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Review Article
Role of Phycoremediation to Remove Heavy Metals from Sewage Water: Review Article

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Abstract
Sewage water has enrichment of many plant nutrients, so it can be used for irrigation purposes. Nevertheless, if sewage water uses for irrigation without any pre-treatment, with the passage of time toxic contaminants like heavy metals get accumulated into soil and transformed from soil to crops and vegetables. Ultimately, they enter into food chain. Long-term exposure of these heavy metals to human body can have fatal effects because most of the heavy metals are carcinogenic. To overcome the problem of accumulation of heavy metals, bioremediation is the one of the best technique to remove toxic contaminants from sewage water. Use of algae for bioremediation is known as phycoremediation. This review was aimed to study the role of phycoremediation for the removal of heavy metals from sewage water. In this study, different techniques used in phycoremediation were compiled, ability of some micro and macroalgae species of algae to absorb various heavy metals were reviewed. Some factors like temperature, pH and concentration of contaminants which may affect the efficacy of phycoremediation were also observed. On the basis of literature reviewed in this article, it was concluded that phycoremediation is an eco-friendly technique in which algae is used to remove heavy metals from wastewater. This technique is cost effective, ecofriendly as compare to other techniques. In phycoremediation no hazardous secondary byproducts are produced. So, this technique can be explored as a good tool for reduction of water pollution. The wastewater algae can also utilized for biofuel production.

Key words: Sewage water, heavy metals, bioremediation, algae, phycoremediation, eco-friendly technique, secondary byproducts, water pollution

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INTRODUCTION

Today environmental pollution and its ill effects on human and animals, is a big concern at worldwide. Major resources like water, soil and air have become contaminated by anthropogenic activities. Water is a vital source for ecosystem but now-a-days it become polluted at great extent due to urbanization and Industrialization. In many developing countries a large volume of wastewater is produced by industries and domestic activities[1]. Industries discharge their wastewater into natural water bodies without pre-treatment. The sewage water is rich in heavy metals and other hazardous elements. Due to lowering of water table and shortage of irrigation sources in developing countries, they use sewage water which is inexpensive option. Due to sewage irrigation metals and other contaminants can accumulate in soil, plants and living organisms. As plants have tendency to uptake the heavy metals and other dissolved toxic elements. So by using of wastewater for the purpose of irrigation soil as well crops become contaminated which have directly and indirectly give adverse effect to human, animals and whole ecosystem[2].

Due to increase of population growth and limited sources of fresh water, it is necessary to use wastewater after treatment at ecological and economical level[3]. Number of methods have been tried to reduce the water pollution. Among all attempts bioremediation is one of the ecofriendly successful techniques to remove the toxic contaminants from wastewater. Bioremediation is one of the techniques to where micro-organisms like algae, bacteria or fungi are used to degrade the hazardous contaminants into harmless or less toxic form. There are mainly two types of bioremediation: (1) *In situ* bioremediation in which the microbial activity is enhanced by addition of more micro-organisms and nutrients at source of contamination. (2) In *Ex situ* bioremediation includes the removal of wastewater away from the contaminated site and move to treatment site[4]. In bioremediation various strategies are used to treat the wastewater or soil. Some important techniques are: Bioventing Biosparging, Bioaugmentation and Biopiling[5,6].

BIOREMEDIATION WITH ALGAE

In this article was focused on algae to treat the sewage water. For the bioremediation of wastewater many algal strains are used. The alga is an autotrophic organism and for metabolic activities it requires more nitrogen and phosphorus for protein synthesis. Various algal strains can absorb a significant amount of hazardous pollutants like heavy metals, pesticides and other organic pollutants as their nutrients from wastewater[7]. The process in which algae absorb the heavy metals directly through the cell surface is known as physical adsorption. The process in which the pollutants enter into cytoplasm and the degraded by enzymes to convert them into nutrients is known as Chemisorption[8]. Algae are being most successfully used micro-organism to remove the heavy metals from the wastewater because algal strains can survive in high concentrations of heavy metals and other toxic pollutants. Algae have large surface area to adsorb much amount of pollutants from wastewater, have ability to grow autographically and heterotrophically. They also have potential to genetic manipulation[9].

Mechanism of algae for decontamination of heavy metals: Algae have peptides which bind with heavy metals. The peptide chains in algae bind with heavy metals and form organometallic complex which enter into vacuoles for controlling the cytoplasmic concentration of heavy metals. In this way algal cells check the toxic effects of heavy metals. The peptide chains are known as Phytochelatins and metallothioneins. The MTs are gene-encoded polypeptides and PCs are enzymatically synthesized peptides. Phytochelatins are also known as class-III metallothioneins. In algae class-II and class-III metallothioneins are found. Class-I metallothioneins are not found in algae[10]. Synthesis of MtIII can be induced by some heavy metals like Cd^{2+}, Ag^{+}, Zn^{2+}, Hg^{2+}, Au^{2+}, Pb^{2+} and Bi^{3+}[11]. MtIII are very important peptide molecules in algae because presences of these molecules make them capable to survive in high concentration of heavy metals. Biosynthesis of MtIII is directly proportional to degree of pollution[12].

Phycoremediation of sewage water

International level

From 1970-1990: At worldwide much work has been done on phycoremediation of sewage water. In this article year wise work has been observed like Kosaric *et al.*[13] used the *spirulina maxima* for treatment of municipal waste of London. The study revealed that *spirulina maxima* have good capability for removal of nitrogen and phosphorus from wastewater. Chevalier and Noue[14] showed removal of nitrogen and phosphorus from wastewater by using two species of *Scenedesmus* alga. In this experiment 90% of nitrogen at pH 9.0 and 70% of nitrogen at pH 7.7 were removed by two *Scenedesmus* algal strains immobilized in carrageenan. Metal binding capacity of two algal species *Chlorella vulgaris* and *Scenedesmus quadricauda* for silver, copper, cadmium and Zinc was studied by Ramelow and Harris[15]. The results revealed that these two algal species showed very similar binding capacities for silver, copper, cadmium and zinc and metal uptake by algae was highly pH dependent. Amongst all metals, silver was adsorbed very strongly over a wide pH range. Most metal uptake from aqueous solutions by algae occurred within 1 min. Metal binding capacity decrease in order Silver>Copper>Cadmium>Zinc. Aksu *et al.*[16] investigated the adsorption of chromium ions (VI) by two algal species *Chlorella vulgaris* and *Zoogloea ramigera*. The study revealed that adsorption capacity of *C. vulgaris* and *Z. ramigera* increased by increasing the metal ions concentration up to 200 and 75 mg L^{-1}, respectively. Maximum metal adsorption was observed at pH 2.0 and at temperature range of 25-50°C.

From 1991-1995: Adsorption of dissolved metals from industrial wastewater was observed by using a green alga *Chlorella vulgaris* to remove lead ions (II) from wastewater was investigated by Aksu and Kutsal[17]. Absorption of metals was studied in single batch reactor. The findings suggested that it is good alternative technique for wastewater treatment. Freundlich adsorption isotherm method was used to calculate residual or adsorbed metal concentration. Aksu *et al.*[18] measured adsorption of copper ions (II) by two algal species *Chlorella vulgaris* and *Zoogloea ramigera*. The outcome of this experiment showed that adsorption capacity of *C. vulgaris* and Z. *ramigera* increased by increasing the metal ions concentration up to 150-200 and 100- 125 mg L^{-1}, respectively at pH range 4.0-4.5 with optimum temperature 25°C. Ozer *et al.*[19] employed green algae *Cladophora crispata* for adsorption of lead (II) and chromium (VI). The optimum pH and temperature for the adsorption of lead were found to be 5.0 and 25°C whereas for chromium optimum pH was 1.0 and temperature was 25°C.

Two algal strains *Zoogloea ramigera and Rhizopus arrhizus* were examined for their adsorption capacity. In findings adsorption of lead (II) by *Z. ramigera and R. arrhizus* increased by increasing the metal ions concentration up to 150-200 and 200-300 mg L^{-1}, respectively. Optimum pH for both micro-organisms was 4.5-5.5 and optimum temperature was 25-45°C[20].

From 1996-2000: *Chlorella pyrenoidosa, Chlamydomonas reinhardtii* and *Chlorella vulgaris* were applied to eliminate cadmium from polluted water. In this experiment, dry weight of algae was used for adsorption study. In results, these algal species showed initial rapid metal uptake followed by slow metal uptake. About 96, 79 and 57% adsorption saturation showed by *Chlorella vulgaris*, *Chlorella pyrenoidosa* and *Chlamydomonas reinhardtii*, respectively[21]. Matheickal and Yu[22] analyzed heavy metal uptake capacity of three algal strains *Durvillea potatorum*, *Ecklonia radiata* and *Phellinus badius*. They found these algal species have high metal binding capability for lead, copper and cadmium. They also showed that *Durvillea potatorum* have very high affinity for lead as compared to rest of two algae. *Durvillea potatorum* also showed better results when compared to commercial ion exchange resins, activated carbon and natural zeolite.

Kratochvil and Volesky[23] explored algal biomass of *Sargassum* to remove copper ions from ferruginous wastewater. In this experiment Fe (III) concentration was 15-40 mg L^{-1} and was present in the form of suspended solids and Cu^{2+} ion concentration was 25 mg L^{-1}. A flow-through sorption column was used to remove Cu^{2+} from solution containing copper (Cu) and iron (Fe) ions. They demonstrated that biomass adsorb 2.3 meq g^{-1} of metal ions from water and binding capacity of biomass toward metal ions decreased in order of Cu>Ca>Fe. Fe (III) ions were removed by in-depth filtration and Cu^{2+} was removed by biosorption method. Desorption of metal ions from biosorbent was done by using 0.1 M HCl. Yu and Kaewsarn[24] applied marine alga *Durvillaea potatorum* in binary adsorption system for removal of copper (II) and cadmium (II) from aqueous solution. It was found that adsorption capability of alga for each metal in binary system was lower as compare to single biosorption system but total capacity of biosorption for both metals was similar to single biosorption system. Optimum pH was 5.0 for this experiment. Temperature and light, metal ions have not showed any effect on biosorption rate. In this experiment 90% copper and cadmium, adsorbed by alga within 10 and 30 min, respectively and equilibrium observed after 60 min in this experiment. Travieso *et al.*[25] examined the effect of two algal strains *Chlorella vulgaris* and *Scenedesmus acutus* on zinc (Zn), cadmium (Cd) and chromium (Cr). In this experiment 96 h was minimum time period for inoculation of algae. In the culture media growth rates were 0.02 h^{-1} for *Scenedesmus acutus* and 0.015 h^{-1} for *Chlorella vulgaris*. The generation times were 37 h 53 min and 45 h 35 min, respectively. *Chlorella vulgaris* resist maximum concentration of 45 mg L^{-1} for Cr, 2 mg L^{-1} for Cd and 600 mg L^{-1} for Zn. Maximum resistance showed by *Scenedesmus acutus* for Cr was15 and 2 mg L^{-1} for Cd and 100 mg L^{-1} for Zn.

Two algal strains were analyzed by El-Elany and Issa[26]. One strain was metal tolerant: *Nostoc linckia* and another one was metal sensitive *Nostoc rivularis*. Both strains were grown in three levels of sewage water 25, 50 and 75%. Growth rate was stimulated at 50% for *N. linckia* and 25% for *N. rivularis*. In 25% of sewage water both strains showed increase in chlorophyll content, protein content, oxygen and respiration. In moderate and high levels of sewage water reduction in metabolism was observed in both algal strains. As compare to moderate level, in low level of sewage water *N. linckia* showed metal uptake 30 fold of zinc and 10 fold of cadmium and *N. rivularis* showed metal uptake 10 fold of zinc and 2 fold of cadmium.

From 2001-2005: Kaewsarn and Yu[27] investigated Cd (II) adsorption capability of pre-treated biomass of marine algae *Padina* by using batch and column experiment. The findings revealed that pH 5.0 was optimum pH at which pre-treated biomass of *Padina* sp. removed 0.53 mmol g^{-1} concentration of cadmium (II) from wastewater. In this experiment, 90% of cadmium (II) was adsorbed in 35 min. Terry and Stone[28] compared the adsorption capacity of living and nonliving biomass of green algae *Scenedesmus abundans* for cadmium and copper. The results showed that lower concentration of *S. abundans* removed cadmium and copper concentrations above 4 mg L^{-1} each. It was also shown that living biomass performed much better than non-living biomass and lower concentration of alga was more effective than higher concentration in removing heavy metals from contaminated water.

Donmez and Aksu[29] studied about biosorption of chromium (VI) ions by two strains of *Dunaliella* algae: *Dunaliella* sp. 1 and *Dunaliella* sp. 2. In this experiment effect of pH, initial metal ion concentration and salt concentration was studied. They found that biosorption was strongly depend on pH and at pH 2.0 maximum adsorption capacity was shown by both strains. In this experiment they also demonstrated the effect of presence of salt on biosorption. In the absence of salt both strains adsorbed 58.3 and 45.5 mg g^{-1} but in the presence of salt biosorption decreased by 20.7 and 12.2 mg g^{-1}. Uptake capacity of both strains increased by increasing initial metal concentration and equilibrium reached at concentration of 250-300 mg L^{-1}. Zeroual *et al.*[30] tested biosorption of mercury (Hg) by pre-treated algal biomass of *Ulva lactusa.* The maximum adsorbed concentrations of mercury were 27.24, 84.74 and 149.25 mg g^{-1} at respective and pH 3.5, 5.5 and 7. Above 90% of the mercury adsorbed within 20 min. Equilibrium was reached in 40 min. Pre-treated biomass gave better biosorption results than native biomass. Metal uptake by alga increased with the increase of the bed height (surface area). Biosorption of mercury decreased with the increase in initial metal concentration and at high concentration *Ulva lactusa* showed early saturation. Pena-Castro *et al.*[31] investigated metal uptake capacity of alga *Scenedesmus incrassatulus* to remove chromium (VI), cadmium (II) and copper (II). The algal strain removed all tested metals by 25-78%. Chromium (VI) and cadmium (II) showed high interaction with alga hence removed at high concentration but bivalent metals were not removed due to high pH. Chromium (VI) was removed very efficiently in continuous cultures as compare to batch culture, because actively growing algae accumulated chromate easily in continuous culture.

From 2005-2010: Chen and Pan[32] explored live spirulina alga to remove lead (Pb) from wastewater. At various lead (Pb) concentrations live *spirulina* has grown in wastewater samples. The growth of algae was checked at wavelength 560 nm. About 72 h medium effective lead concentration was 11.46 mg L^{-1}. In findings alga showed rapid adsorption of lead in initial stage. Spirulina removed 74% lead in initial time 0-12 min and maximum metal uptake was observed 0.62 mg/10^5 alga cells. Pavasant *et al.*[33] investigated biosorption capacity of macroalgae *Caulerpa lentillifera* to remove Cu^{2+}, Cd^{2+}, Pb^{2+} and Zn^{2+}. In results they showed that biosorption capacity increased with pH and maximum metal removal capacity of alga was in order of $Pb^{2+}>Cu^{2+}>Cd^{2+}>Zn^{2+}$. Sorption equilibrium reached in 20 min. Results also revealed that there are some functional groups present on algal surface which are responsible biosorption of all metals.

Romera *et al.*[34] conducted experiment to study the biosorption ability of six different algae *Codium vermilara*, *Spirogyra insignis*, *Asparagopsis armata*, *Chondrus crispus*, *Fucus spiralis* and *Ascophyllum nodosum* for cadmium (Cd), nickel (Ni), zinc (Zn), copper (Cu) and lead (Pb). In this experiment influence of pH and metal concentration on biosorption was observed. The results showed that optimum pH was 6 for removing Cd, Ni and Zn and less than 5 for Cu and Pb. The best results were shown by algae at lowest algal concentration of 0.5 g L^{-1}. The maximum biosorption observed by *Fucus spiralis.* Karaca[35] examined four algal species i.e., *Dunaliella salina*, *Oocystis* sp., *Porphyridium cruentum* and *Scenedesmus protuberans* and used these species to remove the metal ions lead (Pb^{2+}), cadmium (Cd^{2+}) and nickel (Ni^{2+}) from wastewater. The results showed that *Dunaliella salina* have highest biosorption ability followed by *Oocystis* sp., *Scenedesmus protuberans* and *Porphyridium cruentum*. The biomass concentration of 20.0 mg of *Dunaliella salina* gave maximum sorption results for Pb^{2+} while 100 mg was required for Cd^{2+} and Ni^{2+}. Results also showed that optimum pH for biosorption was in range of pH 4-6.

Fucus vesiculosus, brown algae was investigated by Mata *et al*.[36] for bioreduction of Au (III) to Au (0). They found that optimum range of pH for reduction was 4-9 and maximum metal uptake was at pH 7. Initially there was no change in pH, redox potential and gold concentration but in second stage sharp decrease in pH, redox potential and gold concentration was observed. In the end of experiment colour of solution change yellow to reddish purple. Gold particles were present in the form of micro precipitates on the algal surface and as nano-particles in the solution. Tuzen and Sari[37] used green alga, *Cladophora hutchinsiae* for removal of selenium (IV) from aqueous solution. Maximum biosorption capability of alga was found to be 74.9 mg/gat pH 5, at temperature 20° when biomass concentration was 8 g L^{-1} with contact time of 60 min.

From 2011-2018: *Dunaliella* alga was tested by Imani *et al*.[38] for its biosorption ability for cadmium (Cd), lead (Pb) and mercury (Hg). In results alga showed rapid metal absorption since beginning till 1 h as 67, 65 and 72% for Hg, Pb and Cd, respectively. After 1 h, alga showed a constant rate of metal absorption till 40 h. Zhou *et al*.[39] determined the metal uptake capacity of two algal strains *Chlorella pyrenoidosa* and *Scenedesmus obliquus* for Zinc (Zn) and copper (Cu). The results demonstrated that both strains showed maximum removal efficiency near about 100%. After 8 days of culturing, the alga *C. pyrenoidosa* removed 72.8-95.6% zinc and 79.3-90.9% copper. On other hand, *S. obliquus* removed 72.8-99.7% of zinc and 75.9-91.4% of copper. *C. pyrenoidosa* showed highest removal capacity for copper ions than *S. obliquus* and *S. obliquus* showed highest removal efficiency for zinc ion.

Abdel-Aty *et al*.[40] investigated the biosorption capacity of blue green alga *Anabaena sphaerica* for cadmium (Cd) and lead (Pb). They found that maximum concentration of Cd (II) and Pb (II) uptake by alga was 111.1 and 121.95 mg g^{-1}, respectively.

The results also showed that the mechanism of biosorption was chemisorption and they revealed the presence of amino acids, carboxyl, hydroxyl and carbonyl groups on algal surface which are responsible for metal uptake by algae. Monsef *et al*.[41] worked on the bioremoval capacity of red alga *Gellidium* sp. and *Eichhornia* sp. In the experiment these organisms were exposed to Lead (from Pb $(NO_3)^2$ or Cadmium (from Cd $(NO_3)^2$ at a concentration of 10 mg L^{-1} for a time period of 240 min. The results showed that *Eichhornia* sp. had high capacity for bioremoval of Lead and Cadmium (97.15 and 97.48%) in 15 min, while *Gellidium* sp. had highest efficiency for removal of cadmium (96.80%) in 30 min.

Ye *et al*.[42] examined red algae *Porphyra leucosticta* for its bioremediation capability toward cadmium (Cd) and lead (Pb). In results maximum adsorption for Cd (II) capacity showed by alga was 31.45 mg g^{-1} and for Pb (II) was 36.63 mg g^{-1}. For this whole experiment initial biomass concentration 15 g L^{-1}, contact time was 120 min and optimum pH was 8.0. Initial concentration of metal ions in solution was 10 mg L^{-1} of Cd (II) and 10 mg L^{-1} of Pb (II). Bioremediation capacity of *Porphyra leucosticta* in solution was 90% for Pb (II) and 70% for Cd (II). On other hand in real wastewater bioremediation capacity showed by alga was 75% for Cd (II) and 95% for Pb (II). Sheekh *et al*.[43] conducted a study on two algal strains *Chlorella vulgaris* (fresh water algae) and *Chlorella salina* (marine alga) to treat sewage water. The study reported the potential of both algal species to reduce the many physico chemical parameters like pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS), phosphate, sulphate, nitrate, ammonia, magnesium, calcium, sodium, potassium and some heavy metals like Cu, Zn, Cr, Ni, Co Mn and Fe. In this study the removal capacity of both algal strains was 13.61-100%. The *C. vulgaris* showed higher bioremediation capability than *C. salina* in reducing most of the physicochemical parameters.

Ammari *et al*.[44] treated aqueous solution with intact and NaOH treated dried mass of alga *Hydrodictyon reticulatum*. The maximum biosorption capacities were 7.40 mg g^{-1} for intact algal mass and 12.74 mg g^{-1} for alkaline-treated biomass. In results alkaline-treated algal tissues showed better performance than that of intact tissues. Biosorption reached equilibrium after 24 min for alkaline-treated alga and for intact bioadsorbents equilibrium reached after 240 min of contact. Kahashan and Kadhim[45] examined the biosorption capacity of three algal strains *Oscillatoria* sp., *Westiellopsis prolifica*, *Stigonema* sp. In results that the *Oscillatoria* sp. has reduced heavy metals in high ratios: 100.3% for Iron, 99.5% for Lead, 66.2% for zinc, 33.5% for cadmium and 29.1% for copper. *W. prolifica* showed the ability to reduce heavy metals by 99.7% for Iron, 99.5% for lead, 56.4% for Zinc, 40.2% for Cadmium and 29.1% for Copper. *Stigonema* sp. showed higher efficiency than the rest of algae in reduction of some heavy metals with ratio of 100% for Iron, 100% for lead, 73.8% for zinc, 44.3% for copper and 22.3% for cadmium.

Phycoremediation of sewage water

AT national level

From 1991-2000: At India level a very less work has been done on phycoremediation. Out of which important work has been reviewed in this article like *Anabaena doliolum* and *Chlorella vulgaris* were applied by Mallick and Rai[46] to remove NO_3^-, NO_2, PO_{43}^-, $Cr_2O_{72}^-$ and Ni^{2+}. In this study algal strains were used by immobilized on chitosan, agar, alginate and carrageenan or even used as free cells also. In results carrageenan-immobilized cells showed better results in removing NH_{4+} and Ni^{2+}. Agar-immobilized cells, showed good metal and nutrient uptake capacity but growth rate was slow. Overall results showed that chitosan were more efficient in removing contaminants from wastewaters than cells immobilized on agar, alginate and carrageenan or even free cells.

Ahuja *et al.*[47] observed the biosorption capacity of *Oscillatoria anguistissima* for copper (Cu^{2+}). The observations of this study revealed that metal adsorption by alga is highly pH dependent and maximum metal removal occurred at pH 5. Biosorption of Cu^{2+} increased by increase in concentration of copper ions in solution. Pre-treatment of algal biomass with HCl increased the adsorption capacity for copper. *O. anguistissima* removed copper effectively from mine water with initial metal concentration 68.4 μg mL^{-1} at pH 3.45. Adsorption of Cu^{2+} ions decreased, with the presence of Mg^{2+} and Ca^{2+}.

From 2001-2005: Gupta *et al.*[48] found that filamentous green alga *Spirogyra* could adsorb chromium (V1) from wastewater. The result of this experiment showed that maximum adsorption of chromium concentration by Spirogyra was 14.7 mg kg^{-1}. Optimum pH for this experiment was pH 2.0. Equilibrium reached in 120 min. Initial concentration of biomass was 5 mg L^{-1}. Vijayaraghavan *et al.*[49] investigated the biosorption ability of algal strain *Ulva reticulata* for copper (II) ions from aqueous solution. They found that at optimum pH 5.5 maximum biosorption of Cu (II) observed i.e., 74.63 mg L^{-1}. In this experiment at various initial concentration (250-1000 mg L^{-1}) sorption equilibrium reached between 30-120 min. Various desorbing agent like 0.1 M HCl, H_2SO_4, HNO_3 and $CaCl_2$ were used to recover copper from solution. They found that $CaCl_2$ (0.1 M) in HCl was suitable copper-desorbing agent.

Oscillatoria sp., *Phormidium* sp., *Chlamydomonas* sp. and *Ulothrix* sp. were studied for metal accumulation capacity by Rai *et al.*[50]. In this study the findings revealed that all algal strains showed biosorption for many metals like Cu, Mn, Zn, Cr and Fe. The biomass of algae accumulated metal ions in order of Cr<Fe<Zn<Mn<Cu. All algal strains showed maximum growth rate in tannery effluents with high chromium concentrations (12.5-16.1 mg L^{-1}) and some major algal strains accumulated substantial amount of chromium.

From 2006-2010: *Spyrogyra* alga was investigated for its biosorption capacity for copper (Cu) by Gupta *et al.*[51] and findings revealed that metal uptake capacity of the biomass strongly depends on pH and algal dose. The maximum biosorption capacity of Cu (II) was 133.3 mg g^{-1} of dry weight of biomass at an optimum pH 5 in 120 min. The optimum algal dose was 20 g L^{-1}. They used various desorption agents including HCl, EDTA, H_2SO_4, NaCl and H_2O but maximum desorption 95.3% was found with HCl in 15 min. Ahluwalia and Goyal[52] used mixed microbial biomass of *Aspergillus niger*, *Penicillium chrysogenum*, *Rhizopus nigricans*, *Ascophyllum nodosum*, *Sargassum natans*, *Chlorella fusca*, *Oscillatoria anguistissima*, *Bacillus firmus* and *Streptomyces* sp. to observe biosorption capability for Pb, Zn, Cd, Cr, Cu and Ni. In results, this biomass showed highest metal adsorption capacities ranging from 5-641 mg g^{-1}.

Gupta and Rastogi[53] studied the metal uptake capacity of green algae *Spirogyra*. They found that *Spirogyra* is very effective in removal of lead from wastewater. *Spirogyra* showed maximum adsorption capacity for Pb (II) at initial concentration of lead 200 mg L^{-1}. Optimum algal biomass which was around 140 mg g^{-1} at pH 5.0 in 100 min. Gupta and Rastogi[54] treated aqueous solution with raw and pre-treated alga *Oedogonium hatei* for removal of Cr (VI). The optimum conditions for biosorption were found to be: contact time of 110 min, biomass dose of 0.8 g L^{-1}, pH and temperature 2.0 and 318 K, respectively. Maximum biosorption capacities of acid-treated algae and the raw were 35.2 and 31 mg Cr (VI) per g of dry adsorbent, respectively. Results also showed that there are some functional groups like- OH, -COOH and $-NH_2$ which are responsible for biosorption of heavy metals. Biosorbent regenerated up to 75% by using 0.1 M NaOH solution. Kumar and Goyal[3] conducted a study by using *Chlorella* sp. for the treatment of domestic wastewater generated at village of Sanghol, district Fatehgarh Sahib, Punjab (India) and in results alga showed reduction in BOD by 79% COD93%. The *chlorella* sp. removed zinc by 60-70% from culture medium containing 5-20 mg L^{-1} Zn^{2+} and lead was removed by 66.3% from culture medium containing 1 mg L^{-1}. Zinc toxicity lead to constant declined in cell no from 538×10^5 to 8×10^5 cells mL^{-1}. Cell number increased in medium containing lead concentration up to 20 mg L^{-1}. The maximum metal uptake by live *Chlorella* for Zn^{2+} and Pb^{2+} was 34.4 and 41.8 mg g^{-1}, respectively.

From 2011-2018: *Cyanothece* sp., *Oscillatoria* sp., *Synechococcus* sp., *Nostoc* sp. and *Nodularia* sp. were studied by Dubey *et al.*[55] for their bioabsorption capacity. In results cyanobacterial species showed maximum metal removal efficiency in range between 97.0-99.6% at 5 ppm, 83.9 and 99.7% at 10 ppm concentration of contaminants. Also mixed culture of cyanobacterial species showed maximum metal removal efficiency in range between 91.6 and 100% at 5 ppm with a maximum range of 99.3-100%, while at 10 ppm concentration of contaminants. Kumar and Oommen[56] used *Spirogyra hyalina* to check its bioabsorption capacity for cobalt (Co), mercury (Hg), lead (Pb), cadmium (Cd) and arsenic (As) from wastewater. The results showed that lead (Pb) and cobalt (Co) adsorbed at greatest amount at 80 mg L^{-1}. Cadmium (Cd), mercury (Hg) and arsenic (As) were adsorbed highest at initial concentration 40 mg L^{-1}. The order of metal uptake by the dried biomass was found to be Hg>Pb>Cd>As>Co.

Dixit and Singh[57] reported in their study about influence of various factors on the biosorption of lead (Pb) and cadmium (Cd) by *Nostoc muscorum*. In results algal strain showed maximum biosorption of Cd and Pb were 85.2 and 93.3%, respectively within 30 and15 min at 60 and 80 µg mL^{-1} concentrations of metal. The increase in biosorbent dose lead to increase in biosorption rate. The optimum pH for biosorption of Pb was 5 and for Cd was 6 and optimum temperature was 40°C. Sibi[58] studied the bioremediation of Arsenic (III) and Arsenic (V) by fresh water algal strains *Chlorella*, *Oscillatioria*, *Scenedesmus*, *Spirogyra* and *Pandorina*. The results showed that these microalgae species were arsenic tolerant. Maximum concentration of arsenic adsorbed by algae was found 0.8 g L^{-1} at pH 4 and at temperature 32°C. Metal uptake capacity by algae for As (III) was higher than the As (V). These five algal isolates showed different growth rates in the presence of arsenic. *Spirogyra* reached at stationary phase after 5 days. *Oscillatioria* showed growth in 8-10 days. *Pandorina* showed growth phase of 11 days. *Chlorella* and *Scenedesmus* showed growth phase of 13 days.

Kumar *et al.*[59] examined marine micro algae i.e., *Chlorella marina* to treat the various types of wastewater domestic sewage, industrial effluents and aquaculture. In results *C. marina* decreased 64% ammonia, 51% phosphorus, 88% of nitrite and 75% nitrate. Cell number of biosorbent increased 3×10^6 to 1.5×10^7 cells mL^{-1}. Among heavy metals chromium (Cr) was reduced by 89% and lead (Pb) was reduced by 87%. Das *et al.*[60] focused on study of microalgal strain *Chlorella vulgaris* to observe its biosorption capacity for various nutrients and heavy metal chromium (Cr). In time period of 21 days *C. vulgaris* showed 100% reduction of nitrate and chromium on 6th and 12th day, respectively. In same experiment alga strain removed 91.73% of phosphate by day 6 and over 99% by day 21, 67.4% of sulphate by day 21. Levels of COD and BOD were reduced by 94.74 and 95.93%, respectively, after 21 days. Warjri and Syiem[61] isolated *Nostoc* sp. from a water sample collected from a coal mine in the West Khasi Hills of Meghalaya, India. They used alga to study its tolerance capacity against Chromium (Cr) and found that *Nostoc* sp. is able to grow in the presence of 15 ppm Cr, which was 30 times the higher concentration recorded in that area. The optimum conditions for alga were pH 6.0 with 3 µg mL^{-1} biomass. Maximum sorption capacity showed by *Nostoc* sp. for chromium was 20 mg g^{-1} of biomass.

CONCLUSION

Literature and studies from various sources indicated that the use of algae in phycoremediation is very effective and has potential for future applications. Phycoremediation is the most beneficial method as it is a cost effective, easy to handle, less labor work is needed. Produce no hazardous secondary byproducts and residues can be used for biofuel production. Literature reviewed at India level in this article also indicated a very less work has been done on phycoremediation in India. So there is a big need to explore this ecofriendly technique to reuse water resources and reduction of water pollution in India.

SIGNIFICANCE STATEMENT

This study discovered that phycoremediation technique is very easy method to reduce and reuse of water pollution. This technique can be used in both small and large scale industries, by farmers, in villages and towns where sewage treatment plants facility is not available. By using genetic engineering of algal strains, this technique can be made more beneficial. So this study gave a good scope to researchers also.

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