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PHYCOREMEDIATION: A NOVEL AND SYNERGISTIC APPROACH IN WASTEWATER REMEDIATION

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ABSTRACT

Pollution such as water pollution got intensified with an increase in population density. So, it became important to deal with various industrial and household contaminants like dyes, heavy metals, microbes and radioactive materials. Hence, to remediate the water from such hazardous contaminants in a rapidly developing world, new technological inventions are required globally. Nanotechnology is getting increased attention as it is an advanced technology and shows advantages compared to other innovations. Various technologies are available in remediating water such as algal turf systems and nanoparticle-based adsorption. There are several ways of nanoparticle synthesis, but the algae-based synthesis is very significant and environment friendly. The potential and efficiency of algae in waste water remediation is remarkable and several contaminants can be detoxified, transformed and volatized by algae. There are several potential benefits associated with the algae mediated phycoremediation due to its advantages over conventional systems of remediation and heavy metal removal. Algal strains are easy to culture and adaptive in nature and can be easily manipulated within the laboratory. In this review, we have discussed the biological green nanoparticle synthesis using algae as an eco-friendly, cheap and cost-effective sustainable technology. However, algal mediated waste water treatment is yet in a primary stage and many innovative steps are necessary for adaptive remediation strategies, which can sustainably address global waste water issues.

Keywords: Algal Flow way systems, Microalgae, Nanoparticles, Phycoremediation, Water-remediation

INTRODUCTION

Water plays a major role for the functioning of ecosystems and the health of people. It is a universal solvent and with industrial and urban development it gets contaminated by many pollutants. So, its treatment becomes a necessity and several treatments have been implemented. In the last decades, developments in nanotechnology provides the opportunity of effective removal of pathogens and pollutants from water **(Joshua *et al.*, 2015)**. Wastewater affects us humans in different ways and a mix of industrial, agricultural, domestic waste and rainwater run-off makes wastewater contaminated with myriad of pollutants **(Summer *et al.*, 2006)**. The characteristics of waste water vary depending on the source so that the composition of waste water differs from place to place. Wastewater is composed of microbes and wide range of contaminants such as dyes, **(Karin, 2006),** chemicals, synthetic organic or inorganic compounds, heavy metals, complex chemicals, radioactive substances, oil as shown in Table 1.

Table 1 Different type of pollutants

POLLUTANTS	TYPES	EXAMPLES	SOURCES
PHYSICAL	Sediments	Slit and soil	Soil erosion
	Thermal pollution	Heat	Industries and power plants
	Solid waste		
CHEMICAL	Nutrients	Fertilizers	Agricultural and domestic waste
	Toxic inorganic material	Acids, metals, Caustics, salts	Industrial and domestic effluents
	Persistent organic Pollutant (POPs)	Pesticides, plastics, detergents and oils	Industrial, domestic, agricultural waste
	Radioactive materials	Uranium, radon, thorium etc.	Mining, power plants, natural sources
BIOLOGICAL	Pathogens, microbes	Bacteria, viruses, parasites	Sewage and human or animal excreta

The adulteration of various contaminants arising from diverse sources into the water makes it highly unsuitable for consumption. There are various side effects are also associated with the water pollution, which not only affect humans but also ecosystem functioning as shown in Figure 1.

Figure 1 Impact of wastewater

There are several conventional methods to remediate the wastewater efficiently **(American Public Health Association, 2005)**. The method of treating the waste water must be harmless to both humans and the environment. Besides being ecofriendly it must be done with least effort and economical. A sustainable way is provided by a biological treatment that is provided by bioremediation. Bioremediation is the most common technique used to treat waste water due to its low cost and environmentally friendly nature. Bioremediation is opted by almost every waste water treating industry **(Gomez *et al.*, 2008)**. The chemical and physical removal of contaminants is expensive and moreover less effective than bioremediation. A comparison is elaborated in Figure 2. Bioremediation is one of the practical approaches of biotechnology which involves the use of organisms for removing contaminants or pollutants from soil or water. The organisms that are involved can be bacteria or other microbes **(Validi, 2001).** The microbes break down the pollutants or decompose contaminants. If the contaminants are microbial pathogens, microbes involved in bioremediation inhibit the growth of pathogens or kill them **(Murugesan and Rama Chandra, 2009).**

PHYSICAL REMEDIATION
- Expensive - requiring energy and machinery for the process
- Electroremediation - hydraulic contaminant barriers as examples

CHEMICAL REMEDIATION
- More chemicals are used to decontaminate others so the toxicity level increases
- Injection of chemicals are provided

BIOREMEDIATION
- Use of natural sources being cost effective
- Environmental friendly
- Microbes and plants are used for decades, being more efficient and less toxic

Figure 2 Comparison of bioremediation with other methods

Advantages and disadvantages of bioremediation strategies are shown below in Table 2. Bioremediation processes need optimal temperature, light, and other conditions to remediate waste water, if the right conditions are not available then it can be improved by adding amendments to the wastewater medium such as molasses, air or vegetable oil so that by utilizing them microbes establish optimal conditions to enhance the bioremediation process **(Witters *et al.*, 2012).**

Table 2 Advantages and disadvantages of bioremediation technologies

TECHNOLOGIES	ADVANTAGES	DISADVANTAGES
IN SITU BIOREMEDIATION (Bioventing, Bioaugmentation, Biosparging)	• The contaminants can be fully transformed into totally harmless substances • Cost effective	• If in the whole process of biotransformation, intermediates is formed, it may sometimes be more toxic than the parent • Some compounds are non-biodegradable
EX SITU REMEDIATION (Biopiling**,** Composting**,** Farming)	• Moisture, heat, temperature can be controlled • Generates less amount of waste	• Time consuming

Phycoremediation

Phycoremediation involves micro- or macro-algae to remediate environment leading to the reduction or biotransformation of toxic compounds from waste water **(Rao et al., 2011)**. Also, the use of microalgae is getting more attention not only due to its ability of effective removal of nutrients but to generate biomass allowing for biofuel production in addition **(Pohl et al., 1988, Christenson et al., 2011)**. The generation of biofuel is the additional advantage of cultivating algae **(Ruiz-Martinez et al., 2012).** It is a more conventional and sustainable method than any other method. Carbon dioxide sequestration is also done by microalgae and hence will help in controlling the rate of global warming, so the mass cultivation is required to attain the desired results **(Becker, 1994).** Algae occur worldwide in aquatic systems and have adapted to diverse conditions. This has additionally enabled the algae to develop a wide resistance to natural conditions including nutrient levels **(Ahmad et al., 2017)**. This advantage prompted the wide utilization of the algae in bioremediation. Algae remove toxins like hydrocarbons, heavy metals and pesticides assisted by different processes like bioconcentration, biosorption, volatisation as well as biotransformation **(Çicek at al., 2018).** With the approach of genetic engineering, dynamic research became possible that improved the bioremediation possibilities with algal strains by improving their photosynthetic effectiveness, versatility and resilience to stressful conditions. Microalgae have a significant place in the tertiary treatment of residential wastewater, in the maturation of contaminated natural water bodies, or the treatment of small–middle-scale municipal wastewater in aerobic or facultative water bodies **(Saravanan et al., 2015**). They improve the expulsion of nutrients, pathogens, and heavy metals and provide oxygen to heterotrophic aerobic bacteria to mineralize organic pollutants, utilize carbon dioxide provided from heterotrophic organisms such as from the respiration of bacteria, fungi, and animals. Photosynthetic air circulation is in this way particularly intriguing to diminish task expenses and confines the dangers for poison volatilization under mechanical air circulation **(Choi, 2016)**. Phycoremediation is an innovative technology that is gaining momentum in the field of environmental studies. Moreover, the majority of conventional strategies depend on physical displacement or chemical replacement, creating a secondary issue of toxic sludge as its disposal increases the load on the techno-economic feasibility of the treatment process. Hence, development of a new technique is essential to fulfill the environmental standards at much lower expenses. The main advantages of using microalgal species, is that it traps the solar energy through photosynthesis and absorbs CO2 along with nutrients from water to synthesize their biomass and produces oxygen. Algae release large amounts of organic compounds which can be assimilated by bacteria **(Li et al., 2017)**. The bacteria, in turn provide an important source of CO_2 required for algal growth, and it changes the pH of the supporting medium **(Jean-Luc Moue, 1995)**. Filamentous cyanobacteria are an excellent nominee for wastewater treatment due to their variable unique characteristics **(Kudre et al., 2017)**. Algae are utilized by several industries, for instance the dairy industry. Primary and secondary treatment methods are quite common in the treatment of dairy wastewater as they are efficient and dependable. The dairy effluent is mainly organic in nature and due to its biodegradable constituents, it is amenable to conventional treatment. It is rich in nutrients, nitrate and phosphate, which is a source of improved algal growth in natural waterways. Fresh dairy sludge is very alkaline and becomes acidic due to fermentation of lactose to lactic acid. Because of these qualities chemical treatment techniques might not be suitable **(Henaa et al., 2015).** It is probably due to this reason that most of the existing dairies have treatment plants based on activated sludge processes. This type of treatment method is not effective in filtering the nutrients from dairy wastewater. This wastewater needs further polishing to remove the nutrients which can be effectively done through the use of aquatic macrophytes. Additionally, dairy waste contains adequate supplements for biological growth, biological treatment strategies are viewed as progressively perfect and efficient **(Khemka et al., 2017)**. The treatment of dairy effluent by *Nostoc* sp, is very efficient and it also proved to be a cost-effective and eco-friendly treatment. The *Nostoc sp*, has a significant job in the removal of COD, BOD, TSS, TDS and other metals **(Gupta et al., 2015)**. Employing this innovation in the treatment of effluents exhibits an alternative instrument to the flow routine with regards to utilizing customary strategies, including physical and chemical technologies. The timely and cost-effective remediation of metal and natural contaminated sites mandate a comprehension of the degree and instruments by which dangerous metals hinder natural biodegradation. The components by which metals restrain biodegradation change with the organization and multifaceted nature of the framework under scrutiny and, furthermore, incorporate both physiological and environmental viewpoints. A careful comprehension of these frameworks, considering different dimensions of multifaceted nature is expected to develop new ways in dealing with the remediation of contaminated sites **(Dadrasnia et al., 2015).**

Applications of algae

Industrial waste removal

The probably largest industrial sector is the textile industrial sector and the textile industry utilizes large amounts of water and chemicals for their work process of textiles, and the consumption of water by textile industries vary from place to place and results in the release of effluents. Many steps are taken to utilize a minimum amount of water and recycle the waste water for further use **(Ajayan and Selvaraju, 2012)**. The two important steps of the textile industries are dyeing and finishing. In these processes, considerable amounts of waste water and effluents are generated which are highly toxic and contain permanent colors which lead to fluctuating pH, BOD, and COD **(Rajvaiday *et al.,* 1998).** Textile waste water, therefore, need great attention and effective removal of dye. Remediation of water discharged from textile industries is made possible by algae. They are found to be effective in the reduction of chemical oxygen demand, reducing the pH **(Ding *et al.,* 2014).** The industries use the algae of different species to remove various contaminants as indicated in Table 3. Also, the decolorization of azodyes were investigated using the algae *Spirogyra* spp. The maximum removal of dyes are possible using algae and the dye removal by algae is achieved by biosorption, diffusion, and bioconversion. Many species of algae have been successfully used in the treatment of waste water **(Sengar *et al.,* 2011).** Such waste waters consist of several pollutants, dissolved nitrogen and phosphorous which can be transformed by algae in the presence of carbon dioxide and light. The water can be remediated or renovated by the help of algae, which we refer as phycoremediation **(Borowitzka, 1998).** It is found that dairy cattle waste inhibits algal growth but now the researchers succeeded in growing algae on cattle manure. Also, it enhances the production of protein feed for algae and hence, efficiently remediates dairy waste water.

Table 3 Various species of algae and their effective contaminant removal

Sr. no.	Algal species	Contaminant removal	References
1.	***Chlorella vulgaris***	Ammonia and phosphorous	**Luz Estela Gonzalez, 1997**
2.	***Scenedesmus dimorphus***	Ammonia and phosphorous	**Luz Estela Gonzalez, 1997**
3.	***S. incrassatulus***	Chromium (VI)	**Peña Castro *et al.,* 2004**
5.	***Dunaliella***	Mercury and cadmium	**Imani *et al.,* 2011**
6.	***Pithophora sp.***	cadmium, chromium and lead	**Brahmbhatt *et al.,* 2012**

Microbial removal

The discovery of therapeutic molecules is becoming important as many bacteria become resistant to most antibiotics. Antibacterial effects have been discovered in many species of algae specially the diatoms have a great potential **(Kaaria *et al.,* 2015**). The antibacterial studies are not only important for studying the interactions on an ecological basis but also to study the capability of algae against other microbes and then finding their possible therapeutic applications **(Kausalya *et al.,* 2015)**. Several algal groups contain bioactive compounds with the potency of acting like antimicrobial agents. The metabolites of these organisms either primary or Secondary are being used by pharmaceutical industries to overcome many diseases **(Venkatesan *et al.,* 2007)**. In the past few decades, marine organisms are getting attention, especially macro- and microalgae, sponges, corals. Their bioactive compounds provide alternatives to many antibiotics and are helpful to combat deadly infections and fatal diseases **(Kaaria *et al.,* 2015).** Microalgae or algae produce a wide range of compounds with biological activities. For example, they consist of antibiotics, toxins and pharmaceutically important compounds which have further use as therapeutics **(Ruiz-Martinez *et al.,* 2012).** They have the antibacterial properties which helps in suppressing the growth or killing pathogenic bacteria or other pathogens.

Nitrogen and Phosphorous Removal

A novel method to reduce the effect of eutrophication is to remove nitrogen and phosphorous from waste water by means of algae **(Bernhardt *et al.,* 2008).** The latest technology is a twin layer method where microalgae are immobilized by adhesion on substrate that needs to be wet and microporous and acts as a growth medium where the diffusion takes place **(Apiratikul *et al.,* 2004).** With the help of this, the microalgae are able to remove phosphate, nitrate and ammonia within nine days which is very helpful in remediating wastewater.

Heavy Metal Removal

The very first accumulators of metals in rivers or any other natural water sources are periphytons as they have a fast-regenerative process and higher biomass than others **(Anjana *et al.,* 2007)**. Microalgae or diatoms are key organisms in the periphyton and being considered as bioindicators, if there is any disturbance in the hydrosystem **(Apiratikul *et al.,* 2004)**. Diatoms have a silica cell wall called frustule and they have diverse forms depending upon the species. The growth cycle of diatoms can be fast with durations from hours to days. However, some interruptions or disturbance in the hydrosystem affects their development and growth. These non-natural factors include heavy metals which results in the deformations of the frustules **(Nanda *et al.,* 2010)**. Diatoms detoxify heavy metals by removing organic or inorganic compounds which are responsible for the formation of natural biofilms **(Imani Saber *et al.,* 2011)**. Diatoms are used as bioindicators of radioactive effluents as they accumulate radioactive minerals in their cell wall and this way remove them from water **(Guasch *et al.*, 2009).**

Algal Flow Way Systems

One of the application of algae is that they are highly efficient in converting renewable solar energy and hence the production of many metabolites. And the world is taking advantage of this due to such properties of algae. Although many applications of algae have been explored still its economic constrains need to be addressed (**Chen *et al.*, 2015)**. There are commercial reactors for algal mass culturing, and all are developed as open flow way systems for instance, paddle wheels help in the circulation of culture. There are open shallow ponds where wheel is paddled to circulate the culture, but they have certain disadvantages. This led to the use of photo bioreactors that are enclosed in which light sources are either artificial or natural **(Williams *et al.*, 2019)**. A method of removing nutrients, organic pollutants, or contaminants has been developed and that is known as algal turf which is used as a scrubber as well as it is also beneficial for biomass production of algae **(Tilak *et al.*, 2017)**. The principle of this technology is based on the fact that the scrubber also acts as growing surface for spores and algae provided on the water which is subjected to periodic water surge action and hence promotes ambient cellular water exchange. The light is supplied either by artificial mode or naturally and the turf is finally harvested before overgrown by algae **(Walter *et al.*, 2008)**. Algal turfs are networks consisting of accumulations of unicellular to branched filamentous algae. These are fastened to rock, plant stems and wood **(Schulze *et al.*, 2017)**. Most algae have species which are present in turfs: green algae in fresh waters, brown and red algae in marine waters and diatoms and blue greens generally **(D'Aiuto *et al.*, 2015)**. Besides, they bolster epiphytes and enmeshed algal unicellulars are frequently kept up by fish and invertebrate slow eaters even with rivalry by bigger algae **(Adeniyi *et al.*, 2018)**. Algae give algal turfs an essential framework according to definition, they are biodiverse networks consisting of protozoans as well as little spineless creatures. Given solid current, flood or wave activity, daylight and ordinary brushing, algal turfs can effectively catch sunlight **(D' Ippolito *et al.*, 2015)**. Most single cells are photosynthetic, the productivity of algal turfs is additionally the consequence of elevated amounts of blending streaming water, constrained against cells by flood, significantly build synthetic trade. Moreover, photosynthesis in most higher plants and planktonic algal cells is biochemically upset in full sunlight, especially at high temperatures **(Hampel *et al.*, 2013)**. Most significant, in any case, due to the forward and backward swashing of filaments in waves, singular cells get glimmering light and none of the cells are completely shaded by others **(Ganesh *et al.*, 2018)**. This permits an abnormal state of light harvest, and as estimated by O_2 discharge, no hindrance is present even in full tropical summer sun at late morning. A high extent of light vitality caught is exchanged to substance stockpiling as included biomass **(Li *et al.*, 2017)**. Algal turfs are without doubt, all around feebly repressed by low supplement levels **(Liu *et al.*, 2015)**. Singular cells can take-up carbon, phosphorus and nitrogen at portions of ppb levels. As the film of water neighboring every cell can't be depleted of supplements in a flood and stream condition, moderately abnormal amounts of profitability happen even at low supplement fixations **(Lin *et al.*, 2018)**. Notwithstanding utilizing raceway lakes for algal development, algal turf scrubbers have been utilized to give tertiary treatment of civil and horticultural wastewaters **(Gismondi *et al.*, 2016; Gügi *et al.*, 2015; Kangas *et al.*, 2017)**. An ATS is a since quite a while ago, slanted stream way that supports an algal biofilm and microorganisms. Wastewater washes over the stream path in a progression of blasts and furnishes the biofilm with supplements **(Pandey *et al.*, 2015).** The algae expel inorganic supplements, including phosphorus and nitrogen, from the wastewater, consequently lessening downstream eutrophication impacts. The supplements are expelled from the framework when the algal biomass (5% to 6% solids) is gathered by scratching **(Pinto *et al.*, 2018)**. These have exceptionally high supplement profluent content (around 2,000 milligrams for each litre of complete Kjehldahl nitrogen [mg/L TKN] 1 and around 500 mg/L of phosphorus) **(Pandey *et al.*, 2016).** These frameworks are not planned for amazing treatment, yet rather limit spillover into surface waters. Past research on ATS frameworks has concentrated on their adequacy in treating wastewater and the financial matters of the procedure yet has not connected life cycle techniques to measure natural effects. ATS frameworks can adequately treat wastewater in lab-scale contemplates (**Úbeda *et al.*, 2017**). HydroMentia Inc. has likewise introduced ATS frameworks to treat rural spillover at business scales. Algal biomass created by ATSs has a low unsaturated fat content and is in this way inadequately appropriate for biodiesel generation **(Pate *et al.*, 2013).** Therefore, biomass of algae is anaerobically processed to deliver biogas that is combusted for power generation.

Nanotechnology in waste water treatment

Nanotechnology provides an opportunity of upgrading waste water treatment. Moreover, it has many advantages like cost effectiveness, reusability and being highly efficient in removing and recovering pollutants due to its high surface area. Nanoparticles such as gold, silver, titanium, copper, zinc and iron etc. can be synthesized through various microorganisms like *E. coli*, *Lactobacillus*, *Pseudomonas*, fungi and algae. These nanoparticles have antibacterial properties, and dye removal or heavy metal removal can be done with the help of such particles, hence being effective in remediating waste water **(Kim *et al.*, 2007).** The defense mechanism of microbes helps in the synthesis of nanoparticles, for instance, the bacterial cell resistance for silver ions is responsible for its nanoparticle synthesis. Nanoparticles are a part of microbial metabolism and can be utilized for many other applications. Nanoparticle research is an emerging scientific field, due to various potential applications in biomedical, optics, electronics and waste water treatment. Nanoparticles are augmented as the materials having new or unique or progressive traits in comparison to other larger particles. Nanoparticles have properties like the surface to volume ratio is higher, high thermal conductivity, steadiness, non-linear optics, specificity **(Buzea *et al.*, 2007).** The applications of nanoparticles due to these properties are show in Table 4. Nanoparticles having such characteristics are currently playing significant roles in medical diagnostics, drug delivery systems, gene therapy applications, and tissue engineering and remediation too **(Balantrapu *et al.*, 2009).**

Table 4 Applications of nanomaterials in pollutant removal

TYPE OF NANOPARTICLES	TYPE OF POLLUTANTS REMOVED
Carbon Nanotubes	Organic pollutants, contaminants
Metal Oxides Nanoscale	Heavy metals
Nano Catalyst	Pesticides, azodyes
Bioactive Nanoparticles (Ag, Au)	Antimicrobial, antibacterial
Biomimetic Membranes	Salt removal
Nanostructured Catalytic	Inactivation of microbes, decompose pollutants

Synthesis of nanoparticles

Various modes of the synthesis of nanoparticles has been implemented as per the requirement like physical, chemical and biological. Figure 3 shows the different methods for nanoparticle synthesis with examples, it can be easily understood by having a look at the figure.

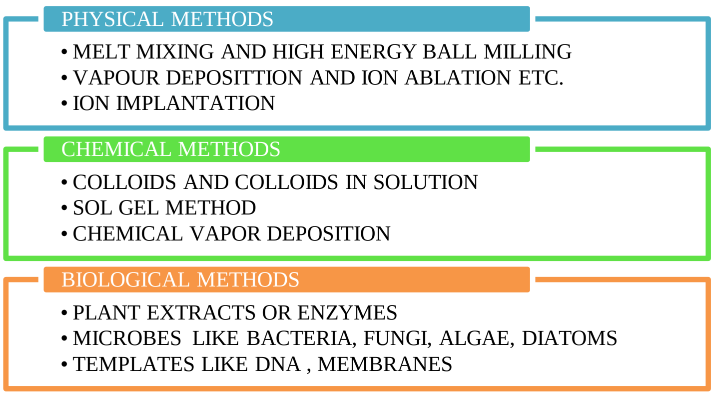

Figure 3 Different methods of nanoparticle synthesis

Green synthesis or biological synthesis

Green or biological or biogenesis is an environmentally friendly method for nanoparticle synthesis with increased usage and applications of nanoparticles, it is required to develop an easy and environmentally sustainable or green path for nanoparticle development. Many routes were followed to develop nanoparticles like plant extracts, bacteria like lactobacillus or *E. coli*, fungi like *Torilopsis*, algae like *C. vulgaris* have been used but among all, microalgae got great attention since they are capable of bioremediating harmful toxins and subsequently transforming them into other useful compounds. In recent times, nanoparticles which are synthesized biologically got high attention in the area of molecular biology and therapeutics due to their unique properties **(Vijayakumar *et al.*, 2012).**

Algae used for nanoparticle synthesis

The main types of nanomaterials that can be synthesized from algae are either metal nanoparticles or metal oxide nanoparticles **(Asmathunisha *et al.*, 2013).** Table 5 shows a few algal strains used for both types of nanomaterials which are later discussed in detail.

Table 5 Different types of nanoparticles synthesis from different algal species

MATERIALS	NANOPARTICLE	SIZE	ALGAL SPECIES	REFERENCES
	Silver	45-80	*Codium capitatum*	**Kannan *et al.*, 2013.**
Metals		25-40	*Padina gymnospora*	**Shiny *et al.*, 2013.**
		45-76	*Sargassum cinereum*	**Mohandass *et al.*, 2013.**
		45-57	*Gracilaria corticate*	**Naveena *et al.*, 2013.**
		60	*Turbinaria conoides*	**Rajeshkumar *et al.*, 2013.**
	Gold	10-30	*Sargassum wightii*	**Singaravelu*et al.*, 2007.**
		18-95	*Stoechospermum marginatum*	**Arockiya*et al.*, 2012.**
Metal oxide	Copper oxide	44-76	*Bifurcaria bifurcate*	**Abboud *et al.*, 2014.**
	Zinc oxide	11-67	*Sargassum muticum*	**Azizi *et al.*, 2014**
		55-80	*Chlamydomonas reinhardtii*	**Rao *et al*, 2016**
		30-57	*Sargassum muticum*	**Azizi *et al.*, 2014**
	Iron oxide	22-80	*Sargassum muticum*	**Mahdavi *et al.*, 2013**

A general procedure for the synthesis of algal based nanoparticles is demonstrated in figure 4, showing a very simple and easy procedure to synthesize nanoparticles if the optimum conditions like temperature, pH and concentration of algal extract and metal salts are provided. The synthesis with biological mode generally takes the time of few hours to several days depending upon the strains.

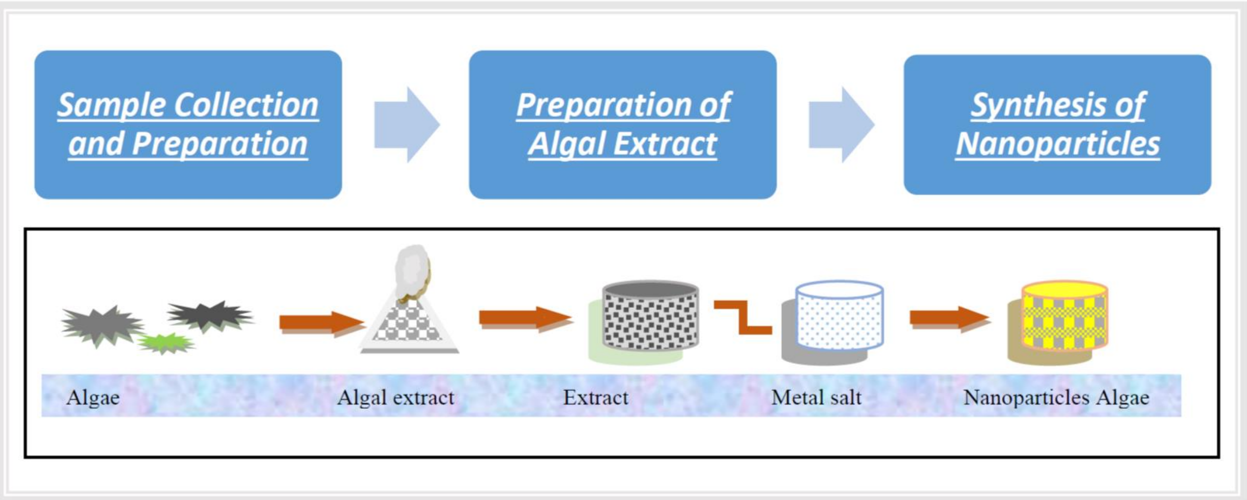

Figure 4 Nanoparticle synthesis from algal extract

Synthesis of metal nanoparticles from algae

The biological based synthesis of metal nanoparticles using different algal species from their salts is a simple process at room temperature. The synthesis can be easily initiated by mixing the solution of metal salt with aqueous algal extract. The color change of the reaction mixture indicates the synthesis of nanoparticles **(Gericke *et al.*, 2006).** The studies have shown the various experimental factors responsible for the nano-synthesis of metals like algal extract concentration, concentration of metal salt, reaction time, temperature, and pH.

Silver nanoparticles- Silver nanoparticles have properties like optical, thermal, electrical, conductance which are used in the development of products like chemical sensors to photovoltaics and from biosensors to diagnostic devices. Furthermore, they have antibacterial properties due to which they are used frequently in treating contaminants. For instance- pastes, conductive inks etc. use silver nanoparticles due to its unique property of high stability, high electrical conductivity and low sintering temperature. There are several applications of silver nanoparticles and many products are incorporated with such silver nanoparticles **(Gilaki, 2010)**. A newly emerging application of AgNPs are antimicrobial bandages, wound coatings and devices, molecular diagnostics. The medical devices and wound dressings containing AgNPs slowly but steadily release levels of silver ions that provide protection against bacteria by killing them **(Salari *et al.*, 2016).** Also, it is efficient in the removal of textile effluents, congo red dye, nitro-phenol etc.

Gold nanoparticles

Au nanoparticles have very unique size dependent properties and that have a wide variety of applications like as catalytic agents, biosensors, pharmaceuticals, for imaging, and electronics and due to these properties researchers are focusing on the different methods to synthesize gold nanoparticles. Algae have been found as potential organisms for its synthesis **(Arockiya *et al.*, 2012).** Researchers found that the functional groups present in microalgae have the capability of synthesizing stable particles with different shapes and these gold nanoparticles are helpful in removing dyes like methylene blue, methyl orange, and dichloromethane with potential applications in remediating wastewater **(Parial *et al.*, 2012).**

Other metallic nanoparticles

There are very less studies which show the synthesis of other metal nanoparticles like cadmium or palladium from algae. However, by the use of marine algae many types of nanoparticles have been synthesized like cadmium sulphide (CdS) nanoparticles. And spherical palladium (Pd) nanoparticles **(Rajvaiday and Markendey, 1998).**

Synthesis of metal oxide nanoparticles by algae

Metalloxides come under the class of organic material and due to their wide range of properties and structures they are being explored extensively. Their characteristics are more complex than those of other pure metal nanomaterials. They have unique properties as they possess different compositions and physiochemical structures which are further utilized in catalytic, magnetic, solar energy, and remediation applications. Current studies show very less or limit the synthesis of metal oxide nanoparticles by the algae.

Zinc oxide nanoparticles

Zinc oxide nanoparticles have certain applications in the removal of heavy metals from water like arsenic removal, cadmium removal, formaldehyde, phenol, and various dyes like brown CGG, organic dyes, methylene blue and malachite green dye. One of the algae which is used for its synthesis is *Cystophora* spp. **(Shamsuzzaman *et al.*, 2013).**

Iron oxide nanoparticles

Iron oxide nanoparticles have many applications especially in terms of water remediation as they are helpful not only in remediating heavy metals like chromium, lead, nickel, but also radioactive materials like uranium, dissolved sulphates and nitrates.

Nanoparticles supported adsorbent models for waste water remediation (Nanoadsorbents)

Adsorption is an effective, economical, and ecofriendly technique that has potential to make water reusable and also fulfill high quality standards of effluents in the industries **(Pan and Xing, 2008**). This technique involves the process of transferring the substance from the liquid phase to the solid surface and this is subjected to physical and chemical interactions. Adsorption can be done batch wise, semi batch or continuous. The adsorption can be of two types either physical or chemical depending upon their intermolecular attractive forces. The Physical adsorption occurs when the adsorbate gets attached to adsorbent through van der Waal forces whereas chemical adsorption occurs through surface modifications and with the help of electronic bonds. There are several adsorbents available, but it is necessary to use low cost adsorbents for effective removal of contaminants. Zeolites, peat moss, activated carbon, and neem bark are very efficient adsorbents. Agricultural wastes or their byproducts can also be utilized as low-cost adsorbents. Adsorbents must have thermal and chemical selectivity, kinetic characteristics and stability. Adsorbents must have regeneration capacity and low solubility in liquids. Various low-cost adsorbents are derived from wastes and nowadays diatomaceous earth is also utilized as adsorbent. The reason for using these adsorbents is that they are economical. In last few decades the new type of adsorbents has been developed to conquer the problem of waste water so that one can reuse it and that are nanoadorbents. Various types of nanomaterials have been synthesized like carbon nanotubes, nanocages, nanorods etc. **(Narr *et al.*, 2007).** Metal oxide nanoparticles exhibits higher adsorption properties as compared to normal sized oxides. Wastewater is commonlyloaded with very hazardous pollutants and contaminants so treatment with those nanoadorbents is necessary as they are highly efficient compared to other adsorbents. Nanomaterials as adsorption material emerged as one of the technologies with great potential to solve the problem of waste water treatment. Some distinctive properties of nanoadsorbents like their small size and high surface area make them unique. This technology is the revolution for waste water treatment technologies capable to revolutionize the wastewater treatment. For instance, silver nanoparticles have been implemented in the fabrication of adsorption models **(Dominika *et al.*, 2019).** This technology is the revolution for waste water treatment technologies capable to revolutionize wastewater treatment. Figure 5 demonstrates the process of waste water remediation by adsorption processes. There are a number of water purification procedures, yet adsorption is a standout amongst the easiest, compelling, and affordable techniques for wastewater purification **(Marichelvam *et al.*, 2018).** In this article a plethora of solid adsorbents are mentioned, like natural adsorbents, agricultural wastes, industrial wastes, biomass, nanoadsorbents: carbon-based nanomaterials, novel metal-based nanomaterials, metal oxide-based nanomaterials **(Xinling *et al.*, 2019),** Spinel ferrite based nanomaterials, nanocomposites, dendritic polymers, geopolymer cement have been mentioned for the expulsion of various pollutants from waste water. Removal of fluoride, phosphate, nitrate and radionuclides from wastewater can be removed by such adsorption models **(Venkata *et al.*, 2018).** Adsorption isotherm models, kinetic models, thermodynamic parameters and adsorption mechanism can be examined after whole adsorption process **(Tanweer *et al.*, 2018).** The present article records distinctive types of adsorbents and surveys best in class of the removal of different pollutants from water **(Juntao *et al.*, 2018).** Sources of contamination and toxicities of pollutants have also been discussed. Adsorption mechanisms responsible for pollutants removal by different adsorbents have been reviewed **(Abhishek *et al.*, 2017**). The present review demonstrates late advancements of nanotechnology in the synthesis of nanoadsorbents **(Menghua *et al.*, 2017).** The primary target of this review is to depict adaptable ways of phycosynthesized nanoparticles and their capacity to adsorb variety of inorganic contaminants, which are available in the water **(Andrea *et al.*, 2019)**. It is evident from the review that synthesized nanoparticles (low-cost adsorbents) have demonstrated high removal capabilities for certain inorganic contaminants from water.

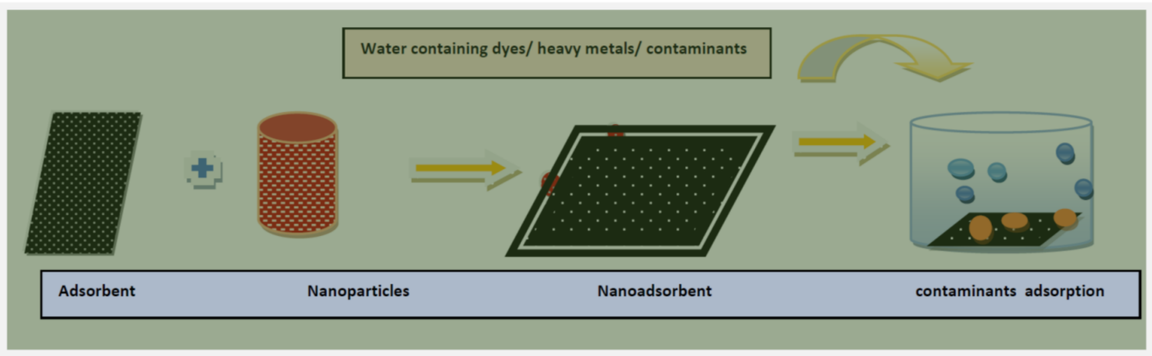

Figure 5 Effective contaminant removal by nanoadsorbents

Because of environmental dangers of effluents, treatment is fundamental before disposal. It may lead to improved water and/or oil segregation, oil recovery, improved quality of water, reuse of water, downstream facility protection and environmental permit compliance **(Ana *et al.*, 2016).** Numerous methods are there for segregation of oil–water emulsions, counting different filters **(Hendrik *et al.*, 2016),** chemical dosing, RO, separation by gravity, micro-filtration**,** ultra-filtration **(Rui-Lin *et al.*, 2015),** biological processes **(Amit et *al.*, 2015),** air flotation **(Arshad *et al.*, 2015),** membrane bioreactor **(Haicheng *et al.*, 2015),** chemical coagulation, electrocoagulation and electroflotation **(Imran Ali *et al.*, 2016).** One common method for the removal of water dissolved organics is adsorption. It includes detachment of substances from the liquid phase to a surface.

CONCLUSION

The removal of nutrients from high organic content waste water is possible by phycoremediation as it has the great potential to mediate eutrophication in the several regions of world. However, more development is still required in this field. The points that can be concluded from this study are: a) Micro- or macroalgae show a high efficacy of nutrient removal. b) Algae are effective in sludge decomposition. Before commercialization or industrial acceptance more studies are required to scale up phycoremediation technology in order to remove waste by utilizing biomass as well. India as a tropical country with abundant solar irradiation is particularly suited for the application of phycoremediation. The invention of algal flow way systems is leading to the development and harvesting of algal turf. These turfs utilize natural as well as artificial light to promote the growth of algae and they are very efficient scrubbers of carbon dioxide, organic pollutants or nutrients found in waste water as well as in natural waters. The biogenic production of various types of nanoparticles is receiving high attention due to its ease and effectivity. Several bacteria and plants are able to synthesize nanoparticles. Now researchers are focusing on the development of nanoparticles through algae. Nanoparticles may have great antibacterial properties has and a great potential in treating waste water whether it comes from sewage, textile, agricultural or other sources. More investigations will be helpful in explore the potential of microalgae to synthesize many other metallic nanoparticles that have other applications in the pharmaceutical, food, cosmetic, medical and wastewater treatment industries. The microalgae can be used for the synthesis of nanoparticles and their biogenesis is getting favored compared to chemical and physical synthesis of nanoparticles. Their biosynthesis is safe, economic, cheap, cost effective, and ecofriendly. More research is needed for the development of nanoadsorbents in wastewater treatment. The investigation and studies about their adsorption abilities make them more productive and reusable at large scale. Furthermore, other adsorbent models or materials should be investigated such as the wood bark, activated carbon, sieves, membranes and their applications in the regeneration of wastewater.

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