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Phytoremediation impacts on water productivity

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Abstract

Phytoremediation is widely viewed as the ecologically responsible alternative to the environmentally destructive physical and chemical remediation methods currently practiced. Soil and water pollution is due to many kind of contaminants from various anthropogenic origins such as agricultural, industrial, wastewater; activities which involve the addition of nutrients, pesticides and on the other hand, industry and urbanization pollute the water with solid wastes, heavy metals, solvents, and several other slow degrading organic and inorganic substances. Dispersion of these contaminants from the source can be through the atmosphere, via the waterbodies and water channels, and/or into the soil itself, and from there they enter the food chain and adversely affects the human life. Important progresses have been made in the last years developing native plants for phytoremediation and/or nano-phytoremediation of environmental contaminants. Generally it is a technology that utilizes plants and their associated rhizosphere microorganisms to remove and transform the toxic chemicals located in soils, sediments, groundwater, surface water, and even the atmosphere. Phytoremediation applied to wetlands is an effective, nonintrusive, and inexpensive means of remediating wastewater, industrial water and landfill leachate. It highly increases water productivity.

Keywords: Aquatic Plants; Contaminants; Phytoremediation; Waste Water; Water Hyacinth, Water Productivity; Wetlands

INTRODUCTION

About three-quarters of all fresh water on earth is locked away in the form of ice caps and glaciers located in polar areas far from the most human habitation. In all, only about 0.01 percent of the world's total water supply is considered available for human use on a regular basis. About three-quarters of global annual rainfall comes down in areas containing less than one-third of the world's population. Fresh water is considered one of the most critical resource issue facing humanity, because the supply of fresh water is limited and at the same time the demand from the world's population is increasing day by day and consequently the demand for global water usage. The amount of fresh water would have to limit the population growth in an area (Schröder *et al*., 2007; Luqman *et al*., 2013; Sharma and Pandey, 2014; Banjoko and Eslamian, 2015; Chandekarand and Godboley, 2015; Upadhyay *et al*., 2019; Hinrichsen and Tacio, 2020; Ubuza *et al*., 2020; Wei *et al*., 2021). At the same time, it has been observed an increase of urbanization affecting the quality and availability of fresh water, meanwhile the request for water for agriculture purpose, for household consumption and industrial use is increasing too. The result of this overuse has caused and is causing a depletion and pollution of surface water and groundwater. In particular, wastes are dumped in lakes and rivers, including untreated or partially treated municipal sewage, industrial poisons, and harmful chemicals that leach into surface and ground water during these anthropological activities. Polluted water, water shortages, and unsanitary living might cause illness such as cholera, hepatitis A, dysentery, dengue and malaria fevers. These pollutants deteriorate the quality of water

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even in exceptionally low concentration and may have the hazardous effects on human health, animals, plants, and aquatic organisms. Moreover a huge amount of water is wasted because of an inefficient irrigation systems, poor watershed management and inappropriate agricultural subsidies (Hinrichsen and Tacio, 2020).

Hinrichsen and Tacio (2020) have also highlighted the water bodies do not respect national borders, so the risk of an escalating tension to access freshwater supplies is high because of enormous amounts of water are wasted due to inappropriate poor watershed management, pollution, and other practices. Further, Schröder *et al*. (2007) has explained that more than 100,000 different chemicals are available, generally these are less or not biodegradable and unfortunately micro quantities of these man-made pollutants are in fresh water resources. It is simple to infer that water pollution is also associated with rising technology. Pollution in water depends on what it is allowed into the effluent stream. The required treatments are different in case of industrial effluents or municipal wastes. European Union claimed for a rigorous action for improving the quality of the water and the protection of natural resources (ETAP). Unfortunately, water pollution has become a fundamental problem for developed and developing countries (Okunowo and Ogunkanmi, 2010; Luqman *et al*., 2013; Toure *et al*., 2018). Pollution has reduced the capacity of waterways to assimilate or flush pollutants from the hydrological system. Inorganic and organic contaminants have become of serious concern, because they are not easy to destroy, they could be transformed from highly toxic to a less toxic form. This type of contamination could alter the aquatic ecosystem, therefore the life of animals, plants and microorganism too. Numerous approaches have been taken to reduce water consumption, but in the long run it seems only possible to recycle wastewater into high-quality water (Sharma and Pandey, 2014; Basilico *et al*., 2015; Wei *et al*., 2021).

Continuous efforts have been made to develop the technologies that are easy to use, sustenance and economically feasible to maintain and/or clean up waters, free of contaminants. United Nations Environment Program defined phytoremediation as ‘‘the efficient use of plants to remove, detoxify or immobilize environmental contaminants” (UNEP, 2019). In particular, phytoremediation means to remove, stabilize or transform the contaminants through the plants and microorganisms in the rhizosphere. Plants can remediate organic and inorganic contaminants, the advantages are the low energy cost and the eco-friendly nature, on the other hand it requires a long time for the growth of the plants and to uptake the contaminants (Haq *et al*., 2020; Nizam *et al*., 2020), it may take at least several growing seasons to clean up a site. Phytoremediation of different types of contaminants requires different general plant characteristics for optimum effectiveness. Plants that absorb these contaminants may pose a risk to wildlife and contaminate the food chain. It is efficient in case of low-mid level of contaminants, unfortunately high concentration of contaminants may inhibit the growth of plants (Jamuna and Noorjahan, 2009; Ansari *et al*., 2020).

This paper attempts to provide a brief review on phytoremediation and water resource with an approach to water productivity.

METHODS

The possible mechanisms are extraction of the contaminants from soil and water, concentration of the contaminants in the shoot, degradation of contaminants by biotic and abiotic processes, and volatilization of contaminants in the atmosphere. it is possible to distinguish the phytoremediation processes in Phytoextraction; Phytostabilization; Phytotransformation; Phytostimulation; Phytovolatilization; Rhizofiltration (Fig.1).

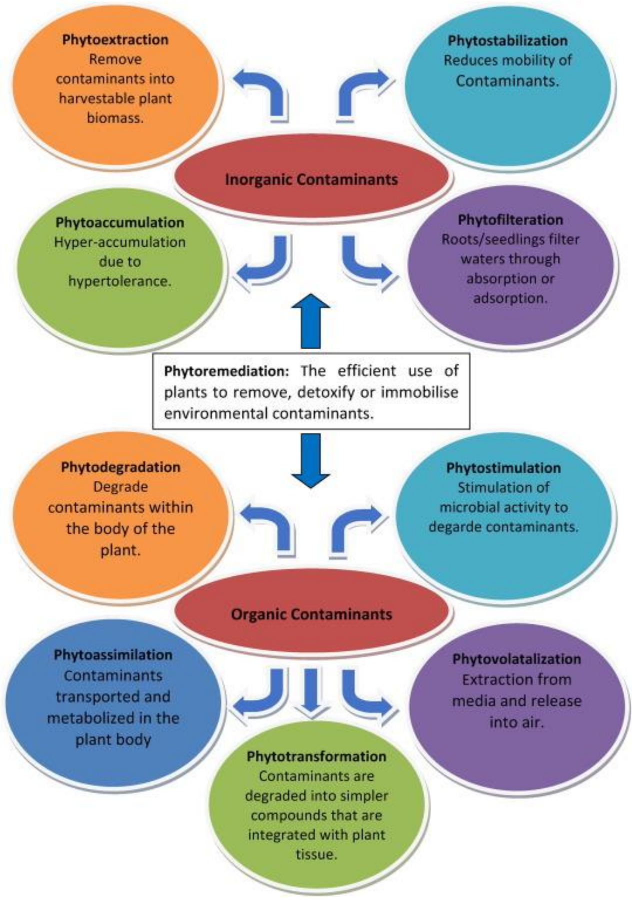

Fig. 1. Phytoremediation processes in aquatic polluted environment (Ansari *et al*., 2020)

In particular Phytoextraction and Rhizofiltration are used in aqueous environments, whereas the other methodologies are generally used in soil environment. Rhizodegradation can involve groundwater movements.

Phytoextraction (Corami, 2017) is the uptake of contaminants by roots and translocation into the shoots. Harvesting the plants, contaminants are removed. Most important disadvantages are slow-growing of the plants, small biomass production and shallow roots. Plants with multiple harvests in a single growth period are considered suitable. Phytoextraction can be divided in continuous phytoextraction (using hyperaccumulator plants) and induced phytoextraction (chemically induced accumulation of metals to crop plants). The main disadvantage in polluted water is that the contamination is heterogeneous and there are hotspots of contamination. Plants can be considered as filters, they could be used in constructed wetlands or in hydroponic setup with a continuous air supply.

Rhizofiltration is defined as the use of plant roots to absorb, concentrate, and precipitate heavy metals from polluted effluents. It occurs in the rizhosphere and water must be in contact with roots (Corami, 2017).

Phytostabilization is defined as the immobilization of a contaminant in soil through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants, and to prevent contaminant migration via wind and water erosion, leaching, and avoiding metals entry in food chain (Corami, 2017). Plants should develop an extensive root system and a large amount of biomass in presence of high concentrations of heavy metals while keeping the translocation of metals from roots to stems and leaves as low as possible.

Phytotransformation or phytodegradation is the breakdown of contaminants through metabolic processes within the plant (Corami, 2017). The degradation might occur outside the plant because of releasing of compounds which cause the transformation, conversely degradation caused by microorganisms is considered rhizodegradation.

Phytotransformation might also occur in an environment free of microorganisms, also in sterile soils where biodegradation could not occur. Unfortunately, toxic intermediate products may form and organic contaminants, after their uptake, might be translocated to other plant tissues and then volatilized, or they might be degraded, or be bound in non-available forms (Corami, 2017).

Phytostimulation or rhizodegradation is the breakdown of organic contaminants in soil by microorganism in the rhizosphere. Groundwater movement may be induced by the transpiration of plants, so that contaminants in the ground water might reach the rhizosphere (Corami, 2017).

Phytovolatilization is the release of the contaminant to the atmosphere, the contaminant is uptaken and by the plant metabolism and transpiration is released. The released contaminants may be also subject to photodegradation in the atmosphere (Mench *et al*., 2010; Corami, 2017).

RESULTS AND DISCUSSION

The most efficient and cost-effective remediation solution in water or soil might be a combination of different technologies. In case of contaminated aquatic environment, a sustainable phytoremediation require plants with a rapid growth and higher biomass accumulation. Some species of wild aquatic weeds are found more tolerant and they can act as a strong obstacle avoiding the entry of contaminants into the food webs (Ansari *et al*., 2020). Glick (2003) have inferred that the interaction between plants and microorganisms improves phytoremediation, so that the bio-augmentation process could be effective. Volkering *et al*. (1998) have studied some bacteria that release biosulfactants (rhamnolipids) making hydrophobic pollutants more water soluble. Incrementing the number of microorganisms through the inoculation of different microorganisms, in particular bacteria which beneficially affect plants (Sood *et al*., 2016), known as plant growth-promoting bacteria (PGPB), these ones seem to be able to produce chemical substances which can modify the environmental conditions (van Hullebusch *et al*., 2005). Cakmakci *et al*. (2006) have found plants which could release organic acids which can solubilize previously unavailable nutrients such as phosphorus or contain lipophilic compounds that increase pollutant water solubility or enhance biosulfactant- producing bacterial populations. The increased request for water resources among urban, industrial, and agricultural interests has led to increase the use of wastewater for irrigation (National Research Council, 1996; Mojiri *et al*., 2016) and consequently to develop a cost-effective and suitable method to allow the use of wastewater for agricultural and industrial purposes. Land application of wastewater is significantly costs-effective, compared with standard water treatment technologies (Adler *et al*., 2003). Adler *et al*. (2003) proposed a thin-film technology that allows plants to selectively extract nutrients from water, making dilute effluents an equivalent source of nutrients as more concentrated effluents.

Luqman *et al*. (2013) have written that if water flows quickly, many of the pollutants present on the surface will reach the main body of water through the run-off, on the contrary if water flows more slowly due to the presence of vegetation on land, more of the pollutants will be filtered out. Furthermore, natural events may lead to changes in chemical properties causing the mobilization of contaminants from sediment and sediment pore water into the water column (Zhang *et al*. 2001; Eggleton and Thomas, 2004; Hooda, 2007). Plants are very effective at removing nutrients to low levels concurrent with the production of a high-value product. It was demonstrated that the reused-water is increased and the majority of this water was returned to the environment in excellent condition (Schröder *et al*., 2007; Mustafa and Hayder, 2020). In particular, trees act as water filters and improve water quality due to their extensive root system (Azzarello *et al*., 2011, Luqman *et al*., 2013). Root system could be considered a huge area that could absorb water and nutrients, and at the same time contaminants. Forests, parks and wetlands can help to slow and filter the water, keeping drinking water sources cleaner and making treatment cheaper. The use of trees to remediate the polluted water is considered as the new emerging technology which is relatively cheaper, it offers restoration of sites, limited decontamination, preservation of the biological activity and physical structure of soils, and is potentially cheap, visually inconspicuous. Moreover, roots can penetrate deeply into the ground and it is possible to treat contaminated groundwater. Unfortunately, plants roots may cause changes at interface between soil and roots releasing organic and inorganic substances. The root exudates may affect the microorganisms (number and activity), the soil particles (aggregation and stability) and the movements of contaminants too (Banjoko and Eslamian, 2015).

Plants act as an hydraulic pump, controlling the migration of water and meanwhile decreasing the migration of contaminants from surface water into groundwater, exerting an hydraulic control. Phytoremediation has been employed in remediating contaminated surface water, groundwater, urban run-off water, desalinization and post desalination treatments, natural and constructed wetlands. Aquatic phytoremediation involves the use of plants for the removal of contaminants from aqueous solutions, these plants are fundamental for primary productivity and nutrient cycling. Many aquatic plants (emerging, submerged or free flowing) have been applied extensively, recently and mostly conducted using hydroponics or field experiment by constructed wetlands. The removal rates are varied and mainly controlled by the physicochemical properties of the water, contaminants, plants and the experimental framework (Ansari *et al*., 2016; Obinna and Ebere, 2019; Ubuza *et al*., 2020). In fact aquatic plants are highly sensitive to pH, temperature and nutrient concentration of the growing media. Among aquatic plants, the floating ones show the higher capacity of metal accumulation, followed by submersed and later the emergent species. In the low-load basin, aquatic plants have significant effect on transport capacity increasing sediment deposition (de Cabo *et al*., 2015; Jasrotia *et al*., 2017) and preventing hydromorphological hazards.

Gupta *et al*. (2012) suggested the water hyacinth (Fig. 2) as a successful plant in phytoremediation, this plant is highly efficient in removing a huge range of contaminants from wastewater and has shown the ability to grow in deep polluted water, moreover it has shown to improve the quality of water reducing the amount of organic and inorganic nutrients and also heavy metals.

If not harvested at an appropriate time, nutrients from the plants are leached back into the water and old plants after death cause anaerobic conditions in water (Fig. 3).

Ali *et al*. (2020) have written that wetlands provide a simple and cheap solution for decreasing the water contamination without causing consequences to natural resources. In case of the application of aquatic plants, it is not necessary any kind of post-filtration, it is possible to treat large volume of water (Upadhyay *et al*., 2019).

In particular, in wetlands areas, water is the key factor controlling runoff and obviously metals too. It is suggested to use wetlands to treat runoff providing a valuable water quality protection because they have the characteristic to improve water quality (Fig. 4).

Fig. 2. Water Hyacinth (Jernelöv, 2017)

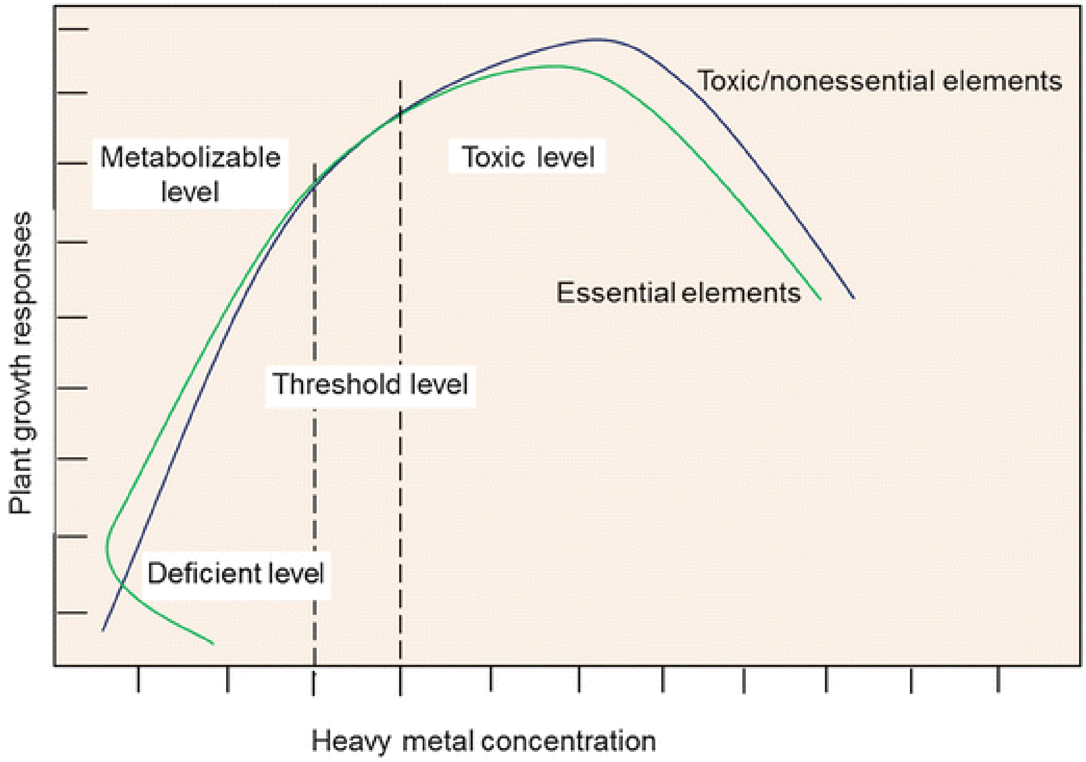

Fig. 3. A bell-shaped curve for plant responses to heavy metal uptake, beyond a threshold limit these metal become toxic (Perveen *et al*., 2016)

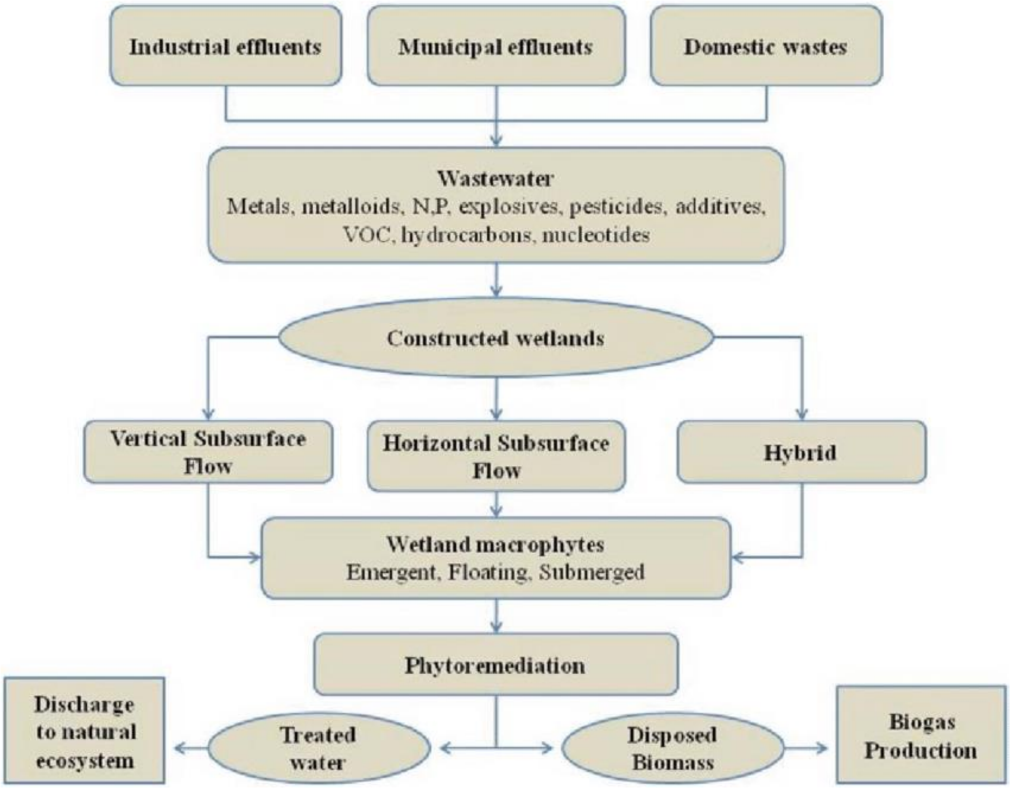

Fig. 4. Phytoremediation in wetlands (Herath and Vithanage, 2015)

Their use for wastewater treatment might be done hand in hand, with a deep scientific study to determine the sequestration of contaminants. Besides, a periodic harvesting of metal accumulated biomass and disposing as hazardous waste, involve added cost. Thus phytoremediation, in combination with burning the biomass to produce electricity and heat, could become a new environmentally friendly form of pollution remediation (Chatterjee *et al.*, 2013). Furthermore, constructed wetlands are the low-cost maintenance systems, they are cost effective producing biomass for energy production, green technologies are more suitable for water clean-up.

Phytoremediation applied to water is able to increase the sustainability of drinking water resource and at the same time it contributes to decrease the amount of energy, CO_2 emission and waste production. The good water quality will lead to additional consumer satisfaction, sustainability for future generations (Fig. 5) (Schröder *et al*., 2007).

Contaminated water resources become less polluted through phytoremediation and aquatic plant, so the water productivity, that is the amount of water consumption for irrigated areas, will increase, mine waters and drainage waters could be considered like green water (effective rainfall) or as blue water (diverted water from water systems).

For example, water hyacinth biomass is rich in nitrogen and other essential nutrients, its sludge contains almost all nutrients and can be used as a good fertilizer (Ajayi and Ogunbayo, 2012). After harvesting, it can be used for composting, anaerobic digestion for production of methane, fermentation of sugars into alcohol green fertilizer, compost and ash in regenerating degraded soils. These operations can help in recovering expenses of wastewater treatment (Gupta *et al.*, 2012). In particular, aquatic plants seem to be the most advantageous solution in case of contaminated water and seems to increase resistance to flow, affecting sediment transport.

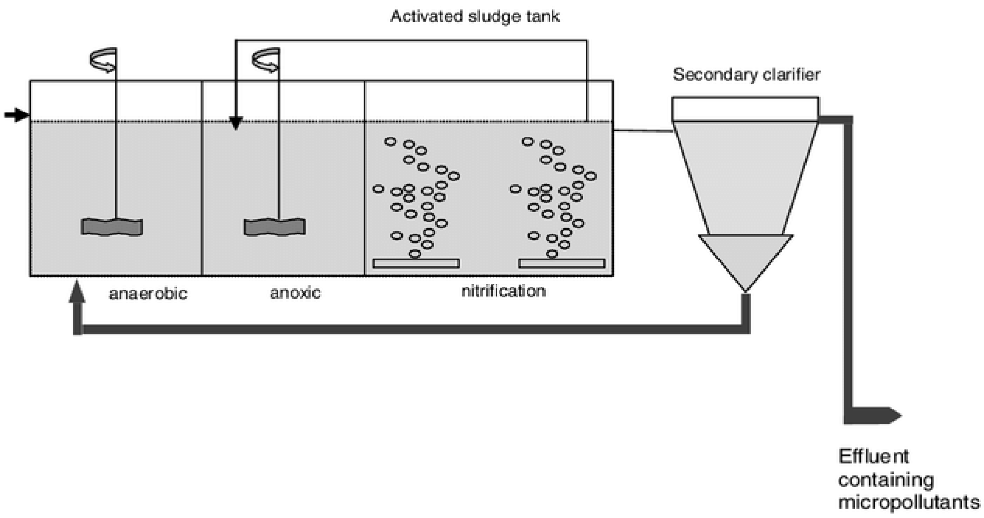

Fig. 5. State of the art of wastewater treatment (Schröder *et al*., 2007)

Wan *et al*. (2016) have calculated the cost-benefit for a phytoremediation project, a soil contaminated by heavy metals. They have calculated all the steps for a two years project, considering the initial cost (pollution investigation, establishment of remediation strategy, soil preparation, irrigation system, and incineration equipment) and operational cost (the cost of labor and materials, cost of using large machines, and the other direct or indirect costs). It is stated that in about seven years the benefits would offset the costs.

The application of phytoremediation at full scale and on site for metal excess in aquatic ecosystems using several macrophytes is limited mainly to the immobilization of toxics in the sediments and rhizosphere-root system. The low translocation to the aboveground tissues main advantage is to avoid the dispersion of pollutants into the food chain. Besides, nanotechnology is one of the most promising technology applications to phytoremediation. Nano-bioremediation (NBR) is the new emerging technique for the removal of pollutants for environmental cleanup.

In particular Das (2018) has applied the phytoremediation and nano-remediation in case of acid mine drainage water. It has been demonstrated that these two technologies are complementary, whereas phytoremediation needs a suitable selection of plants and a long time, nano-remediation is rapid and effective, the disadvantages are the high cost and the accumulation in living organism. So an interdisciplinary approach can be efficient enough to innovative solutions (Srivastav *et al*., 2018).

The advantage of nano-technology is the efficiency and it is defined as an eco-friendly alternatives for environmental cleanup without harming the nature.

Sadowsky (1999) described that using genetic engineering and plant breeding techniques it will be possible to have a much better understanding of the ecology of rhizosphere microorganisms growing in polluted soils and water. Furthermore with the development of biotechnology, the capabilities of hyperaccumulators may be greatly enhanced through specific metal gene identification and its transfer in certain promising species (Lone *et al*., 2008).

CONCLUSIONS

Rapid industrialization and urbanization has resulted in the deterioration of water The increase in the use of inorganic and organic contaminants is of special concern because of their carcinogenic properties. Phytoremediation means to remove, stabilize or transform the contaminants through the plants and microorganisms in the rhizosphere. Plants can be considered as filters, they could be used in constructed wetlands or in hydroponic setup with a continuous air supply.

Phytoremediation results a cost-effective technology and increase the quality of wastewater too, allowing its re-use for many purposes. In the last decade, many progresses have been done and through nanotechnology and genetic engineering further progress could be done.

Fundamentally phytoremediation offers a permanent *in situ* remediation, particularly for waste water. Finally, it is important to emphasize that phytoremediation is environmentally friendly and with better aesthetic appeal than other physical means of remediation. It is an efficient and cost-effective technology to protect natural resources, water in particular. Strong efforts have been made to understand the suitable plants and the mechanism uptake during these years. The recent advances in plant biotechnology have created a new hope in the use of this technology. The main reason to apply phytoremediation to wastewater is the amelioration of the water quality, the standards of regenerated waters and groundwater. Phytoremediation can decompose pollutants to non-toxic low molecular substances, additional chemical substances are not introduce in the environment and finally it is not requested a large investment. It is a water reuse technique that has a great influence on water efficiency and productivity.

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