

Treatment of Water Using Water Hyacinth, Water Lettuce and Vetiver Grass - A Review

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Abstract Phytoremediation techniques for the treatment of different types of wastewater have been used by several researchers. These techniques are reported to be cost effective compared to other methods. Various contaminants like total suspended solids, dissolved solids, electrical conductivity, hardness, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen, nitrogen, phosphorous, heavy metals, and other contaminants have been minimized using water hyacinth, water lettuce and vetiver grass. In this paper, role of these plant species, origin and their occurrence, ecological factors and their efficiency in reduction of different water contaminants have been presented.

Keywords Phytoremediation, Constructed Wetlands, Waste-Water Treatment, Water Hyacinth, Water Lettuce, Vetiver Grass

1. Introduction

Phytoremediation is one of the biological wastewater treatment methods[1], and is the concept of using plants-based systems and microbiological processes to eliminate contaminants in nature. The remediation techniques utilize specific planting arrangements, constructed wetlands (CW), floating-plant systems and numerous other configurations[2]. The removal of wastewater constituents are achieved by different mechanisms like sedimentation, filtration, chemical precipitation, adsorption, microbial interactions, and uptake of vegetation[3], among which, the most effective technology is phytoremediation strategy using CW technology. Besides water quality improvement and energy savings, CWs have other environmental protection features such as promoting biodiversity, providing habitat for wetland organisms and wildlife (e.g. birds and reptiles in large systems)[4], serving climatic (e.g. less CO₂ production[4]; hydrological functions and biomethylation[5]). These systems are generally cost effective, simple, environmentally non-disruptive[1,6] ecologically sound[7] with low maintenance cost[8] and low land requirements[9].

The principles of phytoremediation system are to clean up contaminated water, which include identification and implementation of efficient aquatic plant; uptake of

dissolved nutrients and metals by the growing plants; and harvest and beneficial use of the plant biomass produced from the remediation system[9]. The most important factor in implementing phytoremediation is the selection of an appropriate plant[1,10], which should have high uptake of both organic and inorganic pollutants, grow well in polluted water and easily controlled in quantitatively propagated dispersion[1]. The uptake and accumulation of pollutants vary from plant to plant and also from specie to specie within a genus[11]. The economic success of phytoremediation largely depends on photosynthetic activity and growth rate of plants[7], and with low to moderate amount of pollution[12].

Many researchers have used different plant species like Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms)[12-20], Water Lettuce (*Pistia stratiotes* L.)[21-25], Duckweed (*Water Lemna*), Bulrush (*Typha*), Vetiver Grass (*Chrysopogon zizanioides*)[1,26-28] and Common Reed (*Phragmites Australis*) for the treatment of water. They have used these species for different types of contaminated waters, effluents etc. Mkandawire and Dudel[29] have used duckweed and they found its growth was restricted above 34 °C and pH sensitive. Mashauri et al.[30] used bulrush and his study revealed that the total dissolved solids (TDS) and electrical conductivity (EC) concentration was increased after treatment. Baskar et al.[31] in his study of kitchen wastewater treatment found only 4% TDS removal by common reed. Hence water hyacinth, water lettuce and vetiver grass were selected for review because they efficiently removes the heavy metals and other pollutants with high reproduction rate, efficiency and tolerance of ecological factors. In this paper, role of these plant species have been discussed for the removal of water contaminants.

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2. Role of Macrophytes in Water Contamination Removal

Macrophytes play important roles in balancing lake ecosystem. For the first time, they were recognised during 1960s and 1970s in water quality improvement[32]. Aquatic macrophytes treatment systems for waste-water are the need of developing countries, because they are cheaper to construct and a little skill is required to operate[20]. They improve the water quality by absorbing nutrients with their effective root system[15]. Macrophytes not only retain nutrients by biomass uptake, but also increases sedimentation[33]. These are utilized for nutrient and metal removal from water in the forms of CW or retention ponds because of their fast growth rates, simple requirements, and ability to accumulate biogenic elements and toxic substances[9].

Aquatic plants are grouped into submerged, emergent, and floating-leaved based on their leaf's relation with water. During selection, biomass production, growth rate, and easiness of management and harvest should be taken into account[9]. Wetlands are mainly dominated by the floating aquatic macrophytes[34-36]. Floating aquatic plants can grow in vertical as well as horizontal direction, thereby increasing the photosynthetic surface area. These factors altogether makes floating aquatic plants, one of the earth's most productive communities[9]. The most common aquatic macrophytes among the floating-leaved, being employed in wastewater treatment are water hyacinth and water lettuce [37-39]. Impressive removal rates of inorganic nitrogen [nitrate ($\text{NO}_3\text{-N}$), ammonium ($\text{NH}_4\text{-N}$), and total N] and phosphorus ($\text{PO}_4\text{-P}$ and total P) have been reported using aquatic plants especially when water hyacinth were utilized in nutrient or metal-rich wastewaters[9]. Awuah et al.[25] found 70% of TDS reductions by water lettuce. Vetiver can also be used as hydroponics. Hydroponics is cultivating the crops in nutrient solution or media without soil. This species is known for its wide capacity to adapt various water regime conditions, but probably its temperature requirements were not fully satisfied[10]. Ebrahim et al.[40] found that vetiver root can remove TDS in water about 55.93% by the adsorption method. In India, as there is plenty of abundant and agriculture based lands, therefore, these techniques for wastewater treatment can be used for safe disposal of contaminated water.

3. Selected Plant Species for Treatment of Water

3.1. Water Hyacinth (*Eichhornia crassipes* (Mart.) Solms.)

3.1.1. Plant Origin and Geographical Distribution

Water hyacinth is fast growing perennial aquatic macrophyte (requiring a wet habitat)[41] and prolific free floating aquatic weed[42]. It is a member of pickerelweed

family - Pontederiaceae and Genus - Eichhornia. Its name Eichhornia was derived from well known 19th century Prussian politician J.A.F. Eichhorn[43]. This tropical plant spread throughout the world in late 19th and early 20th century[44]. According to Mitchell[45], the water hyacinth is indigenous to South America, particularly to the Amazonian basin. It reached Australia in 1895, India in 1902, Malaysia in 1910, Zimbabwe in 1937 and the Republic of the Congo in 1952[46]. It is abundantly found in India, Bangladesh and South East Asia[47]. This plant is rounded, upright with shiny green leaves, lavender flowers[48] with dark blue root system[49,50].

It has the great reproduction potential as it grows double in 5 to 15 days[14,16,49,51]. Only ten plants in just eight months can produce population of 655,330 individuals[14]. It commonly forms dense, interlocking mats due to its rapid reproductive rate and complex root structure[52]. It reproduces both sexually and asexually[53]. It is available naturally in wide region over 33° N to 33° S of the equator and grow rapidly from 220 kg/ha-day to 600 kg/ha-day seasonally in pond with density from 224 to 412 tons/ha[54]. The inflorescence bears 6-10 lily-like flowers, each 4-7 cm in diameter[46] and the flowering period lasts for about fifteen days. When flowering cycle ends, flower stalk bends due to that spike reaches under the water surface and seeds are released directly into the water[14,55]. The height from flower top to root top of water hyacinth usually reach upto 1.5 m and more[56]. Arceivala[57] stated that individual plants ranges from 500 to 1175 mm from the top of the lavender flower to root tips.

3.1.2. Ecological Factors

For a phytoremediation system to work efficiently, optimal plant growth is the key parameter. Many environmental factors can influence plant growth and its performance, such as temperature, pH, solar radiation, and salinity of the water. The weight and size of aquatic plants are a function of these factors. Its growth can be described by two ways: first by reporting the percentage of water surface covered for a period of time and second but more useful is by reporting the plant density in units of wet plant mass per unit of surface area[14,48]. Nutrient availability also affects the growth and performance of aquatic plants. As per Makhani[58] it comprises of 95% water and 5% dry matter, out of which silica, potassium, nitrogen and protein is 50%, 30%, 15% and 5%, respectively. It also provides breeding space and sanctuary for birds, fish, snails, insects and other wildlife[59]. Zhao et al.[60] found that nutrient concentration, mean number of ramets, mean height and total biomass of water hyacinth significantly increased with increasing nutrient level. Shorter time is required to reach maximum biomass yield in summer with high growth rate [61] whereas optimal water temperature for its growth is 28-30 °C. Temperature above 33 °C inhibits further growth[55]. If temperature of -3 °C lasts for 12 hours, it will destroy all leaves and temperature of -5 °C for the period of

48 hours will destroy whole plant[48]. Other researchers also found similar results about water hyacinth sensibility to low temperatures. According to Stephenson *et al.*[62], it can survive 24 hours at temperatures between 0.5 and -5 °C but it will die at - 6 to -7 °C and cannot be grown in open where average winter temperature drops under 1 °C. Therefore, it is not suitable for temperate or frigid areas due to their sensitivity to cool temperature[63]. Overall nutrient uptake is greater in summer when temperatures are higher and more favorable for plant growth[64]. Low air humidity from 15% to 40% can also be limiting factor for undisturbed growth of water hyacinth[65]. It tolerates drought as well because it can survive in moist sediments up to several months[55]. Generally, plant grows best in the pH range of 5.5-7.0[9]. Optimal water pH for growth of this aquatic plant is neutral but it can tolerate pH values from 4 to 10[66].

The growth rate of water hyacinth is strongly dependent upon the concentration of dissolved nitrogen (N) and phosphorus (P) in the water[67-69]. Sato and Kondo[70] reported that its maximum growth rate can be achieved at 28 mg/L of total N and 7.7 mg/L of total P. The levels of available nitrogen and phosphorus have often been cited as the most important factors in limiting water hyacinth growth[69,71-74]. According to Reddy *et al.*[69,71,72], 5.5 mg of N/L and 1.06 mg of P/L is required for survival of water hyacinth growth whereas to achieve maximum growth N, P and K (potassium) are added at the rate of 20 mg N/L, 3 mg P/L and 52 mg K/L, respectively. Therefore, to get the maximum growth usually N is added as ammonium nitrate, sodium phosphate as P, and potassium chloride for K. Reddy and Tucker[75] suggested not only its nutrient concentration but also ratios between nutrients play an important role in plant growth. The highest production occurs when the N:P ratio in the water was close to 3.6. Plants need nitrogen for their metabolism to grow and to reproduce. According to Delgado *et al.*[76], water hyacinth prefers ammonium ions rather than nitrate ions. Water hyacinth absorbs ammonia by their roots to incorporate it in their biomass[31]. However, in the absence of ammonium N, a high growth can also be achieved with nitrate as the only source of N[77]. Reddy *et al.*[71] suggests that the overall P requirement of plant is very low in comparison of N. Thinner and longer root enhance geometry for uptake of nutrients from the environment, hence P uptake depends on root length, diameter and surface area in contact with the environment[78]. Morphological plasticity in root system is, thus favorable for water hyacinth to adapt to low-P environment[79]. Reddy *et al.*[72] stated that nitrogen content of hyacinth tissue is inversely related to the K supply rates. It has one of the highest K tissue concentrations when compared with other aquatic plants[80-81] which ranges from 10 to 83 mg of K/g. Such a wide range of tissue K content suggests that it has high K requirement and a high K uptake capability[71]. Reddy *et al.*[72] found that maximum water hyacinth biomass 3.1 Kg (dry weight)/m² at a concentration of 52 mg of K/L. Knippling *et al.*[80] found maximum N, P, K concentration in the leaf, stem and root

tissue of water hyacinth, respectively.

The plant biomass (the sum of leaf, stem and root volumes) relates closely to evapotranspiration potential[82]. Over the years, some researchers have found evaporation from open water to exceed evapotranspiration of vegetated surfaces[83-85]. Water hyacinth evapotranspiration loss is in between 3 to 10 times[54,86,87] in comparison of open water.

3.1.3. Efficiency of Water Hyacinth In Reduction of Water Contaminants

Information in the literature about plant yields and growth rates are varying. The productivity of water hyacinth cultured in nutrient enriched waters and wastewaters has been found to be in the range of 40-88 mt (dry wt) /ha/yr[88,89]. Jo *et al.*[90] evaluated the growth of water hyacinth after 30 days and reported yield of 6402.5 g/m² whereas Sooknah and Wilkie[91] used hyacinth in dairy manure for 31 days and found its yield was 1608 g/m². DeBusk *et al.*[92] evaluated hyacinth in secondarily treated municipal wastewater and reported plant productivity of 16 g/m²/day. Similarly, Ayyasamy *et al.*[93] observed biomass which increased from 75 to 101-106 mg/L, with 37% increase in 10 days. Snow and Ghaly[94] found water hyacinth yields were 83 and 49 g/m² with hydraulic retention times (HRT) of 6 and 12 days, respectively. It has been estimated by Reed *et al.*[95] that 10 individual plants can spread and cover one acre pond within 8 months.

Richards[96] reported poor growth in distilled water because it produced small leaves with inflated petioles. According to Valipour *et al.*[18] water hyacinth is unable to survive in salinities above 2 ppt. Haller *et al.*[97] reported that it can withstand upto 2500 mg/kg (equivalent to 4040 µS/cm) and selenium concentration of more than 10 mg/L has phytotoxic effects on the water hyacinth[98].

The use of water hyacinth as the functional unit in wastewater treatment systems has been increasingly demonstrated and treatment regimens developed as a result of successful pilot projects[35,99].

The water hyacinth has successfully resisted of its eradication by chemical, biological, mechanical, or hybrid means[100]. Adeniran[101] observed that the water hyacinth of CW based requires only 13% of the energy as compared to conventional sewage treatment plant for the same quantity of sewage and concluded that is a viable and cost effective option for the treatment of domestic sewage in a developing economy. It has a huge potential for removal of the vast range of pollutants from wastewater[42,102-104] and has the ability to grow in severe polluted waters[105]. It is also used to improve the quality of water by reducing the levels of organic, inorganic nutrients[106] and heavy metals [19,107-110]. Presence of its fibrous root system and broad leaves help them to absorb higher concentrations of heavy metals[111]. It readily reduces the level of heavy metals in acid mine drainage water[112] and silver from industrial wastewater in short time[113]. This capability makes them a potential biological alternative to secondary and tertiary

treatment for wastewater[35,114-116].

Water hyacinth has been found to stabilize temperature in experimental lagoons, thereby preventing stratification and increasing mixing within the water column[117]. Water hyacinth can convert alkaline pH into neutral[20,23]. The reduction in pH is due to absorption of nutrients or by simultaneous release of H⁺ ions with the uptake of metal ions[20]. Borges et al.[118] obtained EC reduction by 18.1% in 5 days and TDS removal by 39.1% in 20 days. Lissy and Madhu[14] observed an increase in TDS when plant placed in the tank. This increase was due to the presence of clay or other fine particles present in the plant roots and or the presence of high Cr concentrations. On subsequent days, it showed that the TDS value considerably decreased by the accumulation process.

The reduction in pH favors microbial action to degrade biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in the wastewater. According to Reddy[119], the presence of plants in wastewater depletes dissolved CO₂ during the period of photosynthetic activity and an increase in DO of water, thus creates aerobic conditions in wastewater, which favors the aerobic bacterial activity to reduce the BOD and COD[20]. Dar et al.[16] and Shah et al.[120] observed increase in DO level after using water hyacinth in wastewater whereas Mangas-Ramirez and Elias-Gutierrez [121] and Perna and Burrows[122] found lowered DO concentrations beneath the hyacinth mats. Trivedy and Pattanshetty[17] found that systems with shallow depth were more efficient in removing dissolved solids, suspended solids, BOD, COD, nitrogen and phosphorus. According to Valipour et al.[13] and Sooknah[123], higher pond depth can raise the anaerobic zones resulting slow organic degradation rate and foul odour emission. Many researchers[93,124,125] have found that removal of nutrients is more efficient in young plants as compare to old; hence, regular harvesting of old plants is essential. 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[93]. Gamage and Yapa[126] used water hyacinth in textile mill and monitored for a period of one year. They observed BOD and COD removal was 75% and 81.4% respectively whereas Kulatilake and Yapa[127] reported 99% BOD and 80% COD removal for rubber factory effluents. Snow and Ghaly[94] found that the COD reductions decreased as HRT was increased and ammonium (NH₄) reductions were significantly affected by plant type, but were not significantly influenced by HRT. They also concluded that plant type and HRT both have significant effects on nitrate reductions. Koottatep and Polprasert[128] obtained 71.0% (1 day) and 83.0% (5 days) efficiency in COD reduction whereas Jing et al.[129] found 13.0 to 51.0% COD removal in river water. Mohamad[130] observed a rapid heavy metal uptake during first four days of contact time, and such uptake being decreased with time until it reached saturation.

Elias et al.[131] observed 87.0% efficiency in the reduction of ammonia, while as per Jing et al.[129], the

efficiency in treating river water is 78.0-100.0%. Koottatep and Polprasert[128] obtained 84.0-86.0% removal efficiency of total nitrogen in 8 weeks of treatment; Schulz et al.[132] reported 19.0% efficiency in 14 days and 30.0% in 70 days whereas Cornwell et al.[133] reported only 8.4% removal of nitrate-N in 10 months. Ingersoll and Baker[134] reported a removal efficiency of over 90% with an initial nitrate concentration of 30 mg/L. For inorganic N, Reddy et al.[135] reported a reduction of about 80%, while Sheffield[136] observed 94% inorganic N and 40-55% ortho-P reduction. For total P, Reddy et al.[135] measured about 32% reduction, while Ornes and Sutton[137] achieved a higher removal rate of 80%. Bramwell and Devi Prasad[138] observed during a pilot scale study an average decrease in total N and total P by 27.6% and 4.48%, respectively. Sheffield[136] reported that pond with an air stripping unit, a flocculation and settling unit, removes >99% ortho-P, 99% nitrate, and >99% ammonia. According to Knipling et al.[80], harvesting of one acre of hyacinth would remove 170 kg of N and 60 kg of P and in maximum growth, one hectare of hyacinths could remove about 2500 kg of N/yr[139] and as high as 7629 kg of N/ha/yr[75]. According to Ayyasamy et al.[93], nitrate removal efficiency of water hyacinth was increased to 64, 80 and 83% with initial nitrate concentrations of 100, 200 and 300 mg/L, respectively, but it is decreased with 400 and 500 mg/L. This was due to osmotic pressure at higher concentrations not supporting the uptake of nitrate[140]. In the ground water samples, the nitrate removal was greatly dependent upon the presence of other nutrients, such as sulphate and phosphate, which caused lower nitrate uptake by water hyacinth[93].

Gamage and Yapa[126] used hyacinth in textile effluent and found reductions in volatile solids (72.6%), mean suspended solids (46.6%), phosphate (52.9%), sodium (40.2%), potassium (64.4%), dissolved solids (61.07%), total solids (59.4%), total nitrogen (83.5%) and chloride reduction (36.0%). An increase in nitrate ion concentration was observed, suggesting nitrification of organic nitrogen in the medium during the long HRT of 30 days. pH varied from 12.8 to 7.0 at inlet and after treatment it was in between 8.52 to 6.50, whereas John[141] observed pH levels were increased by water hyacinth irrespective of different effluents with HRT's.

Mane et al.[98] indicated that at lower concentrations (5 mg/L) of heavy metals, the plant growth was normal and removal efficiency was greater. Concentrations greater than 10 mg/L, the plant started wilting and removal efficiency was reduced due to toxicity at higher metal concentrations. O'Keefe et al.[142] found similar nature of metal uptake for cadmium. Water hyacinth without reduction in growth have high removal rates for iron (Fe), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), manganese (Mn), nickel (Ni), mercury (Hg) and arsenic (As)[143-146]] from aqueous solutions besides absorbing organic substances such as phenol, formaldehyde, formic, acetic and oxalic acids [144-146]. Liao and Chang[146] found that the absorption capacity for water hyacinth, as 0.24 kg/ha for Cd, 5.42 kg/ha

for lead (Pb), 21.62 kg/ha for Cu, 26.17 kg/ha for Zn, and 13.46 kg/ha for Ni. Valipour *et al.*[18] stated that if heavy metals exceed the saturation limit of 268 and 2152 mg/kg for Cd, 381 and 3372 mg/kg for Cu, 229 and 1850 mg/kg for Ni, 462 and 2764 mg/kg for Zn in shoots and roots, respectively, it can lead to morphological deformity. It is the best species as Cd accumulators[110,147,148]. In California, water hyacinth leaf tissue was found to have the same mercury concentration as the sediment beneath, suggesting that plant harvesting could help mediate mercury contamination if disposed of properly[149]. Mishra *et al.*[111] used hyacinth for coal mining effluent for the removal of heavy metals and observed 70.5 ± 4.4 , 69.1 ± 3.9 , 76.9 ± 1.4 , 66.4 ± 3.45 , 65.3 ± 2.4 and 55.4 ± 2.9 percent Fe, Cr, Cu, Cd, Zn and Ni, respectively was removed. The study revealed that plant roots accumulate heavy metals approximately 10 times of its initial concentration whereas Chandra and Kulshreshtha [150] reported 18.92 (g dry tissue wt) Cr accumulation in roots of water hyacinth.

According to Lindsey and Hirt[151], water hyacinth can be used like food for people or fodder because its leaves are rich in proteins and vitamin A. But it is not recommended to consume if used for removal of heavy metals and toxic substances as it can cause problems when enter in food chain[102]. Its biomass is rich in nitrogen and other essential nutrients. Apart from biogas[152], its sludge contains almost all nutrients and can be used as a good fertilizer with no detrimental effects on the environment[51]. After harvesting, it can be used for composting, anaerobic digestion for production of methane, fermentation of sugars into alcohol [48], green fertilizer, compost and ash in regenerating degraded soils. These operations can help in recovering expenses of wastewater treatment.

3.2. Water Lettuce (*Pistia Stratiotes L.*)

3.2.1. Plant Origin and Geographical Distribution

Pistia stratiotes (L.) is a floating perennial commonly called water lettuce belonging to the family Araceae. It floats on the surface of the water, and its roots hanging submerged beneath floating leaves[23]. While it may have originated in South America but the origin of water lettuce is uncertain. It has been used in Africa as a medicine and fodder for cattle for centuries being recorded in Egypt in 77 A.D.[153]. It has spread over the rest of Africa and parts of Asia and in the 1970s also found its way to Australia[154]. The leaves can be up to 14 cm long and have no stem. They are light green, with parallel veins, wavy margins and are covered in short hairs which form basket-like structures and help in trapping air bubbles, increasing the plant's buoyancy. The flowers are dioecious and are hidden in the middle of the plant among the leaves. The plant can be reproduced by both vegetatively and sexually[23,155].

Water Lettuce is non winter-hard plant, having a minimum growth at temperature 15 °C[156]. In general, the specific growth rate of water lettuce is slightly higher as

compared to the water hyacinth in dry season. However, the rainy spell reduces the growth of the water lettuce because of the lower solar radiation, which is needed for its growth[157]. Fonkou *et al.*[21] stated that lettuce doubles its biomass in just over 5 days; triples it in 10 days, quadruples in 20 days and has its original biomass multiplied by a factor of 9 in less than one month. This evolution indicates that 25 days is the maximum period to allow the plant in the system. Because this plant reproduces rapidly and decays, the efficacy of the system is intimately linked to its careful management through periodic harvesting of part of the biomass produced.

Especially in tropical or subtropical areas, water lettuce (large-leaved floating plant) is used in phytoremediation water systems[158-159]. This is because, compared to native plants, this invasive plant show a much higher nutrient removal efficiency with their high nutrient uptake capacity, fast growth rate, and big biomass production[41].

3.2.2. Ecological Factors

Water lettuce is superior in productivity as compared to other small aquatic weeds such as *Lemna spp*[61]. Knowledge on salinity tolerance of plant can help better utilize the plant(s) without bringing disaster because it has significant effects on growth and performance. According to Haller *et al.*[97], floating plants such as water lettuce have higher survival rate, at higher levels of EC having a killing strength (>4000 $\mu\text{S}/\text{cm}$). This indicates that water lettuce withstand higher salinity conditions but does not grow at higher COD levels[91].

Although water lettuce can produce high biomass and remove large amounts of nutrients and metals, they may not be suitable for temperate or frigid areas due to their sensitivity to cool temperature which significantly affects their performance[63]. Lu[9] suggested that Fe, Cu, and Ni are essential for plant growth, but when present at high concentrations, they are toxic to plant. Lu *et al.*[22] also reported that low concentration of nutrients may reduce the performance of plant in removing nutrients.

3.2.3. Efficiency of Water Lettuce in Reduction of Water Contaminants

Plants are known to accumulate large quantities of nutrients during period of rapid growth[160]. Fonkou *et al.*[21] observed in 25 days, the biomass increased in 7 ponds from the original 518 g/m^2 (average) to 2488, 2578, 2925, 5379, 6176, 6793 g/m^2 respectively whereas Ayyasamy *et al.*[93] observed during the 10 day experiments, the biomass of water lettuce increased from 75 to 92-94 mg/L with 24% increases. Water lettuce of 1.25 $\text{mg N}/\text{L}$ treatment doubled its initial biomass. Plant showed healthy bright green without yellowing of the old leaves. Lower N and P requirements make water lettuce desirable for a polyculture system. The N, P and ash contents of biomass were about 1.5 times lesser in water lettuce than in water hyacinths[161]. A 200- fold difference in dry weight of water lettuce was reported by Aoi and Hayashi[161] between cultivated in rain water and

treated sewage water. Fonkou et al.[21] indicated that the number of leaves per plant decreases, as a result of the decay of the basal leaves that fall back into water, then releasing the substances that were absorbed after 15 days in all the treatment ponds. It was found that EC, DO and ammonia are poorly removed. Unpublished works reported total bacteria, faecal Streptococci and Salmonella sp. to be fairly eliminated in the system by 52.7-64.3 %, 45.6-79.5 and 35.5-66.4 % respectively. DO was increased from 0.75 to 6.02 with improvement of 87.5%.

Dipu et al.[23] found that alkaline pH was changed into neutral using lettuce. Similar results were also reported by Mahmood et al.[20]. The reduction in pH is due to absorption of nutrients and other salts by plants or by simultaneous release of H⁺ ions with the uptake of metal ions[20]. Awuah et al.[25] used lettuce in their study of bench-scale continuous-flow wastewater treatment system with feed of sewage. They observed that lettuce removed TDS by 70%, fecal coliform by 99%, BOD by 93%, COD by 59%, nitrate by 70%, total phosphorus by 33% and ammonia by 95%. Water lettuce is reported to reduce the ammonium ions from the water as it utilizes ammonium (NH₄-N) prior to nitrate (NO₃-N) as nitrogen source and does not switch on the utilization of NO₃-N until NH₄-N gets consumed entirely[161]. Ingersoll and Baker[134] reported nitrate removal efficiency of water lettuce ranged from 31 to 51%. However, according to Aoi and Hayashi[161], at an initial nitrate concentration of 5.5 mg/L, water lettuce had a similar nitrate removal capacity to water hyacinth in batch culture experiments[93]. It has been extensively used to remove metals like Zn, Ni, and Cd from the water column[162]. However, at 20 mg/L Cr, plants of lettuce showed 100% death after three days[163].

Preliminary study by Lu[9] revealed that water lettuce growth decreased the EC in the treatment plot due to salt removal from the waters by plant uptake or root adsorption and it was concluded that water quality in ponds was improved by phytoremediation with water lettuce, as evidenced by decreased turbidity, total solids, NH₄-N, NO₃-N and total Kjeldahl N, and nutrient concentrations. Reductions in ortho P, total dissolved P, and total P concentrations was found by 18-58% compared to the control plots. Metals were substantially accumulated in the roots of water lettuce. A larger proportion of Ca, Cd, Co, Fe, K, Mg, Mn, and Zn were attached to external root surfaces by adsorption or surface deposition while more Al, Cr, Cu, Ni, and Pb were absorbed and accumulated into the roots.

A study conducted by Lu et al.[22] indicated that total suspended solids in the water column were decreased by approximately 10% in treatment plots compared to control plots. Water lettuce growth decreased water pH, which was not expected for it is well known fact that water pH rises with plant photosynthesis. Besides plant uptake, denitrification may also contributed to the decreased NO₃-N concentration in the treatment plots as a more anaerobic condition (dissolved oxygen <1.5) which was created by the growing plants at the water's surface and other anaerobic

micro-sites[164,165]. Aluminium (Al), calcium (Ca), Fe, K, and Mn concentrations in the remediation plots were significantly (P<0.01) reduced by the growth of water lettuce. Water lettuce can be considered a hyperaccumulator for trace metals such as Cr, Cu, Fe, Mn, Ni, Pb, and Zn[166]. Periodic harvesting of water lettuce is necessary not only for maintaining an optimal growth density, but also for effective removal of nutrients (N and P) and metals from the waters, otherwise the nutrients and metals would be released back into the water system after the plant died and decomposed[21,166].

Mukhopadhyay et al.[167] found that the removal is dependent both on the contact time and the initial arsenic concentration. He observed a rapid initial uptake upto 48 hours and gradual attainment of equilibrium after 120 hours. Such concentration and duration dependent removal were also obtained for cadmium using water hyacinth[142] and water lettuce[168] and for Hg (II) using lettuce[169]. According to Mukhopadhyay et al.[167] and O'Keefe et al.[142], metal uptake was higher for low metal concentration and decreased thereafter with increase in metal concentration. Some researchers found similar nature of metal uptake in water lettuce for cadmium and for arsenic. Mishra et al.[170] found water lettuce removed 80% of mercury (i.e. from 10 µg/L to 2µg/L) from the coal mining effluent in 21 days. Mercury accumulation in the roots of lettuce was about four times higher than the shoots at lower concentrations[111,143,171,172]. Maine et al.[42] found water lettuce efficiently removed Cr from water at the concentrations of 1, 2, 4, and 6 mg Cr/L.

3.3. Vetiver Grass (*Vetiveria Zizanioides* L.)

3.3.1. Plant Origin and Geographical Distribution

Vetiver grass (*Chrysopogon zizanioides*) belongs to the Gramineae family. The vetiver is a unique tropical plant that has been proven and used in some 100 countries for soil and water conservation, land rehabilitation, pollution control, water quality improvement and many other environmental applications, particularly the looming food crisis in many parts of the developing world. The vetiver System is easy to use and low cost[173,174]. It is tall erect and native to India, South and South-East Asia[175]. It is found throughout the plains, lower hills of India particularly on the riverbanks, in marshy soils and it is widely used in Karnataka, India[27]. It is an herbaceous perennial plant, the leaves are erected and rather stiff with height ranges from 0.5 to 1.5 m. It has a deep and resistant root system with fast growth[10]. According to Dulton et al.[176], it is characterized by its large biomass and having a dense root system extending up to 3 m in depth. It has fine purple flowers and an architectural aesthetic that can be well incorporated in landscape designs[173].

Vetiver system is based on the use of vetiver grass, which was first recognized early in the 1990s for having "super absorbent" characteristics suitable for the treatment of wastewater and leachate generated from landfill[177].

3.3.2. Ecological Factors

Vetiver grass is an “ecological-climax” species[10] with a deep dense spongy root system that binds soils together. Vetiver can withstand drought[28,178] and is not affected by flood[178]. Although vetiver is a tropical grass[179] can also tolerate extreme temperatures, from -15 °C to 60 °C[28]. According to Zhang[180], it grows rapidly above 25 °C. Many researchers have used vetiver for extreme cold conditions like in Australia, vetiver growth was not affected by severe frost at -11 °C and it survived for a short period at -22 °C in northern China. In Georgia (US), vetiver survived in soil temperature of -10 °C but not at -15 °C[181] whereas Maffei[178] records vetiver having an absolute minimum temperature of -15 °C below which death occurred. Vieritz *et al.*[179] reported that although very little shoot growth occurred at the soil temperature range of 15 °C (day) and 13 °C (night), root growth continued at the rate of 126 mm/day, indicating that vetiver grass was not dormant at this temperature. It was concluded that under frosty weather, its top growth is killed but its underground growing points survived, plants grow more slowly under colder conditions and the growth stages are better defined on the basis of thermal time rather than chronological time. Maffei[178] describes vetiver as growing luxuriantly in areas with temperatures ranging from 21-45 °C. According to Maffei[178] and Zhang[180] root length, root and shoot dry weight increased with increasing temperature from 15/13 to 35/30 °C (day/night) and minimum daily air temperature for growth should be less than 12 °C.

Even though it is not an aquatic plant, vetiver can be established and survive under hydroponic conditions. However, vetiver cannot be established directly in leachate ponds, as it does not float as alligator weed (*Alternanthera philoxeroides*); it needs a floating platform to grow on. Its high affinity for both organic and inorganic chemicals shows that the grass could be used to develop a cost effective and environment friendly remediation for waste water[28]. Xia *et al.*[182] suggested that for sustainable removal of pollutants from leachates, vetiver shoots should be trimmed 2-3 times per year.

3.3.3. Efficiency of Vetiver Grass in Reduction of Water Contaminants

Vetiver grows rapidly and has a huge biomass[182]. It can purify eutrophic water[183], garbage leachates[182] and wastewater from pig farms[184]. It is excellent for the removal of heavy metals from contaminated soil[185,186] and rehabilitating landfills[187]. It has proven to be exceptionally successful in urban environments by demonstrating its ability to absorb pollutants into its foliage[173]. According to Xia *et al.*[182], vetiver has high level of tolerance for polluted water and very effective in removing pollutant from landfill leachates, particularly N and P. Nitrogen and Phosphorus absorption is also expedited because roots have direct exposure to effluents. It tolerates wide range of pH, salinity, sodicity[175,188], acidity and

heavy metals such as As, Cd, Cu, Pb and Zn[188]. It could also absorb higher N, P and K[196]. Jayashree *et al.*[189] used this system upto 60 days for the treatment of textile water and found that pH reduced from 8.6 to 7.8, EC from 1.34 to 0.22 dS/m, total kjeldahl nitrogen from 8.85% to 0.53%, P from 5.9% to 0.81%. Researchers[178,188] found that it has high level of tolerance to salinity.

Vetiver can be used in phytoremediation of contaminated water system and has been reported to adsorb many heavy metals[187]. However, the concentration of heavy metals in wastewater played an important role in vetiver growth. The vetiver ecotypes absorbed Fe>Mn>Zn>Cu>Pb, and they concentrated these metals more in roots than in shoots[1]. It has been used successfully for contaminants removal in many countries such as Australia, China, Thailand, Vietnam and Senegal[181]. Truong *et al.*[175], soils that can even be loaded with very high levels of aluminium (>68 Al/cation exchange capacity %), iron, manganese (>578 ppm) and other heavy metals often associated with acidic soils such as As, Cd, Cu, Cr and Ni. It can also withstand high levels of pesticides and herbicides and also to a wide range of toxics[10].

Girija *et al.*[28] stated that the higher temperature favors their growth and multiplication. Low values of pH become almost neutral after one month of its planting. EC of polluted water is directly proportional to its dissolved mineral matter content and after planting vetiver, the EC decreased to a very low value. Lakshmana *et al.*[27] also found the same result. Hardness was found to be ranging from 106-206 mg/L but after planting vetiver, a 60% removal was observed in 2 months, which is in agreement with Truong and Hart[190]. DO was increased from 0 to 4.5 mg/L after 1 month which is in agreement with Stefanie *et al.*[191]. With an increase in EC, coliforms too increased in number. DO have an inverse relationship with the coliform and is directly proportional to COD and BOD. As the organic matter is the food of coliform bacteria, Boonsong and Chansiri[192] observed higher BOD and COD removal efficiency.

Mane *et al.*[98] found that shoot length of vetiver grass was increased by 18.6% at 200 mM NaCl concentration whereas; increase in root length about 24.8% was observed at 50 mM NaCl. The average leaf area also increased under saline conditions. Dry weight and fresh weight biomass was less effective under salinity stress. They also observed increased levels of polyphenols at elevated salinity due to the accumulation of secondary metabolites. Linear increase in the EC and TDS of the soil was found at increasing salinity and the vetiver is tolerant upto 100 mM of salinity because of increase in growth and photosynthetic parameter. Ebrahim *et al.*[40] indicated decrease of TDS by 55.93% in hard water with the help of vetiver root by using adsorption method.

Department of Natural Resources and Mines, Queensland research showed that vetiver grass has a fast and very high capacity for absorption of nutrients, particularly nitrogen and phosphorus in wastewater[26,193]. Wagner *et al.*[194] found that both N and P supplies increased vetiver growth significantly (<1% level). Growth increased mainly with the

level of N supplied. However, very little growth response occurred at rates higher than 6000 kg/ha/year although rates up to 10,000 kg/ha of N did not adversely affect vetiver growth. Vetiver requirement for P was not as high as for N, and no growth response occurred at rates higher than 250 kg/ha/year. However, its growth was not adversely affected at P up to 1000 kg/ha/year. Anon[195] and Zheng et al.[196] found 98% removal for total P in 4 weeks and 74% for total N after 5 weeks in polluted river water. Wagner et al.[194] used vetiver in hydroponic system using sewage effluent and observed that both N and P removal over 90% from the effluent; it also reduced algae growth and faecal coliforms. Truong and Hart[190] used vetiver for domestic effluent treatment for 4 days and the removal in total nitrogen was 94%, total P was 90%, EC by 50%, change in pH was (from 7.26 to 5.98), faecal coliform changes were 44% and E. coli changes were 91%. Therefore, vetiver has high potential to be used for industrial wastewater treatment.

4. Concluding Remarks

It has been observed that phytoremediation of wastewater using the floating plant system is a predominant method which is economic to construct, requires little maintenance and increase the biodiversity. Many researchers have used water hyacinth, water lettuce and vetiver grass for the removal of water contaminants but their treatment capabilities depend on different factors like climate, contaminants of different concentrations, temperature, etc. Vetiver grass can be grown as floating in water without the soil media (hydroponic way). The removal efficiency of contaminants like TSS, TDS, BOD, COD, EC, hardness, heavy metals, etc varies from plant to plant. Plant growth rate and hydraulic retention time can influence the reduction of contaminants. Therefore, an available knowledge and techniques for removal of water contaminants and advances in waste water treatment can be integrated to assess and control water pollution.

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