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REVIEW ARTICLE



A review on feasibility of phytoremediation technology for heavy metals removal

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ABSTRACT

Quick jump of urbanization and industrialization is responsible for birth of heavy metal pollution. In the aquatic systems, heavy metals are one of the most dangerous pollutants that may be found. It can have both natural and anthropogenic origins. In aquatic ecosystem heavy metal pollution have a serious hazard to biodiversity of aquatic ecosystems, and drinking polluted water contaminated with heavy metals can have severe health risks in humans as well as in all living-beings. The commercial characteristics and side effects of conservative treatment equipment in aquatic environment flagged the way to eco-sustainable technology like phytoremediation. In phytoremediation, Plants are used to clean up the environment from numerous dangerous contaminants. Phytoremediation is cost-effective and ecofriendly expertise for environmentally friendly cleanup. The present review reflects the characteristics of heavy metals and possible environmental threats together with this, review also inspects the role played by the macrophytes in phytoremediation studies in the recent past. In the reduction of heavy metal contamination in aquatic environments which receive the industrial discharges and municipal wastewater, aquatic macrophytes are powerful tools to remediate them.

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INTRODUCTION

Fast industrialization and urbanization have ended in multiplied emission of toxic heavy metals getting into the biosphere (Gazsó, 2001). Activities together with mining and agriculture have polluted good sized regions throughout the sector (Smith *et al.*, 1996; Shallari *et al.*, 1998). Earth's crust is the home for metals where they are found naturally. The composition of metals varies from locality to locality, resulting in spatial differences of surrounding concentrations (Jaishankar *et al.*, 2014). In waste water the generally present heavy metals are arsenic, copper, cadmium, chromium lead, nickel, and zinc, which are quite toxic and have potential risks for human health and the environment (Lambert *et al.*, 2000). The release of heavy metals in biologically to be had forms with the aid of human interest, may additionally damage or modify each herbal and man-made ecosystems (Taylor *et al.*, 1989).

Heavy metal ions consisting of Cu^{2+} , Zn^{2+} , Fe^{2+} are vital micronutrients for plant metabolism however whilst found in excess, can emerge as extraordinarily toxic. Many heavy metals are categorized as precedence pollutants with the aid of US Environmental protection agency. Lead, mercury, arsenic, and cadmium ranked as first, second, third, and sixth risks at the listing from US Agency for Toxic Substances and Disease Registry (ATSDR) that lists all hazards present in toxic waste websites consistent with their occurrence and the severity in their toxicity. The heavy metals like Cd, Pb, Co, Zn and Cr which are very common are phytotoxic at both low and very high concentration are found in waste water. If these metals reach in sediments then they got engaged in the food chain via aquatic plants and animals. In small portions, a few heavy metals are nutritionally important for a nourishing life, however large measures of any of the heavy metal may also cause toxicity (poisoning). In the recent past,

there had been increasing a vast number of cases of heavy metallic pollutions in the environment reputedly because of poisonousness and superficial persistency of heavy metals inside the aquatic ecosystems (Tijani *et al.*, 2005). Contamination by heavy metals is a worldwide stress, even though harshness and levels of pollutants differ from locality to locality. At least 20 metals are labeled as toxic with half of them emitted into the environment that poses huge risks to human health (Akpor and Muchie, 2010). Heavy metal polluted sites must be remediated to reduce the associated risks. Metals cannot be degraded like organic compounds and cleanup typically needs removal of heavy metals. Utmost of the conventional remediation techniques are costly and reduce the fertility of the soil; this afterwards would responsible for bad impacts on the environment (Kumar *et al.*, 2016).

Phytoremediation is a budget operational, eco-friendly, artistically attractive approach best appropriate for developing countries like India. For applications in phytoremediation and phytomining, various effective metal hyperaccumulators are being discovered. Vegetation have the capacity to accumulate nonessential metals such as Cd and Pb, and this capacity may be harnessed to do away with pollutant metals from the environment (Salt *et al.*, 1995; Das *et al.*, 1997; Rogers *et al.*, 2000). Currently there is a large interest in growing inexpensive and environmental friendly technologies for the remediation of soil and wastewater polluted with hazardous heavy metals (Zayed *et al.*, 1998). Plants based bioremediation technologies have obtained current interest as techniques to easy-up contaminated soil and water (Sadowsky, 1999). Many sorts of plants have been tested for phytoremediation, amongst various plant organisms, participants of Lemnaceae and Azollaceae have been documented as capacity accumulators of metals therefore may be utilised for the enrichment of water contamination to decrease the pollution load (Horvat *et al.*, 2007; Rai, 2010). The submerged macrophytes are mainly beneficial within the abatement and tracking of heavy metals (Gupta and Chandra, 1998). Earlier works in the field of waste water treatment confirmed that aquatic macrophytes can be used to partially accumulate or absorb trace metals present in wastewaters (Chandra *et al.*, 1993). The aquatic macrophytes suck/absorb heavy metals by the use of their floor adsorption and/or absorption and store them in a bonded form. Effluent treated by these macrophytes therefore becomes less toxic to the aquatic environment. At metals polluted locations, plants are used to stabilize and remove the metals from the soil and ground water through mechanisms such as phytoextraction, rhizofiltration, and phytostabilization (Kumar *et al.*, 2019a).

The present review will be helpful to understand the concept of heavy metal sources, their harsh effects and need of their removal from contaminated sites. It would also explain the phytoremediation technology and its applications in remediation of heavy metals by different processes. The goal of this review is to give vision into the sources of heavy metals and their dangerous properties on the surroundings and living creatures and remediation strategies to get rid of them or to

minimize their effects by the use of some hyper accumulator plants which usually absorb them and decrease their effects.

CHARACTERISTICS OF HEAVY METALS

Arsenic (As)

Although arsenic occurs as the 20th most abundant element in the geosphere, arsenic is extremely poisonous to the biota. In many zones, arsenic levels in the environment have beaten the safe threshold for human welfare viz, 10 µg/l. Its inorganic forms are poisonous to the environment and living beings such as arsenite and arsenate complexes. Humans may be exposed to arsenic by natural phenomenon unintended sources or from industrial sources (Jaishankar *et al.*, 2014). Arsenic is very chief heavy metal causing anxiety at both ecological and individual health levels (Hughes *et al.*, 1988). Arsenic displays poisonousness even at low exposures (Dikshit *et al.*, 2000) and causes diseases like black foot (Lin *et al.*, 1998). It is now well documented that ingestion of arsenic, even at low levels, leads to carcinogenesis (Mandal and Suzuki, 2002). Gastrointestinal indications such as severe vomiting, injury to the nervous system, disorders of the blood and circulation and ultimately death can be the result of consumption of large amounts of arsenic. Large doses of arsenic when not deadly, may break up red blood cells in the circulation, decrease blood cell production, color the skin, enlarge the liver, produce burning and loss of consciousness in the limbs, and also damage the brain (Mahurpawar, 2015).

Cadmium (Cd)

According to ATSDR ranking, Cadmium is the seventh most poisonous heavy metal. Cadmium is generated by zinc production as a by-product to which humans or animals may get exposed at labor or in the surroundings. It will accumulate inside the body throughout life if once gets absorbed by humans (Jaishankar *et al.*, 2014). Because of its high rate of soil-to plant handover, Cadmium is largely found in vegetables and fruits (Satarug *et al.*, 2011). Cadmium is an extremely poisonous unnecessary heavy metal which is well known for its adverse effect on the enzymatic systems of cells, oxidative pressure and for encouraging nutritive deficiency in plants (Irfan *et al.*, 2013). Consumption for people is assessed as 0.15µg from air and 1µg from water for normal day by day. Inhalation and ingestion of cadmium by humans can affect the health but the main health impacts reported in the literature are through dietary exposure (kidney and bone damage) and inhalation by tobacco, smoking and work-related exposure (lung damage). The highest human organ affected by cadmium is the kidney in both the general population and the occupationally exposed (Mahurpawar, 2015). Smoking a packet of 20 cigarettes can prompt the inward inhalation of around 2-4µg of cadmium, due to which levels may on large scale (Clinton *et al.*, 2014).

Chromium (Cr)

Burning of oil and coal, petroleum from ferrocromate refractory material, catalyst, chromium steel, fertilizers, pigment oxidants,

metal plating tanneries and oil well drilling are the natural sources of chromium occurrence. Chromium is discharged into the environment through waste material and fertilizers, anthropogenically (Ghani, 2011). Chromium is used on a large scale in industries like metallurgy, tanning, electroplating, paints production, pigments chemical manufacture and pulp and paper making. Oxygen is present in the environment in excess due to which, Cr (III) is oxidized to more toxic Cr (VI), which is tremendously poisonous and greatly soluble in water (Cervantes *et al.*, 2001). In the capital of Japan, Tokyo, during August 1975, the underground water holding Cr (VI) spoil masses had a 2,000 times higher limit than the permissible limit of chromium (Zayed and Terry, 2003). The chromium level in underground water has been witnessed to be more than 12 mg/L and 550–1,500 ppm/L in India. (Jaishankar *et al.*, 2014). The industrial wastes discharge and ground water pollution has harshly amplified the chromium concentration in the soil (Bielicka *et al.*, 2005). The toxicity of chromium significantly affects the biological processes in several plants like maize, cauliflower, barley, citrullus and in vegetables. Chlorosis and Necrosis occurs in plants due to the chromium toxicity (Ghani, 2011).

Mercury (Hg)

The metallic mercury is a metal which occurs naturally and is a glossy silver-white, unscented fluid and winds up dull and scentless gas when warmed. Mercury is exceptionally lethal and exceedingly bio-accumulative. Its presence unfavorably influences the marine condition and henceforth numerous studies are coordinated towards the spreading of mercury in water environment. Main sources of mercury contamination include anthropogenic activities such as agriculture, municipal wastewater discharges, mining and discharges of industrial wastewater (Chen *et al.*, 2012). Real sources of mercury contamination incorporate anthropogenic exercises, for example, horticulture, municipal wastewater releases, mining, incineration, and releases of industrial wastewater (Chen *et al.*, 2012). Mercury is widely utilized in thermometers, indicators, pyrometers, hydrometers, mercury circular segment lights, fluorescent lights and as a catalyst. It is additionally being utilized in pulp and paper businesses, as a part of batteries and in dental arrangements, for example, amalgams. Methyl mercury is a neurotoxic compound which is accountable for microtubule obliteration, mitochondrial harm, lipid peroxidation and accumulation of neurotoxic molecules, for example, serotonin, aspartate, and glutamate (Patrick, 2002). The mind remains the objective organ for mercury, yet it can damage any organ and prompt breaking down of nerves, kidneys and muscles. It can make interruption the membrane potential and interrupt intracellular calcium homeostasis. Mercury vapors can cause asthma, bronchitis, and transitory respiratory issues. Mercury assumes a key part in harming the tertiary and quaternary protein structure what's more, changes the cell work by joining to the selenohydryl and sulfhydryl bunches which experience response with methyl mercury and hamper the cell structure (Jaishankar *et al.*, 2014).

Lead (Pb)

Lead is one of the very poisonous heavy metals that accumulate in individuals and affect the whole food chain and disturb the health system of animals, phytoplanktons and human beings. Lead reaches water system together with urban runoff and discharges as for example, sewage treatment plants and industrial plants. The primary sources of lead are Industrial processes of production and their discharges, operations of mining, smelting, combustion sources and solid waste incinerators and some other sources of lead are batteries, lead paint, lead piping used in water delivery system (Singh *et al.*, 2011). Lead is a standout amongst the most noxious metals that have a serious risk to individuals, creatures and phytoplanktons. It can also disturb the kidney and most significantly the brain and nervous system and lead can accumulate over a lifespan and it causes diseases as for example anemia, hepatitis and nephritic syndrome, encephalopathy. It go beyond the WHO (2004) permissible standard 0.15 mg/L and continuous contact may lead to interruption in mental or physical growth in infants and youngsters though adults may have kidney complications and high blood pressure. The aquatic system is also influenced by lead in which young fish are more prone than adults or eggs.

Iron (Fe)

On the earth's crust, iron is the second preeminent abundant metal (EPA, 1993). Elemental position of Iron in the Periodic Table is 26th. For the development and survival of every living life form Iron is a standout amongst the most essential components (Valko *et al.*, 2005). Men made activities such as mining exercises are the sources of iron in surface water. High acceptance of Fe²⁺ by roots, acropetal translocation process towards leaves, tanning of rice leaves and yield loss are incorporated in highlights of iron poisonousness (Becker and Asch, 2005). For different organic redox procedures because of its inter-conversion process amongst ferrous (Fe²⁺) and ferric (Fe³⁺) ions, iron is an appealing progress metal (Phippen *et al.*, 2008). Rice generation is limited by the Corrosive soils and the cause of a macronutrient issue in wetland rice is Zn inadequacy. In flooded soils, the reduced iron (Fe²⁺) present in great concentrations which affected the production of lowland rice tremendously. According to the study of Phippen *et al.* (2008), the poisoning effects of iron on water plants especially rice, reviled that the progression of species of aquatic reed was found to be restrained by convergence of 1 mg/L add up to iron. When the absorbed iron is not capable to bind with the protein, a varied kind of injurious free radicals are formed, which in mammalian cells and biological fluids, consecutively harshly affects the iron concentration (Jaishankar *et al.*, 2014). Destructive effect on the abdominal tract and biological fluids are the fallouts of this circulatory unbound iron. Iron crosses the rate-constraining assimilation step and ends up saturated, when enters into the body in an extremely high level. These free irons enter into cells of the liver, mind and heart. Lipid peroxidation by the free iron results in severe injury to microsomes, mitochondria and other cellular organelles (Albretsen, 2006).

Zinc (Zn)

Zinc has a significant role in numerous biological processes involving development of organisms and normal growth as it is a part of several metal- proteins and metal- enzymes (Zinicovscaia *et al.*, 2018). Actuate oxidative pressure, destruction of DNA molecules, and also can lead to the impairment of growth and reproduction can happen if in any case, zinc is present in abundance in water (Finocchio *et al.*, 2010; Zinicovscaia *et al.*, 2015). In this way, the presence of zinc ions in wastewaters indicates a risk to the aquatic ecosystem and increases numerous perils for human beings (Finocchio *et al.*, 2010). Effluents released from industries engaged in electroplating, galvanization, amalgam production are the frequent source of zinc and other sources of zinc are acid mine drainage, metropolitan wastewater treatment plants, common ores (Ahuja *et al.*, 1999; Kumar *et al.*, 2006; Zinicovscaia *et al.*, 2015). Extra quantity can cause system dysfunctions that outcome in impairment of growth and reproduction. However, Zinc is thought to be generally non-dangerous, particularly if taken orally. (INECAR, 2000; Nolan, 2003). The clinical indications of zinc toxicosis are spewing, bloody urine, diarrhea, icterus (yellow mucus membrane), kidney failure, liver failure and iron deficiency. World Health Organization (WHO) prescribed the greatest allowable concentration of zinc in drinking water as 5.0 mg/L (Kumar *et al.* 2006).

Copper (Cu)

Copper is a metallic element occurs naturally in soil at a usual concentration of about 50 ppm (parts per million). Copper exists in all animals and plants and for humans and animals it is a vital nutrient in small amounts. The smelting, mining and refining of copper, industries manufacturing products from copper for example wire, pipes and metal sheet, and burning of fossil fuels are the main reasons of environmental copper release (Mahurpawar, 2015). Water pipes are regularly made of copper and bath fittings might be produced using brass and bronze compounds that contain copper. Leaching of copper from pipes and bath fittings because of acidic water is the major foundation of copper in drinking water. Blue-green stains left in shower installations indicate the existence of copper in water. Different reliefs of copper to the environment incorporate agricultural use against plant ailments and medicines connected to water bodies to dispose of green growth (Mahurpawar, 2015). As a constituent of metallo enzymes, it is a vital component in mammalian nourishment. In metallo enzymes it performs as an electron donor or acceptor. On the other hand, introduction to abnormal amounts of Cu can result in various unfavorable wellbeing impacts. The utilization of sustenance and drinking water is the main reason of introduction of people to Cu. incidental ingestion is connected with Serve Cu poisonousness; though, some members of the population might be more defenseless to the unfavorable impacts of high Cu intake because of hereditary inclination or infection (Stern *et al.*, 2007). Inordinate human consumption of Cu may prompts serious mucosal disturbance and corrosion, extensive capillary destruction, hepatic and renal injury and central sensory system aggravation tracked by depression.

Extreme gastrointestinal aggravation and conceivable necrotic changes in the liver and kidney can likewise happen. The impacts of Ni exposure change from skin aggravation to harm to the lungs, sensory system, and mucous membranes (Argun *et al.*, 2007).

SOURCES OF HEAVY METALS

Soil, surface water, and groundwater may emerge as infected with risky compounds resulting from human activities (e.g., enterprise, agriculture, wastewater treatment, production and mining) as well as natural activities (e.g., soil erosion and saline seeps). Pollutants can be traced to a selected source, factor source, or result from massive vicinity, nonpoint source. Contaminants are both inorganic and natural compounds (heavy metals, nitrate, phosphate, inorganic acids, radionuclides and natural chemicals) from sources which include waste substances, explosives, pesticides, fertilizers, prescribed drugs, acidic deposition, and radioactive fallout (Sparks, 1995). The two predominant resources of heavy metals in wastewater are natural and anthropogenic. The natural elements include city run offs, volcanic activities, soil erosion and aerosols particulate at the same time as the anthropogenic sources include steel finishing and electroplating tactics, mining extraction operations, textile industries and nuclear power (Akpor *et al.*, 2014). Then foremost usual sources of heavy metal pollutants in wastewater effluents are soil erosion, volcanic activities, aerosol particles and city run offs. it is suggested that volcanic eruptions produce dangerous affects to the surroundings, climate and health of uncovered individuals. other than the deterioration of social and chemical situations and the gases (carbon dioxide, sulphur dioxide, carbon monoxide, hydrogen sulphide) released all through eruptions, diverse natural compounds and heavy metals, consisting of mercury, lead and gold also are launched (Akpor *et al.*, 2014). The activities from volcanoes are mentioned to be answerable for the discharge of metals which includes arsenic, mercury, aluminum, rubidium, lead, magnesium, copper, zinc and a number of others (Amaral *et al.*, 2006). In addition, a few aerosol (high-quality colloidal debris or water droplet within the air, in a few cases they may be gas) particles may additionally deliver one of a kind forms of contaminant; like cloud, smoke and heavy metals. These heavy metal containing aerosols commonly acquire on leaf surfaces in the form of excellent particulates and can input the leaves thru stomata (Sardar *et al.*, 2013). Certain of the human resources of heavy metals in wastewater effluents are metal finishing and electroplating, mining and extraction processes, textiles activities and nuclear activity. Metal finishing and electroplating involve the deposition of skinny protecting layers into prepared surfaces of metal the use of electrochemical methods. Whilst this takes place, toxic metals can be launched into wastewater effluents. This can be both through rinsing of the product or spillage and dumping of method baths. It is also indicated that the cleaning of process tanks and cleaning of wastewater can generate extensive portions of soggy sludge containing high amount of poisonous metals (Cushnie, 1985). In addition, mining processes can launch poisonous metals to the environment. Metal mining and

smelting activities are seemed as important resources of heavy metals in surroundings. In environments in which those activities take vicinity, it's miles indicated that massive amount of toxic metals deposits are found in their water, plants, soils and vegetable (Wei *et al.*, 2008).

IMPACTS OF HEAVY METALS

Impact on soil environment

Heavy metal pollution affects adversely numerous parameters related to plant quality and production together with variety in composition, size and activity of the microbial community (Yao *et al.*, 2003). Because of this, heavy metals are said to be the important source of the soil pollution. The contamination of soil is generally brought out by the numerous metals like Cu, Cd, Ni, Zn, Cr (Hinojosa *et al.*, 2004). Various enzymatic activities of the soil get affected indirectly by the heavy metals as they are responsible for the shifting of the microbial community which synthesizes enzymes (Huang *et al.*, 2009). Heavy metals leave the poisonous effects on soil biota by altering key microbial activities and decline in the number and activity of soil microbes. It is very valuable to monitor the functioning of soil microbes in ecosystems having long term contamination by heavy metals (Wang *et al.*, 2007).

Impact on plants

Heavy metals like As, Cd, Hg, Pb and Se are not compulsory for growth of the plants as they do not engaged in any known physiological activity in plants. Other *i.e.* Co, Cu, Mn, Fe, Mo, Ni and Zn are essential elements for the plants for their growth and metabolism, but when their concentration reaches more than optimal values, these elements can lead to poisoning (Garrido, 2005; Rascio, 2011). Heavy metals uptake by plants and consequent accumulation along the food chain is a latent risk to animal and human health (Sprynskyy *et al.*, 2007). One of the main routes of entrance of heavy metals in the food chain is absorption by plant roots (Jordao *et al.*, 2006). Different plant species and efficiency of different plants in absorbing metals is responsible for the heavy metal accumulation and is evaluated by either soil to plant transfer factors or plant uptake of the metals (Khan *et al.*, 2008). Heavy metals are poisonous in nature for plants and phytotoxicity of heavy metals for plants is responsible for chlorosis, weak plant growth, yield declination and may be even go together with by cheap nutrient uptake, disorders in plant metabolism and decreased ability to fixate nitrogen in leguminous plants (Guala *et al.*, 2010).

Impact on aquatic environment

Ecological balance of the aquatic environment can tremendously get affected by the contamination of a river with heavy metals, and the variety of aquatic animals may become limited with the extent of contamination (Ay *et al.*, 2009). Heavy metals reached to aquatic environment are normally tied up in particulate matter which ultimately settle down and become assimilated in sediments (Singh and Kalamdhad, 2011). Therefore,

surface deposit is very important sink of metals and other pollutants in aquatic systems. These sediment-bound pollutants can be absorbed by rooted aquatic macrophytes and other aquatic life (Peng *et al.*, 2008). The accumulation of heavy metals by an aquatic organism can be moved through the higher classes of the food chain. Carnivores include humans which are present at top of the food chain, attain utmost of their heavy metal burden from the aquatic environment by way of their nutrition, especially where fish are present so there exist the potential for considerable biomagnifications (Ay *et al.*, 2009). One of the most important pollutant for both marine organisms and humans is mercury (Hg) because its effects on marine organisms and potential hazards to humans. A form of mercury which is formed in aquatic sediments by bacterial methylation of organic mercury is Methyl mercury, which is toxic compound of mercury, actually, all the mercury in fish muscles found as methyl mercury (Soliman, 2006). Salmonid species depend upon drift-prone macro invertebrates commercially or recreationally, so it is very important to assess the effects of heavy metal contamination on drift-prone macro invertebrates (Iwasaki *et al.*, 2009).

Impact on humans

By exposure heavy metal pollution can affect the population in many ways causing disorders like insomnia, depression, irritability, fatigue, decreased concentration, gastric symptoms, sensory symptoms (Hanninen and Lindstrom, 1979). The use of heavy metal contaminated food crops is an important food chain path for exposure of humans to heavy metals (Singh and Kalamdhad, 2011). The farming of such plants which have a great ability of removing elements form soils reflects a possible threat as the plant tissue can accumulate heavy metals (Jordao *et al.*, 2006). When metabolization of the heavy metals is not done by the body and they get accumulate in the soft tissues, they become toxic (Sobha *et al.*, 2007). It is reported that the heavy metals are responsible for encouraging tumor and mutations at larger extents in animals (Degraeve, 1981). Heavy metals have the capacity of creating genetic damage to germ cells animals. (Hayes, 1984; Groten and Vanbladeren, 1994; Wagner, 1993). Heavy metals are tremendously toxic in living beings even in smaller amount. Consumption of food or water drinking with very greater grade of heavy metals persistently inflames the stomach which results as diarrhea and vomiting. Similarly, more amount of Lead (Pb) may be responsible for reducing response time, and outcome in anemia, a disease of blood in humans (ATSDR, 1993). Contaminated food by heavy metals can harshly decrease some vital nutrients in the body which decrease immunological defenses, reduced psychosocial abilities, growth delay, incapacities related with malnutrition and larger incidence of upper gastrointestinal cancer degrees (Iyengar and Nair, 2000; Türkdogan *et al.*, 2003; Arora *et al.*, 2008). Cadmium, Copper, Lead, Nickel and Zinc are the heavy metals which can result in deadly health complications in humans when contact is long termed (Reilly, 1991). These heavy metals have lengthy biotic half-lives and also these can store in many organs of the body and so results in irritating side effects (Jarup, 2003; Sathawara *et al.*, 2004; Ata *et al.*, 2009).

PHYTOREMEDIATION PROCESSES

The diverse activities of plants and their related rhizosphere bacteria on pollutants comprise phytoextraction, phytostabilization, phytodegradation, rhizodegradation, rhizofiltration and phytovolatilization (Salt *et al.*, 1995; USEPA, 2001).

Phytofiltration or rhizofiltration

It is defined as the use of plants either terrestrial or aquatic; to absorb, concentrate, and precipitate pollutants from polluted aqueous sources with low contaminant concentration in their roots. Partially detoxification of industrial release, agronomic runoff, or acid mine drainage can be achieved by rhizofiltration. Rhizofiltration may be applicable for lead, cadmium, copper, nickel, zinc and chromium, which are chiefly engaged with in the roots (Chaudhry *et al.*, 1998; USPA, 2000). There are various benefits of rhizofiltration like it can be used as in-situ or ex-situ applications and numerous species are also applicable other than hyperaccumulators. Plants like sunflower, Indian mustard, rye, tobacco spinach and corn have been tested for their capability to eliminate lead from effluent, with sunflower having the highest ability. It is proved by the tests that Indian mustard has ability to remove a varied concentration range of lead (4-500 mg/l) (Raskin and Ensley, 2000). A number of species of *Sargassum* biomass (nonliving brown algae) was found to be an effective biosorbent for heavy metals, like Cu and Cd (Davis *et al.*, 2000). Tomato and tobacco roots gathered from field-grown plants were found greatly effective bioadsorbents that could adsorb strontium (Sr) from an aqueous solution of SrCl₂. Tang and Willey (2003) examined the plant uptake of ¹³⁴Cs. Plants from the Asteraceae family accumulated great concentrations of radiocesium than *Beta vulgaris* and provided a new applicant for phytoremediation of radiocesium-polluted soils. Zurayk *et al.* (2001) assessed the role of wetland plants (*Nasturtium officinale*, *Mentha longifolia*, *Veronica beccabunga*, and *Cardamine uliginosa*) in aquatic phytoremediation of Cr and the result was that Cr was chiefly stored in roots with slight shoot translocation. Accumulation had gotten 6700 mg Cr kg⁻¹ in roots of *V. beccabunga*.

Phytostabilisation

Phytostabilisation is typically applicable in decontamination of soil, residue and sludges (USPA, 2000; Mueller *et al.*, 1999) and depends on roots skill to limit pollutant movement and bioavailability in the soil. It can happen through the sorption, precipitation, complex action, or metal valence decline. Reducing the quantity of water percolating by the soil matrix is the chief resolution of plants which may form dangerous leachate and prevent soil erosion and distribution of the noxious metal to other areas. A compact root system stabilizes the soil and avoids erosion (Berti and Cunningham, 2000). Phytostabilisation does not remove the pollutant from the soil, but it reduces the characteristic hazard of the pollutant (Li *et al.*, 2000). It is valuable for the decontamination of lead (Pb) chiefly along with arsenic (As), chromium (Cr), cadmium (Cd), copper (Cu) and zinc (Zn). The disposal of dangerous material/biomass is not required

(USPA, 2000) and it is very useful when quick immobilization is desired to preserve ground and surface waters are some of the benefits linked with this technology. Reduction of soil erosion and declination the amount of water available in the system is also due to the presence of Plants (USPA, 2000). Polluted land areas affected by mining activities and Superfund sites have been treated by phytostabilization. Jadia and Fulekar (2008) conducted the experiment on phytostabilization in a greenhouse, using sorghum to remediate heavy metal polluted soil and the vermicompost generated by the experiment was used in contaminated soil as a natural fertilizer. The study revealed that at the higher concentration of 40 and 50 ppm the growth was unfavorably affected by heavy metals, on the other hand, the lower concentrations (5 to 20 ppm) inspired enhanced plant biomass and shoot growth. Reduced leaching by stabilization of soil and immobilizing and concentrating heavy metals into the roots was done by the large surface area of fibrous roots of sorghum and intensive penetration of roots into the soil.

Phytoextraction

Phytoextraction is the finest method to eliminate the contamination primarily from soil and separate it, without harming the soil arrangement and productiveness. It is also called phytoaccumulation (USPA, 2000). As the plant absorb, concentrate and precipitate toxic metals and radionuclide from contaminated soils into the biomass, it is appropriate for the remediation of diffusely contaminated areas, where noxious waste occur solely at comparatively low concentration and superficially (Rulkens *et al.*, 1998). Numerous methodologies have been used but the two simple strategies of phytoextraction, which have lastly developed are; i) Chelate assisted phytoextraction or induced phytoextraction, in which non-natural chelates are added to rise the movement and uptake of metal pollutant. ii) Nonstop phytoextraction, in this the elimination of metal depends on the natural capacity of the plant to remediate; only the number of plant growth repetitions are controlled (Salt *et al.*, 1995, 1997). Most plants do not accumulate metals to noteworthy levels in above-ground biomass, while metal-tolerant plants are comparatively common. However, some plant species are skilled of hyper accumulation of metal ions as they are capable to take up and accumulate metals at concentrations of higher than 0.1 percent (by dry weight of plant) or greater (Brooks, 1998). Hyperaccumulators have been used as applicants for phytoextraction due to their capability to uptake metals and translocate those metals from soil into harvested above-ground biomass (Kumar *et al.*, 1995). A range of terrestrial plant species have been recognized as having the capability to hyper accumulate certain metals from soil including *Brassica*, *Aeollanthus*, *Thlaspi*, *Apocynum* and *Paspalum* among others (Baker, 1995; Kramer *et al.*, 1996).

Phytovolatilization

Phytovolatilization is the process in which plants take up pollutants from the soil, convert them into volatile form and transpire them into the atmosphere. Phytovolatilization take place as growing trees and other plants absorb water and the

organic and inorganic pollutants. Some of these pollutants can pass through the plants to the leaves and volatilize into the atmosphere at relatively low concentrations (Mueller *et al.*, 1999). Phytovolatilization has been mainly used for the removal of mercury; the mercuric ion is converted into less noxious elemental mercury. The drawback is mercury released into the atmosphere is expected to be recycled by precipitation and then redeposit back into bionetwork (Henry, 2000). Phytovolatilization of selenium can be done by Indian mustard and canola (*Brassica napus*) and have been reported that it accumulate the selenium (Bañuelos *et al.*, 1997).

Phytodegradation

One of the most significant phases in the procedure of remediation of organic pollutants is degradation of the pollutant. Degradation of a compound denotes to its breakdown into smaller constituents, or its conversion to a metabolite (Arthur *et al.*, 2005). Plants have enzymes which can breakdown and transform ammunition wastes, chlorinated solvents like trichloroethylene and other herbicides. The enzymes are typically dehalogenases, reductases and oxygenases (Black, 1995). In a phytoremediation, degradation can occur in the rhizosphere (soil surrounding plant roots), as well as inside the plant itself. The latter, phytodegradation, occurs when a plant absorb the contaminant into the tissues, and enzymes within the plant got engaged into converting the compound, frequently into molecules that can be more readily cracked down or released in root exudates. Enzymes exuded from microorganisms or plants are applicable in rhizodegradation or transformation of the pollutant in the rhizosphere, in soil organisms such as bacteria and fungi (for example, Schultz *et al.*, 2001; Siciliano *et al.*, 1998). Moreover, degradation of organics done by the microorganisms can be supported by plants, by the nutrient potential of plant root exudates (Kumar *et al.*, 2019b).

Phytoremediation studies

Various plant species which can accumulate the heavy metals has been comprehensively studied and to date substantial growth has been made in the area of hyper accumulation of heavy metals by plants. Different plant species has different mechanisms of metal accumulation, exclusion and compartmentation (Lone *et al.*, 2008). Elimination of contaminants from the polluted waters by accumulation into plant biomass is termed as Rhizofiltration. Hyperaccumulators can be utilized for phytoremediation of lethal and dangerous overwhelming metals and in addition for phytomining of valuable substantial metals, (for example, Au, Pd and Pt). The utilization of hyper-accumulators for phytoremediation may result in the production of a bio-mineral of some business incentive to adapt to a portion of the expenses of soil remediation (Brooks *et al.*, 1998). For specific heavy metals some plants have natural capability of hyper accumulation. These plants of having such a capacity are known as natural hyperaccumulators. Then again, the accumulation capacity of a few plants for particular heavy metals can be improved by their genetic change through biotechnological

techniques. Such genetically altered plants have indicated promising outcomes for phytoremediation of some heavy metals. In any case, since some environmental researchers are doubter about the bio-safety of genetically modified organisms (GMOs), subsequently there is an overall worry about the commercialization of such items (Prakash *et al.*, 2011).

Phytoremediation of heavy metals from the contaminated water by numerous aquatic species have been acknowledged and tested. Some of the hyperaccumulators are duck weed (*Lemna minor* L.), water hyacinth (*Eichhornia crassipes*), sharp dock (*Polygonum amphibium* L.), water dropwort [*Oenathe javanica* (BL) DC], calamus (*Lepironia articulata*), pennywort (*Hydrocotyle umbellata* L.) water lettuce (*P. stratiotes*), (Vara and Freitas, 2003). Removal of Cd, Ni, Pb, Cr, Cu and Zn by the roots of Indian mustard is found to be effective and sunflower can eliminate Pb, Cs-137, U, and Sr-90 from the solutions which are hydroponic (Zaranyika and Ndapwadza, 1995; Wang *et al.*, 2002; Vara and Freitas, 2003). The efficiency of duck weed was examined by Zayed *et al.* (1998) for the removal of Cd, Ni, Cr, Cu, Pb and Se from the solution which was nutrient-added. It was found that duck weed is a decent accumulator for Cd, Se and Cu, but accumulate Cr moderately and poorly accumulate Ni and Pb.

Water hyacinth (*Eichhornia crassipes*) claims a well-built stringy root framework and substantial biomass and has been effectively utilized in wastewater treatment frameworks to enhance water quality by diminishing the levels of natural and inorganic nutrients. *Eichhornia crassipes* was found to be effective in the elimination of Pb from industrial effluents in a green-house study (Santos and Lenzi, 2000). This plant can likewise decrease the concentrations of heavy metals in corrosive mine water while showing few indications of poisonous quality. Water hyacinth amasses follow components, for example, Ag, Pb, Cd, etc., and is beneficial for phytoremediation of wastewater contaminated with Cd, Cr, Cu and Se (Zhu *et al.*, 1999).

Five wetland plant species, i.e., sharp dock, duckweed, water hyacinth, water dropwort and calamus was investigated by Wang *et al.* (2002) with the help of pot experiment for their conceivable use in improving the contaminated waters. The results revealed that sharp dock was a decent accumulator of N and P Duckweed and Water hyacinth largely accumulated Cd with a concentration of 14200 and 462 mg/kg, respectively. Water dropwort accumulated the highest concentration of Hg, whereas the calamus attained Pb (512 m/kg) considerably in its roots. Hydroponic examinations to explore the uptake of As, Cr, Hg, Ni, Pb and Zn by water hyacinth from the aqueous solution at the concentrations extending from 5 to 50 mg/L was conducted by Ingole and Bhole (2003) and found that in aqueous solutions containing 5 mg/L of As, Cr and Hg, the most extreme uptake was 26, 108 and 327 mg/kg dry weight of water hyacinth, respectively. *Pteris vitta* commonly known as Brake fern among the ferns is well recognized for hyperaccumulation of As from polluted soils and waters. It can collect up to 7500 mg As/kg on a polluted site (Ma *et al.*, 2001) without indicating poisonous quality side effects.

Table 1. Phytoremediation of different heavy metals by various hyperaccumulator plants at laboratory scale.

Plant species	Parameter treated	Site/ Location	Treatments	Results/Key findings	References
<i>R. carnea</i> , <i>Agramineus</i> , <i>A. orientale</i> , <i>A. calamus</i> , <i>I. pseudacorus</i> , <i>L. salicaria</i>	Cr, Cu, Mn, Pb, Cd, Fe	Sewage of some Factories in Jinhua, Zhejiang, China.	Total nitrogen (TN), Total phosphorus (TP), Biological oxygen demand (BOD5), Chemical oxygen demand (COD)	Commitment of plants to TN decrease rose from 11.24% to 21.95% at that point diminished to 17.95% as time expanded. The commitment of plants reduced from 33.15% at 5 d to 19.97% at 10 d, and after that to 11.29% at 15 d, which recommends the hydrophytes have a trait for fast retaining phosphorus in short time (inside 5 d). The maximum elimination noticed in the <i>I. pseudacorus</i> group, cleaning ability Cr > Pb > Cd > Fe > Cu > Mn, which are 24.58%, 21.30%, 15.37%, 1.94%, 1.54%, 0.5% greater than CK (unplanted pots watered with sewage taken as Control), respectively.	Zhang et al. (2007)
<i>E. crassipes</i> , <i>L. minor</i> , <i>S. polyrrhiza</i>	Hg and As	Tropical Opencast Coalmine Effluent (coal mines of Northern Coalfields Limited (NCL), Singrauli, (India).	Hg and As Concentration Removal by phytoremediation	Maximum removal of Hg and As from the effluent by <i>E. crassipes</i> (80% and 71% and As and Hg, respectively). Translocation factor of <i>E. crassipes</i> , <i>L. minor</i> and <i>S. polyrrhiza</i> was recorded as 0.73, 0.77, and 0.61 for arsenic and also 0.64, 0.65, and 0.65 for mercury separately on 20th day.	Mishra et al. (2008)
<i>L. minor</i> , <i>A. pinnata</i> , <i>E. crassipes</i>	Cu, Cr, Fe, Mn, Ni, Pb, Zn, Hg, Cd	The Singrauli region, G.B. Pant Sagar, India.	Physicochemical characteristics of the water of G.B. Pant Sagar contaminated with industrial effluent, Heavy metal analysis in effluent, water, and sediments	The rate diminish for various metals was in the scope of 25% to 67.90% at Belwadah, 25% to 77.14% at Dongia nala. 25% to 71.42% at Ash lake site of G.B. Gasp Sagar. The rate decrease recorded at 40, 80, and 120 m additionally considered weakening component.	Rai (2010)
<i>A. dubius</i>	Cr, Hg, As, Pb, Cu and Ni	Laboratory scale study	Bioaccumulation of heavy metals from leach- ate.	Study demonstrated that it can endure As levels of 75 ppm, and can likewise translocate the majority of the As to the elevated parts of the plant up to 100 ppm. In this way the end from this examination was that <i>A. dubius</i> is a hyperaccumulator of As. The impact of introduction of <i>A. dubius</i> to Pb indicated uniform development rate at 25 and 75 ppm of Pb, and somewhat bring down development rate at 100 ppm.	Mellem et al. (2012)
<i>A. pinatta</i> and <i>L. minor</i>	Fe, Mn, Cu, Zn, Ni, Pb, Cr and Cd	Dudhichua mining Site, NCL, Singrauli , India)	Phytoremediation of the coalmine effluent	In effluent phytoremediated by <i>Azolla</i> , the amount of Mn and Cu diminished radically by 58.5% and 55% individually inside a brief time of 24h. But Fe, measures of Mn, Cu, Zn, Cr and Cd lessened considerably by 87%, 82.84%, 71.85%, half and 61.7% individually inside initial four days and from that point the decline was unimportant. Abatement level of Fe, Ni and Pb was beneath half Fe (48.02%), Ni (38.38%) and Pb (37.7%). This examination demonstrates that <i>A. pinnata</i> could disinfect Mn, Cu, Zn, Cr and Cd more rapidly than Fe, Ni and Pb. Then again, in Lemna-phytoremediated gushing the centralization of Fe, Mn, Cu, Zn and Ni diminished by 60%, 76.9%, 80.8%, 66% and 78.2% separately after 4d.	Bharti and Banerjee (2012)

Table 1. Continued.....

<i>Eichhornia crassipes</i>	Cd and Zn	Lab scale study	Removal of Cadmium and Zinc	Water hyacinth aggregated the most noteworthy grouping of metals in roots (2044 mg/kg for Cd and 9652.1 mg/kg for Zn). Be that as it may, moderately little Cd (113.2 mg/kg) was translocated to the shoot, while Zn was translocated at a considerably higher fixation (1926.7 mg/kg). This outcome exhibited that Zn was significantly more portable than Cd.	Lu et al. (2004)
<i>E. crassipes</i> and <i>P. stratiotes</i>	Al, As, Cd, Cr, Cu, Fe, Mn, Pb and Zn	Foundry located in Hayatabad Industrial Estate, Peshawar	Phytoremediation of steel foundry effluent	Deposition of As was in the scope of 0.8132 mg/kg to 1.3124 mg/kg in <i>P. stratiotes</i> and <i>E. crassipes</i> , separately; 0.7706 mg/kg and 0.6013 mg/kg As was caught up in the shoots of <i>P. stratiotes</i> and <i>E. crassipes</i> , while the roots of <i>P. stratiotes</i> and <i>E. crassipes</i> aggregated 0.0426 mg/kg and 0.7111 mg/kg As, separately. <i>P. stratiotes</i> and <i>E. crassipes</i> saved Cd in their tissues to the degree of 0.0139 mg/kg and 0.0231 mg/kg, individual. The shoots of the test plants put away 0.0018 mg/kg Cd each. Similarly, these plants gathered 0.0121 mg/kg and 0.0123 mg/kg in the roots, separately. Cr was stored in <i>E. crassipes</i> and <i>P. stratiotes</i> at concentrations of 1.7826 mg/kg and 1.1778 mg/kg separately; 0.0934 mg/kg and 0.7277 mg/kg of the aggregate Cr was kept in the shoots of <i>P. stratiotes</i> and <i>E. crassipes</i> . So also, 1.0844 mg/kg and 1.0549 mg/kg stayed in the roots of test plants, individually.	Aurangzeb et al. (2014)
<i>Canna x. generalis</i>	Phosphorus and nitrogen	Sewage Treatment Plant	Phytoremediation of Phosphorus and nitrogen	The pH somewhat turned out to be more alkaline amid the treatment, it was seen to have hardly expanded from 6.73 in the channel to 6.76 at the wetland outlet. Nitrate evacuation is anyway at a higher greatness with an extreme decrease of around 52% in its incentive after the treatment. The mean phosphate decrease in the treatment is 8.9% while the wetland indicates irrelevant expulsion of 1% phenolic compound following a month.	Ojoawo et al. (2015)
<i>Phragmites australis</i> , <i>Typha angustifolia</i>	Cd and Pb	Bogdanka river catchment	Accumulation of Cd and Pb in water, sediment and two littoral plants	High collection of Cd and Pb in plant organs was noticed toward the finish of the season. In addition, a higher leaf/rhizome translocation proportion was noted on account of Pb in <i>P. australis</i> . The translocation of estimated parameters was additionally for the most part higher in <i>T. angustifolia</i> plants. In general, plants revealed potential for phytoremediation in characteristic conditions, when moderately low Cd and Pb concentration happened.	Borowiak et al. (2016)
<i>Eichhornia crassipes</i>	pH, EC, TDS, BOD, COD, TKN, P, Ca ²⁺ , Mg ²⁺ , Na ⁺ , K ⁺	Star paper mill effluent, Saharanpur	phyto-kinetic removal of pollutants of paper mill effluent	The results showed that <i>E. crassipes</i> significantly reduced the contents of EC (62.23%), TDS (72.54%), TKN (89.27%), P (72.39%), Ca ²⁺ (51.79%), BOD ₅ (79.93%), COD (85.66%), Mg ²⁺ (51.02%), Na ⁺ (57.10%) and K ⁺ (71.47%) from the paper mill effluent at 2 months of phytoremediation experiments.	Kumar et al. (2017)

Table 1. Continued.....

<i>Eichhornia crassipes</i>	Zn, Ni and Cr	Laboratory scale study	A stock solution (1000 µg/L) each was prepared in distilled water with analytical grade $K_2Cr_2O_7$, $ZnCl_2$, and $NiCl_2 \cdot 6H_2O$	The least uptake of Zn was 1.6 µg/mg d.w. of <i>Eichhornia crassipes</i> at 600 µg/L at a 2h time break of which 41% was concentrated by the shoot and most of the 60% by the root. The uptake amount augmented about fivefold after 15 days at the same concentration of test metal. After 15 days of treatment, Zn uptake was 18.2 µg/mg ⁻¹ d.w. at 600µg/L test metal level.	Irfan and AlAtawi (2017)
<i>Pistia stratiotes</i> L.	TKN, TP, EC, TDS, BOD, COD, Ca^{2+} , Mg^{2+} , Na^+ , K^+ , MPN, SPC,	Uttam Sugar Mills Ltd. Libberheri, Roorkee, Haridwar	sugar mill effluent	Use of <i>P. stratiotes</i> was found to have the potential to eliminate chief pollutants such as COD, BOD, P, and N from effluent of sugar mill. Application of <i>P. stratiotes</i> plant biomass after phytoremediation process was found to have great efficiency to yield biogas.	Kumar et al. (2017)
<i>Eichhornia crassipes</i> , <i>Pistia stratiotes</i> L. <i>Spirodela polyrhiza</i>	TSS, TDS TP, DO, BOD, COD, EC, PO_4^{3-} , SO_4^{2-} , PH, Na, K, Pb, Cu, Fe, As, Zn, Cr, color,	The Abed Textiles Processing Mills Limited at Ghoradia in Narsingai Sadar, Bangladesh	Treatment of Textile Wastewater	<i>Eichhornia crassipes</i> was found most efficient in reducing TDS, EC, TSS and BOD and COD. Assorted treatment was most operative in decreasing pH and amongst the macrophytes and algae; <i>E. crassipes</i> had best potential in reducing pH. <i>Spirodela</i> , <i>Nostoc</i> , <i>Pistia</i> , and <i>Eichhornia</i> , all indicated efficiency in eliminating heavy metals, though, <i>Eichhornia</i> was utmost effective because of its ability to stock greater quantity of heavy metals than other algae and macrophytes.	Roy et al. (2018)

Rai (2008) conducted an experiment to encounter phytoremediation of Hg and Cd from industrial effluents using *A. pinnata*, an aquatic free floating macrophyte. The conclusion of the experiment was that the *A. pinnata* has a tremendous potential of phytoremediation. *Azolla pinnata* accumulated heavy metals, i.e., Hg and Cd (70–94%) and may be utilized as a bioaccumulator to control heavy metals in chlor-alkali effluent and ash slurry. Mishra *et al.* (2008) investigated tropical opencast coalmine effluent and studied the phytoremediation of heavy metals mercury and arsenic through naturally occurring aquatic macrophytes and concluded that three species of aquatic macrophytes *L. minor*, *E. crassipes* and *S. polyrrhiza* showed extremely operative in eliminating heavy metals from the effluent of coal mining throughout 25 days experimentation. The macrophytes eliminated considerable quantities of the Hg and As. However, these metals had led their poisonous effects by reducing chlorophyll, protein and Nitrogen, Phosphorus, potassium, content of the experimental macrophytes.

Roots of the macrophytes indicated improved collector of the heavy metals as they always exposed to greater quantity of Hg and As in contrast to the leaves. Rai and Tripathi (2009) performed a comparative valuation of *Azolla pinnata* and *Vallisneria spiralis* in Hg elimination from G.B. Pant Sagar and concluded that Aquatic plants might be capable applicant for phytoremediation of Hg from thermal power plant, coalmine and chlor-alkali effluent. The results got suggested that both *A. pinnata*, and *V. spiralis*, a can eliminate Hg from industrial discharges. *A. pinnata* taken up Hg more proficiently than *V. spiralis* and is thus suggested for elimination of Hg from polluted waters. Being submerged macrophytes *V. spiralis* may be more valuable to eliminate Hg from sediments in natural/field sites. Rai (2009) assessed a microcosm examination on phytoremediation of Chromium Using *Azolla Pinnata*. The study concluded that *Azolla pinnata* has the wonderful capability to accumulate Cr (III) and Cr (VI) (70–88%) and can be utilized as a bioaccumulator to control heavy metals in, coalmine, ash slurry and tannery effluent. Prasad and Singh (2011) performed an experimentation to find out the metabolic responses of *Azolla pinnata* to cadmium stress and concluded that *Azolla* can be utilized for the treatment of heavy metal to confident degree and as a sustainable performance to eliminate the heavy metal from contaminated sites. Baruah *et al.* (2014) studied the Phytoremediation of Arsenic by *Trapa natans* in a Hydroponic System and the study concluded that *T. natans* is a decent hyperaccumulator of arsenic in the roots as well in aboveground plant portions. Irrespective of the concentration, the roots were found to be best effective in the taking up of arsenic. While some external symptoms of poisonousness were detected at greater arsenic concentration, the plants were incapable to fight arsenic toxicity because of proline synthesis and amassing. Study concluded that *T. natans* can be suggested for the elimination of arsenic from polluted water. Kooh *et al.* (2016) used *Azolla pinnata* for the Separation of poisonous rhodamine B from aqueous solution by adsorption method and reviled that thermodynamics study showed endothermic, spontaneity and physisorption-dominant

adsorption process. The adsorbent, while showed a reduction in the first cycle of renewal, was able to afterward uphold up to five cycles of renewal with distilled water, HNO₃ and NaOH. Akinbile *et al.* (2016) conducted an experiment to find out the Phytoremediation of domestic wastewaters in constructed wetlands using *Azolla pinnata* and concluded that *Azolla pinnata* had proven to be a very reliable in treating municipal wastewater going by the results obtained. Kumar *et al.*, (2017) inspected the potential of *Eichhornia crassipes* using the paper mill effluent and found *Eichhornia crassipes* a very promissive agent for the phytoremediation of paper mill effluent. They reported that the greatest reduction was detected in the EC (62.23%), COD (85.66%), TDS (72.54%), BOD (79.93%), TKN (89.27%), Ca²⁺ (51.79%), P (72.39%), Mg²⁺ (51.02%), Na⁺ (57.10%) and K⁺ (71.47%). Kumar *et al.* (2017) did an experimental and kinetics study for phytoremediation of sugar mill effluent using water lettuce (*Pistia stratiotes* L.) and used its biomass for the production of biogas. The study concluded that *P. stratiotes* achieved remarkable decrease in nutrient (TKN, 72.86%; TP, 71.49%) and pollutant load (EC, 25.69%; BOD, 69.40%; COD, 61.80%; TDS, 57.26%; Ca²⁺, 56.79%; Mg²⁺, 55.01%; Na, 42.86%; K, 54.38%; MPN, 78.13%; SPC, 60.13%) from 75% sugar mill effluent at the end of the experimentation (Table 1 and 2).

NECESSITY OF PHYTOREMEDIATION

There is an urgent need for alternative, cheap and efficient methods to clean up heavily contaminated industrial areas. Phytoremediation, using plants to bio remediate infected soil, water, and air, has emerged as an inexpensive, noninvasive, and publicly acceptable manner to address the elimination of environmental contaminants (Boyajian and Carreira, 1997; Singh *et al.*, 2003). For countries like India, which are still developing, such capabilities of the aquatic macrophytes could be of huge importance where many shallow ponds and marshlands are having unfavorable condition for traditional fish farming and agriculture (Mohan Ram, 1978). Various species show different behavior regarding their efficacy to accumulate elements in roots, stems and/or leaves. Therefore, it will be very useful to find out the better trace element accumulator and its organ that absorbs the highest amount of trace factors (Baldantoni *et al.*, 2004). By the wetland treatment the production of edible biomass of aquatic macrophytes can give back economic returns to harvester. These economic paybacks can be realized by the generation of “bio-gas”, animal feed, fiber for paper making, compost etc. (Lakshman, 1987). Phytoremediation of water bodies may be grabbed as an opportunity along with ordinary treatment approaches like ion exchange resins and electro dialysis, microfiltration, chemical precipitation, sedimentation, and reverse osmosis (Rai, 2009). The treatment of the heavy metal contamination by modern machineries is very expensive for many developing countries like India which may not be able to meet the expense of the huge costs required for the treatment (Rai and Tripathi, 2007; Rai, 2008).

Table 2. Biomonitoring of some sites by means of phytoremediation by naturally occurring hyper accumulator plants.

Plant species/ Soil/ Water sample	Site/Location	Parameters/ heavy metals	Conclusion/Key Finding	References
<i>Bergia odorata</i> , <i>Hydrilla verticillata</i> , <i>Ipomoea aquatic</i> , <i>Najas graminea</i> , <i>Nelumbo nucifera</i> , <i>Phragmites karka</i> , <i>Typha angustata</i> , <i>Vallisneria spiralis</i>	Nal Sarovar Bird Sanctuary, Gujarat, India	Cd, Co, Cu, Ni, Pb, Zn	<i>Ipomoea</i> sp. has the highest capability with respect to concentrating trace element with maximum concentration (639.04 mg l ⁻¹) of Zn and least concentration of Cd (0.21 mg l ⁻¹), trailed by <i>Najas</i> , <i>Vallisneria</i> , <i>Nelumbo</i> , <i>Typha</i> , <i>Phragmites</i> and <i>Hydrilla</i> spp. Alternately, <i>Bergia</i> sp. has the most reduced number of trace element focus with high centralization of Zn (128.63 mg l ⁻¹) and low grouping of Cd (0.40 mg l ⁻¹).	Kumar et al. (2006)
<i>E. colonum</i> , <i>E. crasipes</i> , <i>H. verticillata</i> , <i>I. aquatic</i> , <i>N. nucifera</i> , <i>T. angustata</i> , <i>V. spiralis</i>	Pariyev Community Reserve, Gujarat, India	Cd, Co, Cu, Ni, Pb, Zn	The estimations of the proportion between component concentrations in the sediments and those in the water were lower (1.55-13.16 ppm) for Pb, Cd, Cu, Ni and Zn, while that of Co was watched high (19.81 ppm). The stems and additionally leaves of submerged plants aggregated lower concentrations of trace elements than roots which were well substantiated in other words with the discoveries of Baldantoni et al. (2005). In this manner, among the chose plant species, <i>T. angustata</i> and <i>I. aquatica</i> seem, by all accounts, to be the best observing species because of their accessibility in PCR.	Kumar et al. (2008)
Agricultural soil	Near Bindal river, Dehradun, india.	Pb, Zn, Cu, Ni, Cr, Cd Hg	Centralization of Zn was more and that of Cr was least in both regular and waste water inundated soils in Dehradun. The centralization of Zn, Cd and Cr expanded essentially in waste water flooded soil close Bindal waterway. Nonetheless, the expansion in the convergence of Pb, Cu, and Ni was insignificant.	Pathak et al. (2010)
Sewage water irrigated agricultural soil.	Near sewage treatment plant, Jagjeetpur, Haridwar and Control site tube well-water irrigated agricultural soil near at Gurukula Kangri University, Haridwar	Pb, Cu, Fe, Cd, Zn, Cr	The sewage water enhanced the organic carbon (+30.48%) and ripeness status as far as P (+59.97%), TKN (+87.5%) and K (+25.77%) of the soil which are the fundamental nutrients (NPK) for the development of plants. It was likewise confirmed that the sewage water system to a great degree expanded the measure of heavy metals, for example Cu (+253.17%), Ni (+128.29%), Zn (+696.03%) and Pb (+98.95%) in the soil. As compared with the reasonable permissible limits of Indian standards, the concentration of these metals in the soil was below the limit.	Pathak et al. (2011)
Agricultural soil irrigated by sewage water and tube well water	Rewari City	Physico-chemical and heavy metals	Utilization of sewage water enhance the richness status of the soil as it increment the yield of Rabi crops contrasted with irrigation done by tube-well water for the most part because of increment in OC (+49.19), K (+49.02), N (+109.09) and P (+72.08), which are essential nutrients for the correct development of plants and products. Be that as it may, the main danger of utilizing sewage water can be seen in expanding level of heavy metals content in the soil Cd (+27.41), Fe (+51.40), Pb (+106.64), Cu (+232.27) and Zn (+470.05), which are in the limits of Indian Standard, yet long period utilization of untreated sewage water surely make danger of accumulation of heavy metals in the soil.	Tobriya (2015)
Sediment, water, and phoomdi from Loktak Lake	Loktak Lake (Ramsar site), north-east, India	Fe Mn Zn Cu	Results prescribe the requirement to treat the wetland freshwater for local utilization and horticultural applications because of Fe tainting. Additionally, high BAFs and great TFs found for phoomdi demonstrate its promising potential in phytoremediation of nutrients and metals and use in re-vegetation of waterlogged polluted sites and developed wetlands intended for wastewater treatment.	Meitei et al. (2016)
SIDCUL effluent	The State Infrastructure and Industrial Development Corporation of Uttarakhand Limited (SIIDCUL), Haridwar	Cd, Cr, Cu, Fe, Mn, and Zn	The higher assimilations of heavy metals in SIDCUL effluent are likely due to close to the disposal site. The outcome demonstrated that accumulation of heavy metals is ceaselessly expanding in sediments and soil close by effluent channel. Heavy metal concentrations are greatest in amount close to the disposal site and diminishing with distance 34. In aquatic frameworks metals are transported either in soils or on the surface of suspended sediments 35. The accumulation of Cd, Fe, Cr, Cu, Mn and Zn in sediments are shifted by the rate of particle sedimentation, the rate of heavy metals deposition, the particle size and the presence or absence of organic matter in the sediments.	Kumar and Thakur (2017)

Conclusion and recommendation

Soil and Water pollution is a serious worldwide concern; to encounter this problem effective remediation methods are needed. Phytoremediation is environmental-friendly, cost-effective and solar-driven technique for heavy metal elimination from aquatic environments with decent community acceptance. Aquatic macrophytes are effective tools to eliminate heavy metals from aquatic bodies and have drawn a lot of responsiveness throughout the world. Both live and dead macrophytes work as a tool of bio-filtration for the heavy metals, in both the natural and manmade wetlands. The problem of discarding of biomass and periodic growth of aquatic macrophytes are few of the limits in the assignment of phytoremediation technique from the laboratory to the field of work. Though, an environmental friendly model has been established by the various works that may control some of the limitations. Biomass of macrophytes can be utilized for various productive applications. Industrial discharges and secondary-treated municipal wastewater can be improved with the application of aquatic macrophytes and disposed biomass may be reused for the production of biogas. Biodiversity prospecting, X-ray diffraction spectroscopy and Genetic engineering are encouraging future visions concerning the use of aquatic macrophytes in phytoremediation applications. A combined methodology and multidisciplinary approach may enable this developing technology to become the new edge in environmental science and technology.

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