitation of iron to keep it in a soluble state by adding Ageless (vitamin C type), which is

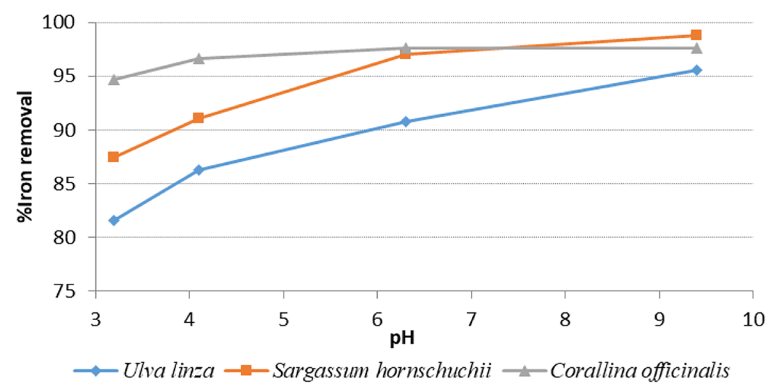
Fig. 6 **a** Percentage iron removal using different dry algal nano-biomass dosage of *Ulva linza*, *Sargassum hornschuchii,* and *Corallina officinalis* after 5 h. **b** Effect of different concentrations of wastewater on iron removal by *Ulva linza, Sargassum hornschuchii,* and *Corallina officinalis* dry nano-biomass (0.1 g) after 5 h. **c** Impact of pH on percentage iron removal by *Ulva linza*, *Sargassum hornschuchii,* and *Corallina officinalis* dry algal nano-biomass (0.1 g) with (100%) wastewater concentration after 5 h



a Percentage iron removal using different dry algal nano-biomass dosage of *Ulva linza*, *Sargassum hornschuchii,* and *Corallina officinalis* after 5 hours.



b Effect of different concentrations of wastewater on iron removal by *Ulva linza, Sargassum hornschuchii,* and *Corallina officinalis* dry nano-biomass (0.1g) after 5 hours.



c Impact of pH on percentage iron removal by *Ulva linza*, *Sargassum hornschuchii,* and *Corallina officinalis* dry algal nano-biomass (0.1g) with (100%) wastewater concentration after 5 hours.

oxygen absorber, D) then the water entered another deoxygenated container and the basic portion [OH^-] is implied for efficient nano-algal removal of iron by adsorbing it before any hydrolysis, F) finally the treated water return to seawater.

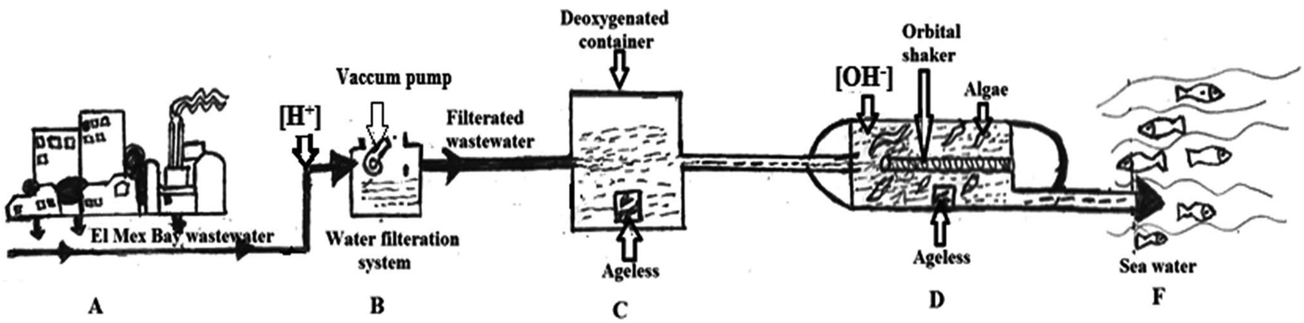


Fig. 7 A proposed model filter using algal species for iron heavy metal removal

Conclusion

Different physicochemical parameters at the study area like pH, temperature, transparency, salinity, OOM, DO, and Ch-a and the effective nutrients as nitrate, ammonia, nitrite, silicate, phosphate, dissolved, and particulate iron were recorded. The results of dissolved and particulate iron were compared with standard limits of world organizations, to know the pollution's status of the studied area (El-Mex Bay). The total concentration of dissolved-Fe and particulate-Fe was 7 mg/l, which is considered very high when compared to many standards. Accordingly, this study focused on the availability of removing iron from this polluted wastewater.

Compared to ordinary ground algal biomass, nanoparticles of dry algal biomass (ground by ball mill) are considered an efficient economic adsorbent for iron removal that occurs at high concentration levels, either dissolved or particulate, at El-Umum drain wastewater of El-Mex Bay. The parameters that have great influences on the adsorption process were shown to be pH, the concentration of wastewater, algal biomass, and contact time. The studied algal species contain different functional groups that are responsible for iron adsorption, as obtained from the results of FTIR.

Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by SMA and MSA-K. The first draft of the manuscript was written by MSA-K, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

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