RESEARCH ARTICLE

Cyanobacteria's role, as a feasible agricultural potential and environmental hazard remediation: Review

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Cyanobacteria, a diverse group of photosynthetic microorganisms, have gained recognition for their potential contributions to agriculture and environmental hazard remediation. This critical review aims to comprehensively analyze the current understanding of cyanobacteria's role in these areas. In fact, cyanobacteria are available both in terrestrial and aquatic environments. In the realm of agriculture, cyanobacteria have shown promise in enhancing productivity through various mechanisms. Their ability to fix atmospheric nitrogen, solubilizing phosphorus, consortia formation etc. boosts soil fertility and downloads usable nutrients for plants. Additionally, cyanobacteria contribute to carbon sequestration by fixing carbon dioxide through photosynthesis, aiding in climate change mitigation. Cyanobacteria have enriched with carbohydrates, proteins, polyunsaturated fatty acids, vitamins and minerals, which avoid starvation, deficiency disease and exacerbation of poverty. The advantage of cyanobacteria bio fertilizers were environmental suitable, counter limitation, renewable and, reduce dependence on synthetic fertilizers. Moreover, the inoculation of cyanobacteria bio fertilizers in the soil improves soil fertility, nutrient availability and crop resilience to environmental stresses. Cyanobacteria also, play a significant role in soil aggregation, enhancing soil structure, water infiltration and nutrient retention. In environmental hazard remediation, cyanobacteria contribute to nutrient cycling by assimilating excess nitrogen and phosphorus, reducing the availability of these nutrients for Harmful Algal Blooms (HABs). Cyanobacteria can synthesize metal-binding proteins, which provide resistance to metal and other environmental stresses. The synthesis and secretion of bioactive compounds and biofilm formation helps, bind with heavy metals, agrochemicals, oil and other wastes enhanced the efficiency of waste remediation. This review aid for further research and technological advancements to harness their full potential. This review also discusses a feasible agricultural potential and ecological contribution of cyanobacteria. Overall, this critical review provides valuable insights into the potential of cyanobacteria in addressing agricultural and environmental challenges. It underscores the importance of understanding their role in sustainable practices and highlights the need for interdisciplinary approaches to maximize their benefits while minimizing potential risks.

Key words: *Cyanobacteria; Toxic wastes; Exopolysaccharide; Heterocyst; Biofertilizer*

INTRODUCTION

Continuous increase of global human population and their demands such as food, pure water, infrastructure, industrial products etc., related to resource distraction, environmental pollution and global warming [1]. In addition, the rapid human population growth and their demands have contributed to huge agricultural land cultivation, increased fertilizer consumption, urbanization and expansion of industries. Moreover, infrastructure, agricultural activities, rapid industrial booming and nuclear explosion have led to land degradation, aquatic pollution, health risks and rise climate crisis. Farmers widely applying mineral fertilizers on their agricultural lands. As these, inorganic fertilizers are expensive and indirectly accumulated in animal or human body and cause health impacts. Hence, excessive use of chemical fertilizers leached down soil nutrients and damage soil organisms. Nowadays, the conventional agricultural systems are highly depending on burning of herbaceous cover, excessive use of chemical fertilizers, herbicides and pesticides have caused contamination of water bodies, damage to soil structure, loss of nutrients, high erosion rates and loss of biodiversity [2].

Furthermore, several industries generating pollutants, due to industrial expansion, various industries, such as chemical, nuclear, textiles, oil refineries, etc., generate pollutants [3].This effluents cause significant risk in excavation, handling and transport of hazardous materials. Hence, the contaminants cause toxicity to surface water bodies and land around industrial, area, which leach down and pollutes ground water bodies to the greatest extent [4]. The run-off contaminated soil by water/wind erosion has many disadvantages as it does not degrade or remediate the pollutants in to simply nontoxic form [5]. Accordingly; contaminated environments are sources of several diseases.

However, designing, formulating and utilizing eco-friendly, cost effective and health auspicious organic based fertilizer would be crucial. The method of treating and remediating wastes is expensive and keeping the ecosystem healthy, safe and productive is a major concern. For a century, numerous physical and chemical methods are used for the degradation and detoxification of effluents, but rather than incomplete degradation, they only change their form. These changed forms are even toxic and have the capability to cause damage even in a very low concentration [6]. The use of photosynthetic bacteria for bioremediation of contaminants is an ecofriendly and cost-effective technique and has properties for possible recovery of nutrients and can solve environmental problems [7-8]. Cyanobacteria are the most promising remedy for agricultural and environmental challenges. Cyanobacteria have emerged as potential candidates for their application in the development of environment safety and sustainable agricultural practices [9,10]. Blue green algae are diastrophic organisms, which have adapted wide habitats such as extremes of temperature, UV irradiance, drought, salinity and rapid hydration/ dehydration cycles [11-13]. Cyanobacteria possess a cellular mechanism that helps them tolerant to environmental changes and reproduce simply as a massive population with high speed. These fast growth rates depend on variations in nutrient types, biotic factors, abiotic factors, climate change or global warming [14, 15].

Actually, cyanobacteria are available in aquatic and terrestrial environments. The application of cyano-bacterial bio fertilizer has eco-friendly, cost effective organic and avoids the dependence on chemical fertilizers. In addition, the inoculation of cyano-bacterial extracts in farmlands and

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polluted environments promote soil fertility, upgrade agricultural productivity and enhances environmental safety. In general, due to phyto-hormones production, exo-polysaccharide secretion, metabolic pathway and symbiotic association forming capabilities cyanobacteria improved performance of plant growth, induced yields and eliminating wastes. In contrast, incommensurate concerns given for cyanobacteria. Yet, due to increased pollution caused by the use of agrochemicals, industrial wastes generation and urbanizations, scientists are seeking ways to explore environment friendly, cost effective organic fertilizers and substrates from nature. The unique property of cyanobacteria can adapt various environments, hence as the native and mutant cyanobacteria easily available almost every environment. They can be isolated, identified and categorized using morphological traits, they have cultivated from various sources such as polythene bag, photo-bioreactor, freshwater, wetlands and wastewaters. So that, enough biomass production and investments of cyanobacteria could be crucial in the near future for potential benefits, as they can be used to produce valuable inoculum/carrier materials, including bio-fertilizers, biodegradable substances and food tablets. Cyanobacteria possess a relatively simple genome; therefore, it is easier to recombine their genes. Molecular conformation further aided in the identification of superior quality traits. So, the present review discusses on the role of cyanobacteria as bio-fertilizer, food values, soil fertility improvement and cyano-remediation. The application of cyanobacteria is broad. Nevertheless, some cyanobacteria members are harmful.

MATERIALS AND METHODS

Cyanobacteria's role, as a feasible agricultural potential

Cyanobacteria as functional foods: The chloroplasts of cyanobacteria contain thylakoid and stroma. Both light dependent and dark reaction (Calvin cycle) are takes place in the body of cyanobacteria. The photosynthetic raw resources of cyanobacteria include light, carbon dioxide, water and nutrients, whereas metabolic products include carbohydrates, protein and lipids [16]. A cyano-bacterium (blue green algae) contains a high concentration of protein, healthy fats, minerals, antioxidants and vitamins [17-20]. Cyanobacteria have been cultured for over 20 years due to their high PUFA content, which can be used as a nutritional supplement in both human meals and animal feed. For a long period of time cyanobacteria members such as, *Spirulina*, *Anabaena* and *Nostoc* are taken as, human food in various nations throughout the world, including Chile, Mexico, Peru and the Philippines. Similarly, the cyano-bacterium *Spirulina* (*Arthrospira*) has been used by the Aztec population as a food supplement.

Moreover, the indigenous population of the Lake Chad region of Africa uses *Spirulina* (*Arthrospira*) as a hardened, sun-dried mats (Dihe) as a food source, rich in proteins, minerals, carotenoids, vitamins, folate and lipids containing essential unsaturated fatty acids. The cyanobacterial extracted pigments, such as astaxanthin, β-carotene and phycocyanin are used in feeds and foods, these are proved to be having much health importance for example phycocyanin a phycobilin protein, plays a major role in cholesterol degradation.

The cyanobacteria members *Arthrospira platensis* (*Spirulina platensis*) was cultivated at a large scale in outdoor ponds or sophisticated photo-bioreactor harvested and marketed as powder flakes, tablets or capsules. It contains more than 60% protein and is rich in beta-carotene, thiamine and riboflavin and considered one of the richest sources of vitamin E and vitamin B_{12}. The cyanobacterial member *Arthrospira* (~20 g) can provide the required regular doses of vitamin B12 and 50% of vitamin B_2 (riboflavin), 70% of B_1 (thiamine) and 12% of B_3 (niacin) in humans. *Spirulina* can be used for feeding hens because it promotes egg production with intense yolk quality, while *Spirulina*-fed fish develop a pink yellow meat of high commercial value. In fact, *N. commune* is a rich source of fibers and proteins. Surprisingly, cyanobacteria members like *Spirulina*, *Anabaena* and *Nostoc* could be a source of amino acids and enriched with essential nutrients, which avoid starvation and malnutrition or deficiency disease, death and exacerbation of poverty. *Arthrospira platensis* consumed by humans, hens and other organisms it provides energy, generate heat, build body tissue, increase body weight, facilitate blood circulation, bone strength, repair damaged muscle, balance cholesterol and develop immunity system.

Cyanobacteria as bio-fertilizer: People use algae in agricultural lands dates from thousands of years ago: For example, in coastal areas of Europe, farmers used to apply algae harvested near the shore in their cultures, both directly or after composting and observed positive effects in soil fertilization. At this time, algal biomass has been extensively used in agriculture, but in the 20th century, products obtained from algal extracts have attracted the attention of farmers worldwide. Especially cyanobacteria are playing pivotal role in ecological and agricultural productivity. Cyanobacteria are major biomass producers both in aquatic as well as terrestrial ecosystems and represent more than 50% of the biomass in many aquatic ecosystems.

Hence, cyanobacteria can be employed as natural bio-fertilizers and contribute to increased productivity in a number of agricultural and ecological circumstances. The application of cyanobacteria fertilizers in conjunction with the formation of organic acids with chelating properties improves the availability of micronutrients to the plant. Chelating compounds can boost micronutrient availability to growing plants. Cyanobacteria are recognized for their agronomic benefits, acting as one of the major determinants of soil fertility by providing organic matter, nitrogen and phosphorus, reducing the loss of fertile soil due to erosion and winds and thus favoring plant settlement. Several studies have indicated the favorable effects of cyanobacteria as a source of bio-fertilizers on a variety of crops, including cereals such as rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) and radish. The application of cyanobacteria in soils enhances nitrogen availability, which is one of the important macronutrients for plant growth and development.

In the rice field, a cyanobacterial inoculum composed of *Aulosira fertilissima*, *Anabaena sphaerica*, *Nostoc hatei*, *Cylindrospermum majus* and *Westiellopsis* prolific boosted nitrogen availability in the soil, improving rice productivity, grain and straw yields.

The utilization of cyano-fertilizer has been shown to decrease soil pH and increase β-carotene concentration in kale, as these, the decrease in soil pH also may facilitate the increased uptake of Zn and Fe in kale. Inoculation with various nitrogen fixing cyanobacteria species such as *Nostoc, Calothrix, Tolypothrix* and *Scytonema* in non-waterlogged soils has also shown beneficial results in terms of soil quality improvement and plant growth promotion in a variety of crops such as tomato, wheat, maize and lettuce.

Similarly, Singh and Datta demonstrated that utilizing *Anabaena variabilis* strains in a rice field promoted an overall improvement in rice crops (e.g., increase in plant height and leaf length and improvement of seed, grain and straw productivity). Munoz-Rojas et al., conducted a restoration study on seeds of native Australian plant species, which they covered with cyanobacteria before planting in the soil. It demonstrated a considerable increase in seed germination percentage when compared to seeds that were not covered with cyanobacteria. Swarnalakshmi et al., found that using a biofilm composed of the cyanobacterium *Anabaena torulosa* in wheat crop boosted nitrogen availability in the soil considerably. In wheat plants, *Anabaena* sp. applications dramatically enhanced seed germination rate, shoot length, tillering, number of lateral roots, spike length, grain weight, protein content, micronutrients and endogenous phytohormones pool.

When Innok et al., applied *Nostoc* sp. vegetative cells to a rice field; they obtained grain production increases comparable to those produced with a chemically based nitrogen fertilizer. Osman et al., added the cyanobacterial species *Nostoc entophytum* and *Oscillatoria angustissima* to the soil designed for pea plant production, resulting in a considerable rise in the germination percentage, photosynthetic pigments and growth parameters of this plant. This rise was caused by increased nitrogen fixation by cyanobacterial magic activity. Prasanna et al., reported that the response of various cyanobacterial bacterial consortia as fertilizers for soybean and mung bean production, showed positive effects in terms of nitrogen availability in the soil and plant fresh weight. Cyanobacterial members like *Anabaena* iyengarii var. tenuis, *A. fertilissima*, *Nostoc commune*, *N. ellipsosporum*, *N. linckia* and *Gloeotrichia natans* are promoting the productivity of rice fields in Chile. Soil injected with various cyanobacterial strains such as *Nostoc carneum*, *N. piscinale*, *Anabaena doliolum* and *A. torulosa* has significantly higher acetylene reducing activity. Acetylene reducing activity is highest at harvest stage when wheat fields are inoculated with an *Anabaena Serratia* biofilm along with rock phosphate. The use of bio-fertilizers increased the phosphorus concentration in celery because cyanobacteria have phosphorus solubilization activity in addition to the ability to produce several organic acids that lower soil pH, resulting in the transformation of phosphorus from an unavailable to an available form. Additionally, terrestrial cyanobacteria facilitate the increment of trace elements in soil, which are vital for plant development and ion uptake, improving nitrogen content significantly in arid soils.

Saffan and Mohamed showed positive effects when some bioactive substances released by cyanobacteria on the rate of germination of Senna seeds as well as evaluation of the metabolic changes in medicinal plant *Senna alexandrina*. They investigated if the exudates of *Nostoc piscinale* and *N. muscorum* enhanced the germination of Senna seeds. Apart from their beneficial effects on soil and plant protection, the usage of cyanobacteria (culture/ extracts) can directly stimulate plant growth and development by improving germination rates and plant features (e.g., increased shoot and root length, increased leaf area and higher nutritional contents). These gains are due to the activity of cyanobacteria metabolites, which have the potential to stimulate a variety of metabolic reactions, including respiration, photosynthesis, nucleic acid synthesis, chlorophyll production and ion uptake.

Hence, Elarroussia et al., reported that the application of total polysaccharide extracts obtained from *S. platensis* significantly increased the size and length of both tomato and pepper plants. Due to the adaptations of various environments, cyanobacteria isolated from sediments, freshwater, marine water, arid environment, salt affected soils and wastewater. In the laboratory by useful media/BG 11 Media cyanobacteria cultured and identified based on morphological features and molecular sequencing. As the identified effective species, mass cultivated and the biomass applied to seeds, seedling and plants. It provided micro and macro plant nutrients, enhanced amino acids and promoted growth parameters of plants and induced high yields.

Nitrogen fixation by cyanobacteria: Plants utilize nitrogen for their metabolic activities. Nitrogen, an essential macronutrient that determines agricultural productivity, is the largest and most expensive agricultural input. Despite the fact that air and dissolved dinitrogen (N_2) in soil and water is abundant. However, most plants (save those in mutualistic associations are unable to consume atmospheric nitrogen due to chemical inertia, but free-living and symbiotic eubacteria, including cyanobacteria, are able to utilize dinitrogen (N_2) through the process of biological nitrogen fixation. Blue-green algae (cyanobacteria) are able to fix atmospheric nitrogen (N_2), converting it into organic nitrogen forms, which are more easily assimilated by all plants.

Some cyanobacterial members are endowed with specialized cells known as heterocyst–thick-walled modified cells, which are considered the site of nitrogen fixation by nitrogenase enzymes. The enzyme is a complex catalyzed enzyme that converts molecular N_2 into a reduced form such as ammonia. The Nostocacean cyanobacteria are distinguished by un-branched filaments and the presence of heterocysts, which allow for nitrogen fixation. The beneficial effect of heterocyst cyanobacteria on plant development and nutrient uptake. Hence, rice production in tropical nations is mostly dependent on biological N_2 fixation by cyanobacteria, which are found naturally in paddy fields.

Cyanobacteria, especially the dinitrogen-fixers cyanobacteria, increase the nitrogen content in natural desert soils and make it available to plants. Yet, soil surface treated with different heterocystous and non-heterocystous cyanobacteria have enhanced total nitrogen, available nitrogen and available phosphorus. Cyanobacteria can contribute to about 20–30 kg N ha^{-1} as well as the organic matter to the soil, quite significant for the economically weak farmers unable to invest for costly chemical nitrogen fertilizer (Table 1).

TABLE 1

Some nitrogen fixing cyanobacteria genera

Filamentous heterocystous	Filamentous non-heterocystous	Unicellular
Anabaena, Anabaenopsis, Aulosira, Calothrix, Camptylonema, Chlorogloea, Chlorogloeopsis, Cylindrospermum, Fischerella, Gloeotrichia, Haplosiphon, Mastigocladus, Nodularia, Nostoc, Nostochopsis, Rivularia, Scytonema, Scytonematopsis, Stigonema, Tolypothrix, Westiella, Westiellopsis, Wollea	*Lyngbya, Microcoleus chthonoplastes, Myxosarcina, Oscillatoria, Plectonema Boryanum, Pseudoanabaena, Schizothrix, Trichodesmium*	*Aphanothece, Chroococcidiopsis, Dermocarpa, Gloeocapsa, Myxosarcina, Pleurocapsa, Synechococcus, Xenococcus*

N_2-fixing cyanobacteria, particularly, *Nostoc*, form symbiotic associations with a wide range of plants, like flowering plants, as well as with algae and supply fixed nitrogen to their host, this activity promotes plant growth and productivity. Some cyanobacteria have heterocystous/a nitrogenase enzyme; which is the powerhouse of nitrogen fixation or nitrogen fixing machine. Blue green algae are tiptop diazotrophic microorganisms (Figure 1).

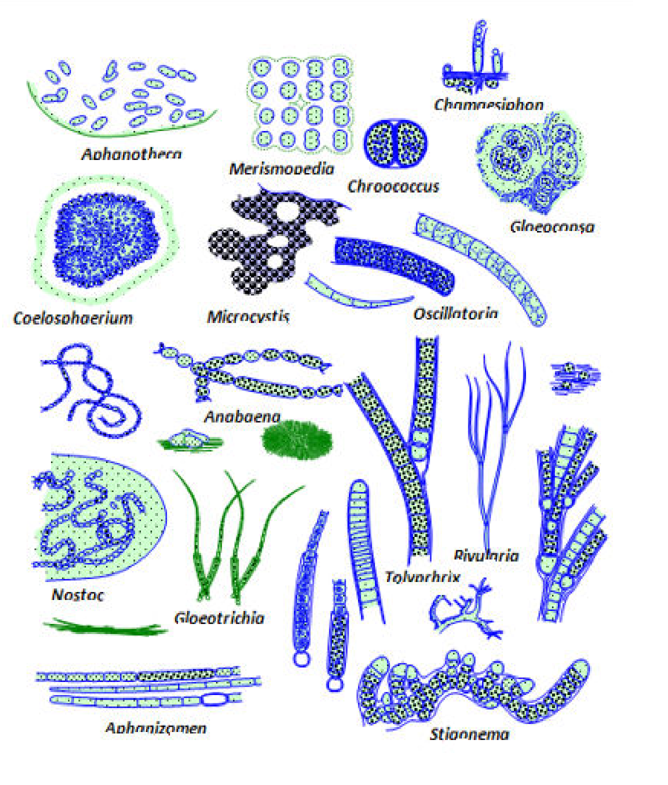

Figure 1) *Nitrogen fixing cyanobacteria*

Phosphate up take: Phosphorus is one of the most important plant macronutrients, regulating all biological processes directly or indirectly. Phosphorus, for example, is required for all important plant metabolic processes such as photosynthesis, energy transfer, signal transduction, chemical formation and respiration. Although soils contain a significant amount of Phosphorus in both inorganic and organic forms, its availability is one of the primary factors limiting plant growth and development. The reason for this is that most soil phosphorus is occluded or insoluble and so unavailable to plants, which can uptake phosphorus from soil solution as orthophosphate ions H_2PO_4 and HPO_4^{2-}. Cyanobacteria have an impact on plant phosphorus availability because they have the ability to convert non-usable forms of inorganic phosphorus to usable forms *via* biological processes. Cyanobacteria can mobilize insoluble inorganic phosphate in soil and mineralize inorganic phosphorus into soluble forms. Furthermore, the application of cyanobacteria in crop fields plays an essential role in the mobilization of inorganic phosphates *via* extracellular phosphatases and the excretion of organic acids.

The enzymatic profile of soil inoculated with cyanobacteria demonstrated the participation of acid phosphatase and alkaline phosphatase in the phosphate solubilisation and therefore proved promising in soils inoculated with strains such as *Anabaena doliolum*, *A. torulosa*, *Nostoc carneum* and *N. piscinale*. According to Swarnalakshmi et al., wheat has the maximum phosphorus absorption in *Anabaena Pseudomonas* biofilm, which affects all biological processes directly or indirectly. Cyanobacteria are capability to provide usable phosphorus to plants in the soil.

Production of plant growth promoting substances: Cyanobacteria contain a variety of extracellular products such as growth promoters, vitamins, helpful enzymes and nutrients, which are known to play an important role in plant growth promotion. Much investigation indicated, cyanobacteria produce extracellular polymers with a wide range of chemical compositions, particularly exopolysaccharides, which promote microbial growth and, as a result, improve soil structure and exoenzyme activity. Cyanobacteria may release plant growth-promoting substances. Hence, cyanobacteria have been shown to benefit crop growth by producing a variety of substances such as growth-promoting regulators, vitamins, amino acids, polypeptides, biotin, metabolites that act as allelochemical agents, proteins, total soluble sugars, antibacterial and antifungal substances that exert phytopathogen biocontrol and polymers, particularly exopolysaccharides that improve soil structure and exoenzyme activity. Exopolysaccharide (EPS) production and active metabolites secretion has been shown to be involved in biofilm formation in cyanobacteria.

In addition, plant growth promoting substances like auxin, cytokinin, gibberellin, etc., released by cyanobacteria accelerate seed germination, seedling growth, root growth, stem growth and download both essential and beneficial plant nutrients.

Cyanobacteria as soil improvement and soil fertility: Cyanobacteria are pioneers on many nutrient-poor and abiotically demanding substrates, forming stable organo-mineral layers that other species can recruit and flourish on. Blue green algae play principal role in waste recycles and biogeochemical cycles. Cyanobacteria develop massive microbial consortia on the soil, which binds the soil particles and form networks at soil layers. Fortunately, the symbiotic associations between cyanobacteria and crop plant create advantages. Moreover, the network of plants and cyanobacteria establish soil fertility, supply nutrients to the plants, improve the productivity of crops in sustainable manner and counter limitation of chemical fertilizer.

Diverse cyanobacteria members, particularly found in rice fields. Filamentous cyanobacteria group always invaded agricultural soil and rice fields. Cyanobacteria can penetrate unstable substrates due to adaptation to varied ecosystems and their presence can improve the environmental role and functions of the soil bio-crust through carbon sequestration and nitrogen fixation. The breakdown of cyanobacteria biomass and exopolysaccharides incorporates organic materials into the soil, increasing the humus concentration. In fact, soil organic carbon content increased after cyanobacteria inoculation. Cyanobacteria release complex organic carbon compounds and polysaccharides that can improve soil properties as aggregation, porosity, permeability, soil particle binding, ventilation and humidity.

Furthermore, Cyanobacteria enhance plant growth and development, giving benefits such as

- Contributing to soil fertility in many environments;
- Producing numerous biologically active compounds; and
- Having a better effectiveness in heavy metal bio-sorption (bioremediation).

Cyanobacteria drive a vital part in the soil microbial community, aiding in the biological restoration of soil deterioration. Cyanobacteria produce a complex surface matrix of EPS (Extracellular Polymeric Substances), water, lipids, proteins and other chemicals that aid in soil colonization by limiting moisture loss and increasing soil particle aggregation. Cyanobacterial activity occurs in the soil's top crust and EPS acts as a glue agent on soil particles. The EPS can bind soil particles together, causing soil aggregation organic content accumulation and an increase in the top layer's water retention capacity.

Around the globe, million hectares of agricultural lands affected by salt either several anthropogenic or natural activities. Salt-affected soil is commonly known as saline soil, sodic-soil or saline sodic soil based on their Electrical Conductivity (EC), Exchangeable Sodium Percentage (ESP) and Sodium Adsorption Ratio (SAR). Furthermore, Usar soils (saline/alkaline, sodic, alfisol and solonetz) highly distributed in the northern part of India (2.5 million ha) are characterized as alkaline and saline, based on the total salt content, imparting high osmotic tension to plant roots for the absorption of water and nutrients.

Cyanobacteria could be used to recover alkaline soils because they form a thick stratum on the surface of the soil during the rainy season and the winter months. This approach termed "algalization" or "cyanobacterization," has been widely studied since the 1950's as an eco-friendly agricultural technique to increasing soil productivity and yields efficiency. In collaboration of salt-resistant plants and cyanobacteria could sustainably remove the salts in the soil and improve the soil fertility. Cyanobacterial species, such as *Microcystis aeruginosa*, *Anabaena oscillarioides* and *Anabaena aphanizomenoides*, have exhibited salt tolerance ranging from 7 g/L to 15 g/L. Polysaccharides have antioxidant activity and can serve as carbon sinks. The ecofriendly benefits of a cyanobacterial EPS matrix include moisture preservation and retention, soil-texture improvement, dust trapping, nutrient sequestration and acting as a reservoir of carbon. Nitrogen fixation is the possible remediation method for salt-affected soil.

Really, the application of cyanobacteria as a CO_2 fix has arisen as one of the best action because they possess a carbon-concentrating mechanism to concentrate CO_2 around the active site of RuBisCO. Because the rate of CO_2 fixation in cyanobacteria is approximately 10-50 times higher than that of terrestrial plants and most efficient, it seems to be a potentially available and easily manageable method to combat the problem of global warming and CO_2 emissions. Moreover, thermophilic cyanobacteria, such as *Synechococcus lividus*, *Synechococcusa quatilis*, *Chlorogloeopsis* sp. and *Mastigocladus laminosus*, having the ability to resist higher temperatures and can therefore be used for CO_2 sequestration from flue gas. The thermophilic and elevated CO_2 tolerance of cyanobacterial mats in large water pools can solve the problem of NO_x, SO_x and CO_2 from flue gas. Yet, less studied has been the effect of cyanobacteria inoculation on soil CO_2 fluxes. In a recent investigation in China, soils inoculated with cyanobacteria showed 3.3 times higher C fixation rates than non-inoculated soils. Munoz-Rojas et al., investigated that the cyanobacteria inoculation of mine waste substrate over 90 days showed a significant increase in the amount of organic carbon from 0.6 g kg^{-1} to 1.9 g kg^{-1}. Cyanobacteria's increased organic C substrate also supports a more prolific and diverse population of soil micro-fauna.

Hence, biocrusts, particularly those dominated by cyanobacteria, are employed as indicators of biodiversity and soil health. In arid, semiarid and desert environments, cyanobacteria are one of the most important microorganisms forming biological soil crust communities, which are recognized to have major roles in hydrological, erosion, biogeochemical and ecological processes and to provide critical services to society. Because of these established roles, soil inoculation with cyanobacteria, also known as cyanobacterisation is advocated as a long-term approach for improving soil quality and combating degradation processes in dry lands.

The decomposed body of cyanobacteria is mixed with the soil and forming mucilaginous agent for soil, increasing humus content and compatibility for plant growth. A *Spirulina maxima*, for example, is known to live under high alkaline circumstances (pH 11) and high salinity, providing an advantage and protection from other competitors and grazers. Cyanobacteria are capable of solubilizing nutrients from insoluble carbonate nodules through the secretion of oxalic acid, thus improving the physicochemical quality and quantity of soils, such as soil aggregation, by lowering their electrical conductivity, pH and water evaporation. Exopolysaccharides produced by cyanobacteria have character of chelating phosphorus and metal ions and buffering H_2O_2. Treatment of radioactive substances from the environment was achieved with a terrestrial cyanobacterium, *Nostoc commune*.

Soil contains living and nonliving things directly or indirectly. As these, soil is damaged by natural, animal and human made activities. However, maintaining, building, reclaiming, preserving, conserving soil and keeping soil health were crucial. Cyanobacteria are diazotrophic microorganisms. Cyanobacteria recover salt affected soils, prevent soil erosion, maintain damaged soil body and replace/succession and invading of bare lands and launch symbiotic relationships with mosses, liverworts, non-vascular and vascular plants (Figure 2).

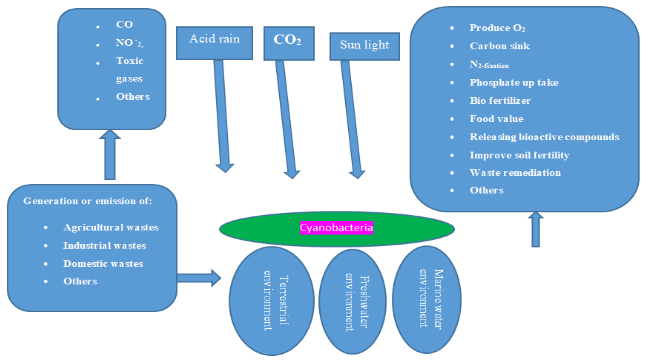

Figure 2) *Agricultural and environmental application of cyanobacteria*

Environmental hazard remediation (Cyanoremediation)

Cyanoremediation of agrochemicals: On the agricultural sector, for the seek of agricultural productivity farmers use agrochemicals. Pesticides and herbicides are agrochemicals used in agricultural fields to kill pests and herbs such as insects, weeds, pathogenic fungus, rodents etc. In fact, as the same time, this chemical is hazardous to agricultural lands, surface water and ground water. In addition, the excessive usage of pesticides in the recent times which poses serious threat to health as they contaminate water.

Moreover, several kinds of insecticides have been noticed in surface water and roused pronounced public attention as the pesticides can result into adverse health hazards even at less concentration. Agriculture run-off introduces harmful substances into aquatic systems, such as organochlorine and organophosphorus. Their accumulation can cause gene and cytotoxicity, immune system dysfunction, reproductive health problems and even death. Hence, it may increase the dangers to the ecosystem and damage a wide spectrum of soil and water microorganisms. Earthworms, which are important for soil processes, have been found to be more vulnerable to the sublethal and lethal effects of these insecticides. However; cyanobacterial bioremediation is an essential method for removing contaminants. Cyanobacteria can also be used to remove excess nitrogen and phosphate from agricultural soils.

According to Forlani, et al., cyanobacteria such as *Anabaena sp., Lyngbya sp., Microcystis* sp. *and Nostoc* sp. breakdown glyphosate and mineralized glyphosate are used as a phosphorus source. Scientists investigated water polluted by compounds like PO_4^{3-}, NO_3^{2-} , SO_4^{2-} and Cl efficiently treated by different species of *Oscillatoria* and *Nostoc*. Caceres et al., observed the transformation of an organo-phosphorous pesticide, fenamiphos (ethyl 4-methylthio-m-tolyl isopropyl phosphoramidate) to its primary oxidation product, Fenamiphos Sulfoxide (FSO) by five different species of cyanobacteria and five of green algae. Cyanobacteria can accumulate in their cells very high concentration of pesticides. According to, Attasat et al., experiment the use of *Oscillatoria okeni* and *Chlorella vulgaris* effectively, remove nitrate-nitrogen from tilapia-pond. El-Bestawy, et al., reported that several cyanobacterial genera *Oscillatoria*, *Synechococcus, Nodularia, Nostoc, Microcystis* and *Anabaena* have the ability to treat or degrade lindane residues. According to, Hirooka, et al. investigation the cyanobacterial mixed culture of *Anabaena variabilis* and *Anabaena cylindrical* removed 2, 4-Dinitrophenol (2,4-DNP) from industrial wastewater, without accumulating 2-Amino-4-Nitrophenol (2-ANP), the degradation product which is a potent mutagen. *A. variabilis* had the capability to treat 2,4-DNP at the concentrations of 5 μM-150 μM with a light and dark cycle, 2-ANP was otherwise accumulated in the culture medium.

In addition, cyanobacterial species such as, *Nostoc linckia, N. muscorum*, *Oscillatoria animalis* and *Phormidium foveolarum* degraded methyl parathion, an organo phosphorus insecticide. The laboratory result of Lipok et al., revealed that *Spirulina sp.* could break down the glyphosate herbicide. Thus, it is fact that the cultivation of cyanobacteria in wastewater, ponds, polythene may have great potential to remediate pollutants, pesticides and help in adjusting the physicochemical parameters in the wastewater (Table 2).

TABLE 2
Some pesticides degraded by cyanobacteria

Cyanobacterial species	Pesticide degraded
Anabaena sp., *Microcystis novacekii, Nostoc linckia, N. muscorum, Oscillatoria animalis, Phormidium foveolarum.*	Methyl parathion
Anabaena fertilissima, Nostocmuscorum	Monocrotophos, malathion, dichlorovos , phosphomidon
Anabaena sp. *A. azotica, A. cylindrica, Cyanothece* sp., *Nodularia* sp., *Nostoc* sp., *Oscillatoria* sp., *Synechococcus* sp.	Lindane
Synechocystis sp. Strain PUPCCC 64	Chlorpyrifos
Synechococcus elongatus, Anacystics nidulans and Microcystis aeruginosa	Removal of insecticides contaminants, *i.e. o*rgano-chlorine and organo-phosphorus

Oil and petroleum degradation: Currently, seas, oceans and coastal zones are highly affected by crude oil pollution, which is a major impact to the biodiversity and sustainability of planet earth. The discharge of liquid petroleum pollutants, *i.e.*, crude oil and their by-products into aquatic sources due to anthropogenic activities caused a risk in the aquatic environment. Petroleum oil is an intricate mixture of sequestered hydrocarbon compounds, such as resins, cycloalkanes, n-alkanes, asphaltenes, aromatics and other non-hydrocarbon compounds. Yearly, estimated about, 35 million barrels petroleum has been transport across the world that is an important source of oil contamination. Furthermore, oil refinery effluent is else sourcing which escalate pollution in aquatic system. It is suggested that, about 50% of the total coastal wetland loss has been caused by oil spills.

Eventually, long period/extended time exposure to petroleum products has become a serious environmental risk to all living organisms, including microorganisms, negatively affecting the stability of many aquatic life as well as, terrestrial ecosystems. The consequences of oil and petroleum pollution includes, such as reproduction problems, food disappearance and habitat destruction. Moreover, lead to mutation problems in aquatic life particularly when contaminated with Polycyclic Aromatic Hydrocarbons (PAH). The common sources of hydrocarbon pollution are the spills and leaks of petroleum products, these crude oil and petroleum distillate outputs directly run and mixed with the freshwater/marine environment are immediately subjected to numerous physical, chemical and biological changes.

In addition, the breakup of oil and it's introduced as small particles from the surface to the water column essential process in the disappearance of a surface slick. Moreover, logistics with ships and tanker is the main source of petroleum spillage and about half of these petroleum products are transported across the world by sea. These polluted environments seriously affect soil biota, biodiversity, animals, humans and aquatic life. However, ecofriendly, effective approach needed. Cyanoremediation is effective and cheapest practice operating and remediation of petroleum/oil-contaminated bodies. Chaillan, et al., revealed that cyanobacterial mats are ubiquitous in tropical petroleum-polluted environments and form a high state of a microbial consortium that contains excellent hydrocarbon degraders. Raghukumar et al., showed that mixed cultures of three cyanobacterial species (*Oscillatoria salina, Plectonema terebrans and Aphanocapsa* sp.) treated over 40% of the crude oil. Cyanobacteria may exist in mixed cultures and thus has the capability of remediating culture oil pollution, either alone or in combination.

The consortium of *Oscillatoria* gamma proteobacteria can degrade phenanthrene, dibenzothiophene, the consortium of *Anabaena oryzae* and Chlorella kessleri can be used to biodegrade crude oil under mixotrophic conditions. Cyanobacteria taking up and assimilating organic compounds, which may play principal role in secondary metabolism. Moreover, cyanobacterial species such as *Aphanocapsa* sp., *Oscillatoria salina*, *Plectonema terebrans* and *Synechococcus* sp. formed mats in aquatic environments and have been successfully used in the bioremediation of oil spills around the globe. Oil and ammonia concentrations drive role in determining distribution of these cyanobacterial mats' microbial diversity in oil field wastewaters. *Phormidium* sp. that isolated and identified from oceans and seas eliminates 40% of spilled diesel oil and hexadecane within 10 days and has capability to remove C_{10}-C_{28} hydrocarbons under aerobic autotrophic conditions.

Cyanobacteria can oxidize oil components as well as other complex organic compounds such as herbicides and surfactants. Many laboratory experiments revealed that cyanobacteria can degrade crude oil and other complex organic compounds, such as surfactants. Cyanobacteria accelerated cycling of hydrogen and organic acids produced as metabolites. Cyanobacteria have a unique ability to remediate oil and petroleum contaminated water and soil in a short and long period as result of exopolysaccharide production, mat formation, consortia formation and due to metabolic pathways and signal transduction (Table 3).

TABLE 3
Degradation of organic chemical pollutants by cyanobacteria

Cyanobacterium	Pollutant and its removal efficiency
Oscillatoria strain OSC	n-octadecane 40% pristine 50% phenanthrene 50% dibenzothiophene 80% (1 mg ml^{-1} organo clay complex containing 16.68 (%) of petroleum compounds)
Phormidium sp., *Oscillatoria* sp. *Chroococcus* sp.	Diesel 99.5% (0.6% v/v)
Phormidium sp. *Oscillatoria* sp. *Chroococcus* sp.	Total petroleum hydrocarbon 99% (diesel 0.6% v/v)
Cyanobacteria	Oxidize oil constituents and complexed organic compounds, *i.e.,* herbicides and surfactants
Cyanobacteria and chemotrophic bacteria consortium	Wastewaters and oil-contaminated sites
Oscillatoria-gammaproteo bacteria consortium	Biodegrade crude oil under mixotrophic condition
Consortia of cyanobacteria and bacteria (*Aphanocapsa* sp. BDU 16, *Oscillatoria* sp. BDU 30501 and Halobacterium US 101)	Wastewater treatment and help to reduce calcium and chloride content in water bodies for fish survival
Oscillatoria boryana BDU 92181	Removal of melanoidin from distillery effluents

Radionuclide and heavy metal remediation by cyanobacteria: Due to anthropogenic and natural activity, radionuclide and heavy metals generated from several sources. Radioactive compounds are most toxic and dangerous substances. Radionuclides reached our environment from metallurgical mining, nuclear power tests and discharge from nuclear reactors. The toxicity of radioactive compounds is rising under most environmental challenges, which escalates health risks and serious threats of life. Heavy metals exist naturally and released in the environment during weathering and volcanic eruptions, but, due to the extensive anthropogenic activities such as tanning, mining, smelting, agricultural practices and automobiles have intensified the heavy metals pollution than those occurring naturally.

In several countries including China, India, Bangladesh, Australia, America and many European countries, high concentrations of heavy metals, such as lead, chromium, iron and copper in soils were identified. Heavy metal (HM) is commonly for metals and metalloids having an atomic density of 5 g/cm^3 that include Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Nickel (Ni), Copper (Cu), Iron (Fe), Selenium (Se), Lead (Pb), Palladium (Pd), Mercury (Hg), Cobalt (Co), Zinc (Zn), etc.

Tough, among all radionuclides, Uranium isotopes (238U, 235U and 234U) consider as most dangerous element due to its extreme toxicity and radioactivity. Heavy metal-containing effluent is thrown into the ecosystem as a result of fast industrialization and large-scale mining activities, resulting in ecological damage. This also offers harmful health risks to all flora and animals because of the loss of environmental quality caused by heavy metal toxicity. Furthermore, heavy metals, polycyclic aromatic hydrocarbons, halogenated aromatic compounds, Benzene, Toluene, Ethyl benzene and Xylene (BTEX) compounds and other pollutants are regularly released from petrochemicals, oil refineries, pharmaceutical and agrochemical industries, among others.

So far, chromium compound effluents have been released from the leather sector, textile manufacture, metal finishing, electroplating and other industries. The discharge of chromium-containing wastewater from these enterprises into aquatic systems causes major environmental concerns and the released harmful compounds remain suspended in the atmosphere for an extended period in the form of radioactive dust. This contaminated dust condenses into radioactive fallout, causing pollution in soil and surface water bodies and then passed to the food chain.

Several studies have found that hard metals have deadly consequences on human health when they come into touch with them, including the danger of leukemia, leucopenia, renal damage and even genetic problems. Heavy metals are harmful to humans and can cause chronic and acute health impacts such as headaches, memory loss and mental confusion, a sensation of unreality, skewed perception, allergies, visual issues, cardiovascular disease, diabetes, muscle cramps and death (Table 4).

TABLE 4
Pollutants causes health impacts in humans

Pollutants	Disorders
Lead	Neurotoxic, anaemia, high blood pressure
Arsenic	Hypo-pigmentation, cancer
Cadmium	Kidney damage, cancer
Chromium	Cancer, ulceration, nephritis
Nickel	Chronic disorder of lungs, bones
Mercury	Neurotoxic, respiratory disorder
Pesticides	Neurotoxicity, cancer
Benzene	Carcinogenic effect
Uranium	Mental retardation, estrogenic effect
Polycyclic aromatic hydrocarbon	DNA damage and mutations

Heavy metals are dangerous contaminants that endanger aquatic organisms' biological cycles due to changes in the structural structure of nucleic acids, proteins and osmotic balance. Heavy metals are persistent environmental pollutants that can be found in soil for extended periods. Because of their accumulation in the food chain, these contaminants are hazardous and pose a serious threat to food safety, human and environmental health. Metal toxicity has an impact on aquatic bodies, soil biota, plants, animals and, eventually, humans. Due to oxidative stress, it damages cell shape and inhibits the cytoplasmic enzyme.

Currently, the quantity of harmful compounds in our surroundings is increasing due to a variety of circumstances. Various approaches are visible to eliminate polluted environments in order to rehabilitate them. They include chemical precipitation, membrane filtration, ion exchange and adsorption, surface capping, solidification, vitrification, electrokinetics, chemical immobilization, encapsulation and soil washing, but it is costy, less efficient and cause health and environmental risks. However, biological waste remediation processes, is the most efficient, nontoxic and cheap. Biological remediation known as bioremediation involving plants or phytoremediation, microbes or microbial remediation and animal remediation. Scientists recommended that application of microorganisms efficiently treated waste and heavy metals from polluted sites. Bioremediation methods contribute numerous advantages, e.g., cost-effective, environment friendly, high public acceptance, simple to implement, sustainable, without disturbing the soil fertility and biodiversity. The removal of heavy metals, radionuclide and other wastes from the environment by cyanobacteria is pragmatic.

Cyanobacteria are photosynthetic bacteria, belonging to the kingdom Prokaryotes, which are found in various habitats, even in the desert, salty soil. They are ubiquitous, diverse and Omni present on earth and their habitats range from geothermal hot springs, volcanic vents etc., to frozen ponds of Antarctica and from marine to terrestrial ecosystems. Cyanobacteria show a strong tolerance for the extreme environments, as a study revealed the survivability of cyanobacteria in the outer space and also under UV radiation within 548 days and also, cyanobacteria have evolved many mechanisms to survive, compete and achieve dominance in several habitats.

Blue green algae are morphologically diverse, existing as free-living or colonial or form consortia with diverse microorganisms or rhizosphere or mutualistic relationships with plants. This activity promotes agricultural productivity and environmental greenness. The colonies of cyanobacteria ether filaments, sheets or even hollow balls. Hence, cyanobacteria can remove toxic contaminants occurring naturally or xenobiotically. They are purely adapted to the adverse environment, ranging from halophilic to cryophilic. The outer layer comprised of an extra polymeric substance (polysaccharide) possesses several binding sites for environmental remediation. It is also able to synthesize metal-binding proteins (metallothioneins) that are able to bind to inorganic pollutants such as heavy metals *via* cysteinyl thiolate bridges to cysteine ligands. Blue green algae can produce primary and secondary metabolites. Also, cyanobacteria are having multiple biosynthetic metabolic pathways for synthesizing bioactive secondary metabolites; their richness in bioactive compounds is an evolutionary adaptation.

According to, Gerwick, et al., secondary metabolites are mostly available in Oscillatoriales (49%), nostocales (26%), chroococcales (16%), pleurocapsales (6%) and stigonematales (4%) of cyanobacteria phylum. The size of cyanobacteria is microscopic and, their agricultural and environmental applications are extraordinary. Cyanobacterial application can be an excellent option for remediation of contaminated soil, freshwater, marine water and sediments. Yet, the treatment of waste effluents generated from various waste sources, surprisingly cyanobacteria has collected, initiated over the last one decade and revealed the best output in both organics and inorganics discharge remediation.

Cyanobacterial bioremediation is the activity of removing complex pollutants from the environment and using them to boost their augmentation and metabolism or change them from a toxic to a nontoxic form. These cells have high efficiency for binding pollutants, such as toxic metal ions, due to the presence of various lipids, enzyme, proteins and polysaccharide receptors on their surface. When toxic complex pollutants are trapped by surface receptors, they bind passively to the cellular structure phenomena known as ''bio-sorption'', while the utilization of these pollutants in the metabolic cycle after crossing *via* the cell membrane actively is referred to as ''active uptake''. Both passive bio-sorption and active uptake of pollutants by the cyanobacterial cells are termed ''bioaccumulation'' and the phenomenon is referred to as the phycoremediation tool.

The phycoremediation approach (the use of algae or cyanobacteria for environmental safety) the capacity to treat wastewater and atmospheric pollution within a single treatment line, while generating biomass for bioprocessing. Removal of Cu (II) under laboratory condition has been reported by De Philippis, et al., using two capsulated, exopolysachharide-producing cyanobacteria, *Cyanospora capsulata* and *Nostoc* PCC 7936.

According to Raungsomboon et al., experimental work, cyanobacteria removed lead. The elimination of the pollutants by Cyanobacteria showed the species and contaminant-dependent. The cyanobacteria members like *A. variabilis* and *Anabaena oryzae* have excellent degraders. The highest discharge of total solids was observed by *Tolypothrix ceytonica*, followed by *A. variabilis*. In the case of pollutant metals, *T. ceytonica* exhibited the highest bio-sorption capacity. Some cyanobacteria such as, *Oscillatoria willei* BDU130791, *Phormidium valderianum* BDU20041, has excellent property in bio-calicification of calcium pollutants like the ossein effluents that were released during gelatin production from cattle bones. Cyanobacteria can occur in wild, mutant or genetically modified forms for heavy metal bioremediation. The features associated with cyanobacterial EPS (exopolysaccharides) offer a great potential for biotechnological applications. Metal-binding proteins, known as Metallothioneins (MTs), can be synthesized by cyanobacteria. *Anabaena doliolum* has a metal-binding protein that gives resistance to metal and other environmental challenges. The presence of several proteins and polysaccharides on the cyanobacterial surface aids in the efficient binding of the HMs. The presence of negative charge on the EPS gives an added advantage as effective chelators of metals from solutions.

The exopolysaccharides synthesized by cyanobacteria have two distinct characteristics which makes them unique compared to other bacterial polysaccharides. First is their anionic nature due to the presence of uronic acid and sulphate containing sugars which impart to them the ability to form hydrated gels? Secondly, cyanobacterial exopolysaccharides are predominantly complex heteropolysaccharides with about 75% of them constituted of six or more different types of monosaccharide units.

The polysaccharide content of loosely and firmly bound extracellular polymeric substances was shown to rise in response to treatment with oxide nanoparticles of Ce, Cu and Zn in *Microcystis aeruginosa*, showing that the presence of metals could also drive EPS formation. The type of the heavy metals and the functional groups present on the biofilm's surface have a substantial influence on the biofilm-heavy metal interaction. This interaction involves molecular-scale chemical processes such as electron transport pathways, mineral nucleation and so on. The sequestration ability was dependent on the cyanobacterial species dominating the microbial mat composition. Biofilms dominated by *Phormidium* species exhibited high sequestration (*99%) of Cu when challenged with 20 mg/dm^3 of Cu$_2$? solution, while that dominated by Released Polysaccharides (RPS), was found to be most efficient in the removal of heavy metals. The RPS could also bind multiple metal ions when exposed to them sequentially also. Comparison of the binding of two heavy metals Cu(II) and Cd(II) added sequentially showed that while Cu(II) could displace bound Cd(II), the displacement of bound Cu(II) by Cd(II) was not significant, in fact initial binding of Cd(II) resulted in higher binding of Cu(II). Among the three mono metals, Cu(II), Pb(II) and Cd(II), the removal of Cu(II) was primarily found to be through bio-sorption by both RPS and cell surface, while Pb(II) was mostly adsorbed by RPS and Cd(II) completely by RPS. Nostoc commune could sequester only 87% Cu and axenic *N. linckia* only 50%.

It has been observed that cyanobacterial biofilms show good heavy metal tolerance, suggesting cyanobacterial biofilms hold a good promise for heavy metal bioremediation. The cyanobacterium *Cyanothece* sp. CCY0110 has been successfully used for the removal of Cu, Cd and Pb individually and in combination from water bodies. Addition of a support bases for the formation of biofilms also allowed the retention of heavy metal sequestration capabilities of the cyanobacterial biofilms. Biofilms generated from axenic cultures of *Nostoc muscorum* using glass as a support base efficiently sequestered Cd(II) from aqueous solutions in the pH range of 5–9 and concentration range of 1–100 ppm Cd(II) and from waste water (Table 5).

Heavy metal adsorption by cyanobacterial biofilms following Langmuir adsorption isotherms as shown for *N. muscorum* biofilm for Cd(II) and *Nostoc sp*. biofilm for Cr.

TABLE 5
Heavy metal bioremediation through cyanobacteria

Cyanobacteria	Metal
Lyngbya putealis	Cu, Co
Phormidium sp. *and Oscillatoria* sp.	Cr
Oscillatoria sp.	Cd
Cyanobacteria (Blue-green algae)	Benzene, toluene, phenanthrene, pyrene
Oscillatoria spp.	n-Alkanes
Nostoc carneum, Nostoc insulare, Oscillatoria geminata and Spirulina laxissima	Cs, Sr, Ra and Am
Anabaena torulosa	U

Spirulina platensis	Copper 79.2% (500 mg l^{-1}) a zinc 88.0% (500 mg l−1) iron 100% (500 mg l^{-1})
Anabaena inaequalis	Cr
Cyanobacteria	Pb, Hg and Cd
Nostoc sp.	Hg, Pb , Cd and Gamma hexachloro cyclohexane
Oscillatoria spp.	Cu, Pb, Cd and Co
Spirulina spp.	Pb and Cd

According to Faisal, et al., investigation two cyanobacterial strains, *Oscillatoria* sp. and *Synechocystis* sp. reduced Cr (VI) to Cr (III). The co-existence of cyanobacteria with microbial diversity in wastewaters, which can regulate purification of the wastewaters. Similarly, the heavy metals like zinc, mercury, nickel, cadmium, chromium and iron existent in textile waste were reduced and adsorbed on the surface *Lyngbya* sp. filament. Active or dead inoculum of *Synechocystis* sp. can efficiently eliminated uranyl ion due to the presence of an extracellular hemolysin, such as protein (HLP), which conjugate with polysaccharides and play role in the adsorption of radioactive compound.

The cyanobacteria member *Spirulina platensis* potentially absorbs cadmium, trivalent chromium, zinc and their efficiency can be increased by immobilizing them even the dried mass of it, which is a good bio-sorbent of chromium. Similarly, *Anabena* sp., are very potent absorbers of toxic metals like lead, cadmium, zinc etc.

Cyanobacterial inoculation is an alternative means for total removal of heavy metal pollutants with low toxicity due to their cultivate autotrophic and heterotrophic nature, as well as potential for genetic manipulation. Moreover, due to bio-sorption, waste accumulation and biosynthesis pathway cyanobacteria remediate toxic wastes. Cyanobacterial biofilms or mats have also been shown to be successful in heavy metal bioremediation.

Cyanobacteria biofilms were used to change the composition of the periphytic community biofilm, which helped maintain high photosynthetic and metabolic rates. The resulting EPS produced attached to the Nanoparticles (NP), which reduced the toxicity investigated with TiO_2 NPs while retaining the Cu_2 degradation capability. Cyanobacteria are extraordinary environmental cleanup and, scavenging capabilities. As, result of symbiotic association formation, heterotrophic and photosynthetic nature, metabolic pathway, presence of negative charge on the exopolysaccharides, presence of protein binding sites, cyanobacteria may drive roles in accumulation of toxic wastes, biogeochemical cycles, remediate emerging pollutants partially or totally depending on waste concentration and species.

RESULTS AND DISCUSSION

Cyanobacteria are universal class of microorganisms with systematic activity, ubiquity and diversity. Despite the fact that cyanobacteria are widely found in almost every environment, as a result, isolating, selecting and determining prospective cyanobacterial strains with high efficiency require advanced biotechnological skills. Cyanobacteria have various characteristics, the most notable of which are their fast growth, strong photosynthetic activity and suitability for genetic engineering. The use of cyanobacteria in croplands is projected to have a significant effect on maintaining acceptable amounts of soil organic matter, soil aggregation, improving soil fertility and retaining moisture and reduces nutrient losses due to active metabolite secretion, filament formation and symbiotic relationships with other organisms. Furthermore, inoculating soils with cyanobacteria can give useful solutions for CO_2 and other gases implicated in global warming. The development and application of cyano-bacterial bio-fertilizers would support ecological greenness, low-cost solution for chemical fertilizer, driving bioremediation of wastewaters, herbicides, pesticides, heavy metals and providing both macro and micronutrients for crop production.

In addition to product development, further research must be conducted on strain upgrading to achieve high productivity, growth rate maintenance and cell potential enhancement for survival in response to unfavorable condition. Such research will pave the way for the transition from laboratory-based experimentation to large-scale industrial and commercial level. Indeed, genetically modifying cyano-bacterial strains to increase their efficiency may entail the addition of one or more features related with plant growth promotion and environmental cleanup. As a result, research includes the selection of appropriate cyanobacteria species to ensure successful survival, high quality inoculant and field performance, as well as the optimization of cyanobacteria culture conditions to enhance biomass yield. In this context, it has been demonstrated that cyanobacteria may be cultured in ponds and photo-bioreactor. Furthermore, there is a need to raise awareness among farmers about the potential advantages of cyano-bacterial bio-fertilizers and agriculturists from all over the world should focus on ways to further examine the development of cyanobacteria farming project for the economic benefit of farmers, ensuring food security, poverty reduction and, ecological advantages,

CONCLUSION

Cyanobacteria are autotrophic, versatile microbes and adapt various environments, such as freshwater, marine water, desert and harsh habitats. The application of cyanobacteria is broad, environmental auspicious, cost-effective organic, available and easy to manipulate. The importance of cyanobacteria in agriculture and environment conducted the enhancement of agricultural productivity, environmental cleanup and ecological restoration capabilities. Some cyanobacteria have heterocystous (nitrogenase enzyme) which are the powerhouse of nitrogen fixation. Cyanobacteria release active metabolites and exopolysaccharides. These factors play significant role in retaining soil moisture, soil reclamation, solubilizing phosphorus, improve soil organic carbon contents and, reduce global warming. Hence, due to release of exopolysaccharides, presence of protein binding sites, enzyme production and symbiotic association, cyanobacteria are recycling, accumulating and degraded wastes. It can be, concluded that the application of cyanobacteria plays a vital role in agricultural productivity and environmental remediation. As result, screening and culturing, biomass cultivation, harvesting, processing, formulating and utilizing, cyanobacteria as food supplements, bio-fertilizer, inoculant and as waste remediation are widely not familiar. Furthermore, environmentalists, agriculturalists, microbiologists, biotechnologists and all stakeholders cooperatively work towards stating a central dogma for future studies, superior quality selection and cyanobacteria cultivation.

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