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ORIGINAL ARTICLE

Algae Efficacy as a Potent Tool for Heavy Metals Removal: An Overview

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Water pollution with heavy metals sharply increased worldwide and became a serious problem a cause to expansion industrial activities worldwide. Pollutants caused deleterious effect on living organisms in ecosystems. Thereby, various physico-chemical and biological methods were employed for overcoming this problem. Algae (micro and macrophyla) among biological systems displayed multiuse applications in food and industry. Of which they exhibited a significant and important role as a useful tool in heavy metals removal capacity. Algae as renewable resources, their abundance worldwide and ability to concentrate heavy metals in their tissues, encouraged scientists to focusing on their implementation in heavy metal pollutants reduction from environmental ecosystems. Their efficacy and advantageous over physico-chemical methods make them as alternative, eco-sustainableand potent way for heavy metals removal.

Key words: Algae, Biosystem, Biosorption, Heavy metals, Pollutants, Removal capacity

From very long time up till now, environmental pollution by heavy metals was considered as a global public health concern and has been dramatically increased due to their exponentially increased used for various purposes like *e.g*. industrial, agricultural, domestic and technological applications (Bradl, 2002; Nazal, 2019).

Wastewater (municipal and industrial) is any water type negatively affected in quality due anthropogenic influence. Wherein, nickel, lead, chromium, cadmium, zinc and iron were the most toxicant elements against all living organisms' life (Jamers *et al*., 2013; Saleh, 2017a).

Effluents of factories can be used for irrigation purpose worldwide. However, these effluents have different harmful materials needed treatment before using for irrigation or other purposes. Green technology based upon algae biomass seems to be a good and alternative way for bioremediation. This tool has been investigated too earlier over the past 40 years by Ryther *et al*. (1972).

According to Kumari *et al*. (2006)"Bioremediation is a pollution control technology that uses biological systems to catalyze the degradation or transformation of various toxic chemicals to less harmful forms. It was considered as a cheaper and potent method and highly uses increasing for environmental pollution reduction. It has been documented that sewage disposal formed an ecological problem threatening urban and semi-urban countries. Moreover, the effluents from residential and industrial discharge is considered as a principal source of water pollution; where they discharged into open drains that finally joins the rivers (Kumari *et al*, 2006).

Heavy metal pollutants like lead, cadmium, mercury, arsenic, iron, nickel, copper, aluminium and zinc are considered as a major poisoning and toxicant environmental pollutants (Dias , 2002).Toxicant pollutants danger comes from their easily absorption and fast accumulation in low organisms and then transported to human through food chain (World, 1992; Pinto *et al*., 2004). Thereby, wastewater treatment to resolve this crisis is requested.

Different physico-chemical methods including filtration, adsorption, chemical precipitation, ion-exchange, phytoremediation etc. are integrated for removing heavy metals toxicity from wastewaters (Mehta and Gaur, 2001). The limitations occurred with physico-chemical methods such for example, their efficacy is limited for selective metals and not for all and very expensive tool (Fawzyaand Issa, 2016; Djati Utomo *et al*., 2016). Thereby, living organisms *e.g*.plant (Gupta and Sarine, 2009);bacteria (Iyer *et al*., 2005; Javanbakht *et al*., 2014), yeast (Goksungur *et al*., 2005), fungi (Anayuri *et al*., 2009; Javanbakht *et al*., 2014) and algae (Mallick and Rai, 1992; Lawton *et al*., 2013; Javanbakht *et al*., 2014; Jerold *et al*., 2016; Fawzya and Issa,2016; Ghazal *et al.,*2018; Bilal *et al*., 2018)are as alternative way to solve this problem with low cost. Among these biological systems, microalgae highly absorb nutrients because they require metals as micronutrients for their biological process and huge amounts of nitrogen and phosphorus for proteins synthetize (45-60% microalgae dry weight).

It has been demonstrated that algae (both live and dried biomass) can consider as a good biosorbents for heavy metals elimination and reduction form ecosystems. Over past year, population expansion and industrial activity caused freshwater quality deterioration through the world leading finally to freshwater shortages around some areas. In this regards, U.S. geological survey revealed that global water demand will exceed supply by 56% in 2025 (http://www.theworldwater.org/water_facts.php.).

This review will focus on application of algae (micro and macro) species used as a biological system for heavy metals removal. As known, algae taxonomy includes many criteria like colors (pigments), cell wall composition, flagella number and position, structure cellular, growth patterns, branching and sporangia types. Based upon the mentioned criteria, they divided into green algae (Chlorophyta), brown algae (Phaeophyta), red algae (Rhodophyta) (Wajahatullah*et al*., 2009; Bilal *et al*., 2017) and blue-green algae (Cyanophyta).

It has been demonstrated that since 1990 up till now, more than of 5000 publications regarding heavy metals bioadsorption, and that approximately 6% of these reports have been focused on marine algae application (Nazal, 2019).

Reviewing of the literature published

Algae exhibited a critical role as a potent biosorbent of heavy metals and showed different removal capacity according to algae species, their density and form (live or dried biomass), heavy metal concentration and formula, pH of solution, their application in single or combined of more than one species and others (Bilal *et al*., 2018).

It has been documented that the request of wet seaweed for different purposes was approximately 8 million in 2003, 19 million tonnes in 2010 and 24 million tonnes in 2014. However, the world production of cultivated algae increased day by day worldwide in recent years and that this impressively augments particularly in Indonesia (FAO, 2014; McHugh, 2003).

Among biological systems, microorganisms implementation (particularly bacteria, fungi, yeasts and algae biomass) has received huge interest for heavy metal sorption due to their characteristic *e.g.* high surface to volume ratio; large availability, rapid kinetics of adsorption and desorption and low cost (Abbas*et al*., 2014).

Microalgae are highly biodiversity approximately between 200.000- several millions, of which less than 10,000 were described (Sharma and Rai, 2011). Delrue *et al*. (2016) reported that microalgae displayed high board range as pollutant scavengers (domestic, industrial and agricultural).

Earlier, Oswald and Gotaas (1957) reported utility of microalgae for wastewater in sewage treatment. Among them, *Chlorella vulgaris*, *Neochloris oleoabundans*, *Scenedesmus dimorphous*, *Spirulina*, *Nannochloroposis*, *Dunaliella salina* and *Botrycoccus braunii* species were mainly used for wastewater treating (Chong *et al*., 2000).

Prabha *et al*. (2016) reviewed the utility of some algae used for wastewater treatment *e.g.Chlorella vulgaris* and *Scenedesmus dimorphus* (Ammonia NH_3 and Phosphorous), *Padina* spp. and *Cladophora fascicularis* (Copper Cu), *Spirulina* and *Spirogyra* (Lead Pb), *Chlorella vulgaris* (Copper Cu, Cadmium Cd,Zinc Zn and Lead Pb), *Scenedesmus obliquus* (Cadmium Cd), *Sargassum sinicola* (Cadmium Cd and Copper Cu) and *Dunaliella* (Mercury Hg, Cadmium Cd and Lead Pb).

Bayramoglu *et al*. (2006) reported that *Chlamydomonas reinhardtii* removal capacity was 89.5 mg/g, 66.5 mg/g and 253.6 mg/g for Hg, Cd and Pb heavy metals, respectively. Whereas, Kumar *et al*. (2015) reported the importance of *Chlorella marina* (Butcher) for removing of Chromium (Cr) and Lead (Pb) from waste waters.

Cheng *et al*. (2017) reported that *Chlorella vulgaris* removal capacity for Cd was recorded to be 95.2% and 96.8% with dead and live algae, respectively.

Wang *et al*. (2010) reported that *Chlorella vulgaris* microalgae capacity for removing phosphorus by more than 99%. Similarly, Salgueiro *et al*. (2016) reported efficacy of *Chlorella vulgaris* microalgae for removing phosphorus by more than 99% and the chemical oxygen demand (COD) by 71% from wastewater.

Kshirsagar (2013) reported the capacity of two microalgae *Chlorella vulgaris* for removal of nitrate and chemical oxygen demand (COD); whereas, *Scenedesmus quadricauda* showed best removal capacity for biochemical oxygen demand (BOD) and phosphate. In this respect, BOD reduction level was recorded to be 70.91 % and 89.21 % using *C. vulgaris* and *S. quadricauda,* respectively. Whereas, COD removal level was recorded to be 80.64% and 70.97% using *C.vulgaris* and *S. quadricauda*, respectively after over 15 days.

Great attention has been given to implementation of microalgae in bioremediation of colored wastewater due to their capital role in carbon dioxide fixation. In this regards, Singh *et al*. (2010) reported that the removal of color from textile dyes effluent mechanism could be realized either by biosorption or bioconversion. For example, the removal level of the color from the mono-azo dyes by conversion it into aniline ranged between 63 - 69% by *Chlorella vulgaris*.

Recently, Ghazal *et al.* (2018)reported removal capacity of five microalge (*Anabaena flos aquae, Nostoc elepsosporum, Nostoc linkia, Anabaena variabilis* and *Chlorella vulgaris*) for BOD and COD, after 4 weeks incubation. They reported that the removal BOD capacity was recorded to be 73.96, 98.92, 85.63, 82.00 and 92.24%; whereas, for COD it was recorded to be 60.00, 98.00, 75.00, 80.00 and 97.63% by *A. flos aquae, N. elepsosporum, N. linkia, A. variabilis* and *C. vulgaris,* respectively. Moreover, they reported that their capacity to remove some heavy metals. In this regards, the reduction level for Cr was 60.36, 99.19, 67.31, 97.57 and 90.94%; whereas, for Pb it was 73.00, 98.80, 89.40, 94.00 and 96.40; while it was 46.67, 95.00, 69.33, 66.00 and 88.33% by *A. flos aquae, N. elepsosporum, N. linkia, A. variabilis* and *C. vulgaris,* respectively.

Previously, Hammouda *et al*. (1995) reported that a mix of *Chlorella* sp. and *Scenedesmus* sp. together could remove 90% of the COD of an urban wastewater (from 180 to less than 20 mgO2/L.

Vijayakumar and Manoharan (2012) reported increase in dissolved oxyge (DO) content and reduction BOD and COD up to 95% was observed using both *Oscillatoria brevis* and *Westiellopsis prolifica* in dye industry effluent.

Balaji *et al*., (2014) reported the potent role of several *Spirulina* strains (*S. indica*, *S. maxima* and *S. platensis*) for Zn and Ni biosorption.

Lima*et al*. (2004) reported removal p-chlorophenol level (10 mg/L/day) by *Chlorella vulgaris* and *Coenochloris pyrenoidosa.* Whereas, Papazi and Kotzabasis(2013) reported the capacity of *Scenedesmus obliquus*for removing 3,4-dichlorophenol (6 µmol/day); 2,3-dichlorophenoland 2,5-dichlorophenol(9 µmol/day); 2,4-dichlorophenol (10 µmol/day) and 2,6-dichlorophenol (13 µmol/day).

Peng*et al*. (2014) reported the capacity of *Scenedesmus obliquus* for removing progesterone and norgestrel (0.3 µmol/day); *Chlorella pyrenoidosa* for removing norgestrel (0.2 µmol/day) and progesterone (0.3 µmol/day). Wang *et al*. (2013) reported

Chlorella pyrenoidosa importance for removing triclosan by 104 mg/L/h. Whereas, De Godos*et al*. (2012) reported *Chlorella vulgaris* importance for tetracycline removing. While, Sethunathan *et al*. (2004) reported capacity of *Chlorococcum* sp. and *Scenedesmus* sp. for removing α-endosulfan by 0.135 mg/L/day and 0.140 mg/L/day, respectively. Kumar *et al*. (2015) reviewed of 63 bioremediation cases out of 265 microalgae-heavy metal couples (other cases are adsorption experiments on dead cells with or without pretreatment) from 0.02 to 1378 mg/g. Ke *et al*. (2010) reported the importance of *Selenastrum capricornutum* for removing PAHs + heavy metals and they reported heavy metals positive effect on PAHs reduction.

Salgueiro *et al*. (2016) reported that the levels of phosphorous and COD decreased rapidly due to the fast assimilation by *Chlorella Vulgaris* microalgae in nine days of culture in wastewater. Some studies have demonstrated that this microalga can grow faster in presence of organic acids or glucose that function directly as essential organic nutrients (Wang *et al*., 2010).This indicates that microalgae could assimilate some organic compounds, resulting in a rapid drop of chemical oxygen demand concentration during the first days of the culture.

Tüzün *et al*. (2005) reported that *Chlamydomonas reinhardtii* capacity to remove Hg^{2+}, Cd^{2+} and Pb^{2+} was approximately 98%. Whereas, Felisco and Billacura (2018) reported microalgae *Nannochloropsis oculata* capacity for Pb removal from industrial wastewater.

Blue-green algae (Cyanophyta) were also considered as potent tools for heavy metals removal. In this regards, El-Enany and Issa (2000) reported that *Nostoc linckia* could be consider as tolerant to heavy metals (Zn and Cd) and is able to accumulatethese metals.

Whereas, Rai and Tripathi (2007) reported blue – green alga *Microcystis* removal capacity for chromium (VI), cadmium (II) and copper (II) in single or in combination. They reported the importance of *Microcystis* as eco-sustainable approach to remove the mentioned metals. Moreover, Gelagutashvili (2013) reported cadmium (Cd), chromium (Cr), silver (Ag) and gold (Au) removal by cyanobacteria *Spirulina platensis*, *Streptomyces* spp. and *Arthrobacter* species living and non-living cells, from aqueous solution. The previous study reported thatcyanobacteria capacity to remove the mentioned metals depend on cyanobacteria type and uptake conditions. Whereas, Goswami*et al.* (2015) reported that *Nostoc muscorum* removal capacity was 66% for Zn and 71% for Cu. Indeed, Shilpi *et al.* (2015) reviewed cyanobacteria potent for heavy metals removal. Indeed, Fawzya and Issa(2016) reported that

Cyanosarcina Fontana showed high heavy metals accumulation of Fe^{2+}(93.95%), Pb^{2+} (81.21%), Cu^{2+} (63.9%), and Mn^{2+} (48.49%)from sewage plant compared to *Anabaena oryzae.*

Overall, microalgae frequently used for chemical pollutants removal are summarized in Table 1.

As for macroalgae, they were accounted to be approximately 9000 macroalgae species around the oceans worldwide (Wajahatullah *et al*., 2009; Saleh and Al-Mariri, 2017).It has been demonstrated that macroalgae showed different affinities towards the same metal depend upon the macroalgae chemical structure (Volesky 2003).

It has been reported that *Spirogyra* sp. capacity to remove Cr was 14.7 mg/g d.m (Gupta *et al*., 2001); *Spirogyra* sp. capacity to remove Pb was 140 mg/g d.m (Gupta and Rostogi 2008a) and *Spirogyra* sp. to remove Cu was 133.3 mg/g d.m (Gupta *et al*., 2006).

Feng *et al.* (2004) reported that *Ecklonia maxima* metal sorption capacity was 85-94, 227-243 and 83.5 mg/g d.m for Cu, Pb and Cd, respectively. Indeed, Gupta and Rostogi (2008b) reported that *Oedogonium* sp. capacity removal of Pb was recoded to be 145 mg/g d.m.

*Ulva lactuca*among chlorophyta was used as a potential tool for bioremediation of reject water(Robertson-Andersson *et al*., 2008; Nielsen *et al*., 2012; Sode*et al*., 2013), and other *Ulva* spp.(Lawton *et al*., 2013).Asnaoui *et al*. (2014) reported *U. lactuca* capacity for removing chromium (Cr) form solution. The previous study showed that living organism capacity to remove Cr was 84 %and to be 96%for crushed algae.

Whereas, Ben Chekroun and Baghour (2008) reviewed the most algae species used for heavy metalsbioremediation*e.g.Ascophyllum nodosum* (Gold Au; Cobalt Co; Nickel Ni and Lead Pb), *Caulerpa racemosa* Boron (Br), *Fucus vesiculosus* (Zinc Zn and Nickel Ni), *Sargassum fluitans* (Copper Cu; Iron Fe; Zinc Zn and Nickel Ni), *Sargassum natans* and *Sargassum vulgare* Lead (Pb), *Spirogyra hyalina* Cadmium (Cd), Mercury (Hg), Lead (Pb), Arsenic (As) and Cobalt (Co).Moreover, Christobe and Lipton (2015) reported that the maximum arsenic removal capacity was 90.2% at biomass weight of 2g/100 ml for *Sargassum wightii* (brown alga) and *Gracilaria corticata* (red alga).

Toxic metal removal from wastewater by *Laminaria hyperborea*brown marine macroalgae according to matrix type and operating conditions has been reported by many reports; e.g (Zn^{2+}=2.4-4.3 mg/L, Ni^{2+}=2.2-4.2 mg/L and Cu^{2+}=2.1-2.5 mg/L) (Cechinel *et al*. 2016); (Zn^{2+}=18.1-21.5 mg/L) (Mazur *et al*. 2016). Whereas, Castro *et al*., (2017) reported *Fucus vesiculosus* brown marine macroalgae capacity for removing some metals (Zn^{2+}=546.0 mg/L, total Cr=10.8 mg/L and total Fe=22.9 mg/L).

Sarı and Tuzen (2008b) reported that red alga *Ceramium virgatum* removal capacity for Cd was recorded to be 39.7 mg/g.

Recently, Mazur *et al*. (2018) reviewed brown marine macroalgae as a potential tool for heavy metals removing from industrial wastewaters. Indeed, they discussed advantages and disadvantages of the different methods (chemical precipitation, coagulation/flocculation, membrane filtration, electrochemical processes, ion exchange, adsorption and biosorption) employed for removing heavy metals from wastewaters.

Djati Utomo*et al*. (2016) reported comparative study between marine algae (MA) and freshwater algae (FA) biomass for Cu, Pb, Cd and Zn heavy metals absorption. They reported that MA showed higher absorption capacity of the mentioned metals compared to FA once. In this regards, absorption capacity was 22%, 67%, 98%, 39% of Cd, Cu, Pb and Zn respectively, for MA. Whereas, it was 18%, 29%, 94%, 37% of Cd, Cu, Pb and Zn respectively for FA.

Ibrahim and Mutawie (2012) reported removal capacity of red algae *Laurancia obtusa*, *Geldiella acerosa & Hypnea* sp. for Cu, Zn, Mn & Ni. They reported that this capacity was 94%, 85% and 71% for *L. obtusa*, *G. acerosa* and *Hypnea* sp., respectively.

More recently, Nazal (2019) reviewed some macromarine algae (red, green, and brown) applied for heavy metals removal from aqueous solution.

It has been demonstrated that brown algae out macroalgae occupied an attractive position for heavy metals removal by showing the highest metal binding capacity (Ofer et al., 2003; Herrero *et al*., 2006).

Overall, macroalgae frequently used for chemical pollutants removal are summarized in Table 2.

As for aquatic plants, they exhibited a significant role in heavy metals biosorption. In this regards, *Hydrilla verticillata* and *Ceratophyllum demersum* aquatic plants were used to remove Cd, Hg and Cu heavy metals from aqueous solution (Gupta and Sarine 2009).

Algal heavy metals biosorption mechanisms

Algae species developed various mechanisms defense against heavy metals. Anyway, it has been demonstrated that the mechanisms involved in pollutants biosorption are not clearly evident.

For microalge, different mechanisms of pollutants biosorption process by algae have been reported. In this respect, Ahluwalia and Goyal (2003) proposed that pollutants biosorption process consists of two steps. Firstly, metals ions bind and secondly, they accumulate on the binding sites.

Javanbakht *et al*. (2014) proposed that biosorption process of heavy metals by microorganisms includes the following mechanisms: transport across cell membrane, complexation, ion exchange, precipitation, and physical adsorption. Whereas, Rajfur (2013) reviewed sorption properties of marine and freshwater algae and the physicochemical factors impact on algal sorption properties. The previous review showed that temperature, pH, intensity of the photosynthetically active light and the presence of other ions and anions were the major abiotic factors affect metals sorption process.

As for cyanobacteria, El-Enany and Issa (2000) reported that *Nostoc linckia* cyanobacteria showed high tolerance to heavy metals (Zn and Cd) through adsorption them on the cell surface and/or due to sequestration them via metal-binding protein. Whereas, Shilpi *et al.* (2015) reviewed cyanobacteria potent for heavy metals removal in correlation to antioxidant enzymatic systems [superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX) and Glutathione reductase (GR)]. Similarly, different studies demonstrated their capacity to remove heavy metals related to the above antioxidant systems; e.g. Sultan *et al*. (2007) applied *Anaebaena doliolum* to remove Cd and Cu. Whereas, Singh *et al*. (2012) applied *Anabaena* spto remove Cd. While, Zutshi *et al*. (2014) applied *Hapalosiphon fontinalis* to remove As. Moreover, Balaji *et al*., (2014) reported that Zn and Ni removal capacity by several *Spirulina* strains (*S. indica*, *S. maxima* and *S. platensis*) could be related to their content of different functional group (carboxyl, hydroxyl, sulfate and others) binding site with metals.

Moreover, macroalgae (seaweeds) among algae species were considered as a potent and good pollutants biosorbent due to their large surface area, highly poly-functional groups content on the metal-binding site (for both cationic and anionic complexes).

It has been demonstrated that metals accumulation and uptake capacity by algae biomass mainly depends on the polysaccharide (*e.g*. alginates and fucoidans) contents availability on the cell surface (Herrero *et al*., 2006). They reported that marine brown alga among different algae species, displayed an important role in pollutant biosorption due to their richness on polysaccharide.

Among these groups, carboxyl, amine, imidazole, phosphate, sulfate, sulydryl, and hydroxyl groups, as well as proteins and sugar molecules were mainly involved in biosorption process. In this respect, ligands of seaweeds were considered as an ionic interaction with metals in the aqeous solutions, forming a critical and major mechanism for binding (Yun *et al*., 2001).Tamilselvan *et al*. (2011) reported that carboxyl (–COOH), hydroxyl (–CHOH) and amine (–NH2) groups were the main functional groups involved in Cr, Pb, Cd and Hgbiosorption by*Acanthophora spicifera* algae using FT-IR. Whereas, Dekhil *et al*. (2011) reported that O–H bending, N–H stretching, C–N stretching, C–O and S=O stretching as functional groups detected in Pb(II) and Cd(II) ions sorption in the *Caulerpa racemosa* green alga using FT-IR.

Saleh (2015) reported biosorption of 4 heavy metals (Cu, Pb, Zn and Cd ions) from aqueous solution using green algae *Ulva lactuca* (Chlorophyta). The previous study revealed that the C-H, C=O, CH_2 and C-O-C groups were mainly involved in heavy metals absorption based on fourier transform raman spectroscopy (FTRaman) technique. Moreover, Saleh (2017a) reported biosorption of the same above mentioned pollutants by *U. lactuca* based on fourier transform infrared spectroscopy (FTIR) analysis. The previous study revealed that O-H, N–H, –C–O, P-O-C, S-O, C-C, -C-C, –C-OH, C-H and C-I groups were the main functional groups involved in pollutants biosorption processes.

Saleh (2017b) reported functional groups involved in Cd biosorption with *Ulva lactuca* (Chlorophyta) and *Padina pavonica* (Phaeophyta) seaweeds based on fourier transform infrared spectroscopy (FTIR) analysis. The previous study revealed that carboxylic acids (C-O) & amides (C-N stretch) groups and aromatics groups (C–C stretch) were the mainly functional groups involved in Cd biosorption by *U. lactuca* green algae. Whereas, amides groups (C=O stretch), alcohols (O–H stretch) and phenols (H–bonded) were mainly involved in Cd biosorption process by *P.pavonica* brown algae.

Table 1. Microalgae used for chemical pollutants removal.

Green	**Chemical pollutants**	**References**
Chlorella marina	Cr & Pb	Kumar *et al.,* (2015)
Chlorella marina	Ammonia NH_3 and Phosphorous	Prabha *et al.,* (2016)
Chlorella vulgaris	Cu, Cd, Zn & Pb	Prabha *et al.,* (2016)
Chlorella pyrenoidosa&Scenedesmus obliquus	Progesterone & norgestrel	Peng *et al*., (2014)
Chlorella pyrenoidosa	Triclosan	Wang *et al.,* (2013)
Chlorella vulgaris	Tetracycline	De Godos *et al.,* (2012)
Chlorella vulgaris	Phosphorus	Wang *et al.,*(2010)
Chlorella vulgaris	Phosphorus & COD	Salgueiro *et al.,* (2016)
Chlorella vulgaris& Scenedesmus quadricauda	Nitrate, COD & BOD	Kshirsagar (2013)
Chlorella vulgaris	BOD & COD	Ghazal *et al.,* (2018)
Chlorella vulgaris	Cd	Cheng *et al*., (2017)
Mix of *Chlorella* sp. &*Scenedesmus* sp.	COD	Hammouda *et al.,*(1995)
Chlorella vulgaris and *Coenochloris pyrenoidosa*	p-chlorophenol	Lima *et al.,* (2004)
Spirulina sp. (*S. indica*, *S. maxima*&*S. platensis*)	Zn & Ni	Balaji *et al.,*(2014)
Spirulina	Pb	Prabha *et al.,* (2016)
Scenedesmus obliquus	Cd	Prabha *et al.,* (2016)
Scenedesmus quadricauda	Cd	Mirghaffari *et al*., (2015)
Scenedesmus quadricauda	Pb	Mirghaffari *et al*., (2015)
Dunaliella sp.	Hg, Cd & Pb	Prabha *et al.,* (2016)
Micrasterias denticulate	Cd	Ben Chekroun and Baghour (2008)
Scenedesmus obliquus	3,4-, 2,3-, 2,5- 2,4- and 2,6-dichlorophenol	Papazi and Kotzabasis (2013)
Chlorococcum sp. &*Scenedesmus* sp.	α-endosulfan	Sethunathan *et al*., (2004)
Selenastrum capricornutum	PAHs + heavy metals	Ke *et al.,*(2010)
Chlamydomonas reinhardtii	Hg, Cd & Pb	Tüzün *et al.,*(2005)
Chlamydomonas reinhardtii	Cu, Cd & Hg	Bayramoglu *et al*., (2006)
Nannochloropsis oculata	Pb	Felisco and Billacura (2018)
Bleu-green Cyanophyta)	**Chemical pollutants**	**References**
Anaebaena doliolum	Cd & Cu	Sultan *et al*., (2007)
Anabaena sp.	Cd	Singh *et al*., (2012)
Anabaena flos aquae, Nostoc elepsosporum, Nostoc linkia & Anabaena variabilis	BOD & COD	Ghazal *et al.,* (2018)
Oscillatoria brevis&Westiellopsis prolifica	DO, BOD & COD	Vijayakumar and Manoharan (2012)

Nostoc linckia	Zn & Cd	El-Enany and Issa (2000)
Nostoc muscorum	Zn & Cu	Goswami *et al.,* (2015)
Microcystis sp.	Cr, Cd & Cu	Rai and Tripathi (2007)
Spirulina platensis, *Streptomyces* sp. &*Arthrobacter* sp.	Cd, Cr, Ag & Au	Gelagutashvili (2013)
Anabaena oryzae & Cyanosarcina fontana	Fe, Cu, Pb & Mn	Fawzya and Issa (2016)

Table 2. Macroalgae used for chemical pollutants removal.

Green (Chlorophyta)	**Chemical pollutants**	**References**
Cladophora fascicularis	Cu	Prabha *et al.,* (2016)
Spirogyra	Pb	Prabha *et al.,* (2016)
Spirogyra sp.	Cr	Gupta *et al.,* (2001)
Spirogyra sp.	Pb	Gupta and Rostogi (2008a)
Spirogyra sp.	Cu	Gupta *et al.,* (2006)
Spirogyra hyalina	Cd, Hg, Pb, As & Co	Ben Chekroun and Baghour (2008)
Codium vermilara & Spirogyra insignis	Cd, Ni, Zn, Cu & Pb	Romera *et al*., (2007)
Oedogonium sp.	Pb	Gupta and Rostogi (2008b)
Caulerpa racemosa	Br	Ben Chekroun and Baghour (2008)
Caulerpa racemosa	Pb & Cd	Dekhil *et al*., (2011)
Ulva lactuca	Cu, Pb, Zn & Cd	Saleh (2015)
Ulva lactuca	Cd	Saleh (2017b)
Ulva sp.	Zn	Bădescu *et al*., (2017)
Ulva lactuca	Cd	Lupea,and Bulgariu |(2012)
Ulva lactuca	Cd & Pb	Sarı and Tuzen (2008a)
Ulva lactuca	Cu	Murphy *et al*., (2007)
Ulva lactuca	Cr	Asnaoui *et al.,* (2014)
Ulva sp., *Enteromorpha* sp. &*Chaetomorpha* sp.	Fe, Al, Zn, Cd, Cu, As & Pb	Gosavi *et al*., (2004)
Ulva fasciata	As	Christobe and Lipton (2015)
Ulva fasciata	Cu	Karthikeyan *et al*., (2007)
Brown (Phaeophyta)	**Chemical pollutants**	**References**
Durvillaea potatorum	Cd	Matheickal *et al*., (1999)
Padina sp.	Cd	Kaewsarn and Yu (2001)
Padina sp.	Cu	Prabha *et al*., (2016)
Padina pavonica	Cd	Saleh (2017b)
Sargassum sinicola	Cd & Cu	Prabha *et al*., (2016)
Sargassum sp.	Cu	Karthikeyan *et al*., (2007)
Sargassum fluitans	Cu, Fe, Zn & Ni	Ben Chekroun and Baghour (2008)
Sargassum natans &*Sargassum vulgare*	Pb	Ben Chekroun and Baghour (2008)
Sargassum wightii	As	Christobe and Lipton (2015)
Petalonia fascia	Ni and Cu	Schiewer and Wong (2000)
Laminaria hyperborea	Zn, Ni & Cu	Cechinel *et al.,* (2016)
Laminaria hyperborea	Zn	Mazur *et al.,* (2016)
Pilayella littoralis	Cr, Fe, Al, Cd, Cu, Zn, Co & Ni	Carrilho and Gilbert (2000)

Turbinaria conoides	Pb	Senthilkumar *et al*., (2007)
Fucus spiralis & *Ascophyllum nodosum*	Cd, Ni, Zn, Cu & Pb	Romera *et al.*, (2007)
Ecklonia maxima	Cu, Pb & Cd	Feng *et al.,* (2004)
Ascophyllum nodosum	Au, Co, Ni & Pb	Ben Chekroun and Baghour (2008)
Fucus vesiculosus	Zn & Ni	Ben Chekroun and Baghour (2008)
Fucus vesiculosus	Zn, Cr & Fe	Castro *et al*., (2017)
Fucus vesiculosus&Fucus spiralis	Cu	Murphy *et al*., (2007)
Ecklonia sp.	Cr	Yun *et al.,* (2001)
Red (Rhodophyta)	**Chemical pollutants**	**References**
Acanthophora spicifera	Cr, Pb, Cd & Hg	Tamilselvan *et al*., (2011)
Ceramium virgatum	Cd	Sarı and Tuzen (2008b)
Palmaria palmata	Cu	Murphy *et al*., (2007)
Palmaria palmata	Pb, Cu, Ni, Cd & Zn	Prasher *et al*., (2004)
Laurencia obtusa	Cd, Co, Cr, Cu, & Ni	Hamdy (2000)
Porphyra leucosticte	Cd & Pb	Ye *et al*., (2015)
Gracilaria fischeri	Cu & Cd	Chaisuksant (2003)
Gracilaria sp.	Cd, Cu, Zn, Pb, & Ni	Sheng *et al.*, (2004)
Gracilaria corticata	As	Christobe and Lipton (2015)
Gracilaria sp.	Cd & Cu	Tonon *et al.*, (2011)
Gellidium sp	Cd	Abd El Monsef *et al*., (2014)
Laurancia obtusa, *Geldiella acerosa* & *Hypnea* sp.	Cu, Zn, Mn & Ni	Ibrahim and Mutawie (2012)
Palmaria palmate&Polysiphonia lanosa	Cd & Cu	Baumann *et al.*, (2009)
Palmaria decipiens &Georgiella confluens & Myriogramme mangini	As, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Se, Sr, V& Zn	Farias *et al*., (2002)
Asparagopsis armata & *Chondrus crispus*	Cd, Ni, Zn, Cu & Pb	Romera *et al*., (2007)

CONCLUSION

From this point of view:

I. Algae could be considered as a friendly, economic, good and potent heavy metals biosorbent. Among algae, Overall *Chlorella* spp. in particularly *C. Vulgaris* microalga could be considered as the most effective algae species for heavy metals removal. Moreover, its richness in carbohydrate, protein, vitamins and minerals makes it commercially as health supplement or incorporated in food such as cereals. Due to the high importance of *Chlorella* spp. and its multiuse for many purposes; it is advice to its expanding culture worldwide.

II. For macroalgae, brown marine algae (Phaeophyta) among them have received much attention for heavy metals removal; and little studies have been focused on the application of other algae phyla (Chlorophyta and Rhodophyta). Thereby, a expanding application of the latest algae phyla is requested.

III. Test various pretreatments that improve metal sorption capacity of algae, such chemical pretreatment by methanol/HCl are requested before employment it in pollutants removing. Leading finally to strong affinity of metals for carboxylic groups exist in the biomass surface, exhibiting a critical role in cations binding.

IV. Look for a new algae species that show remarkable heavy metal removal capacity and expansion their culture under laboratory or/and field conditions.

V. Expansion our knowledge on the application of a new algal species that show economic, efficient, and practicable means for the heavy metals removal from industrial wastewater.

VI. Concentrated on brown algae among macrophyta due to their highly importance in heavy metals removal.

VII. Monitoring the new emerged pollutants especially those that toxicants, is requested.

However, after how long cycles the tested algae remain efficacy for elimination a given pollutants stay a question arise.

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