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REVIEW PAPER

Managing water quality with aquatic macrophytes

Jatin Srivastava · Amit Gupta · Harish Chandra

Abstract The principal sources of water for human use are lakes, rivers, soil moisture and relatively shallow groundwater basins. Water quality in lakes and reservoirs is subjected to the natural degradation, processes of eutrophication and the impacts of human activities. Water quality problems can often be as severe as those of water availability but less attention has been paid to them, particularly in developing countries. Currently additional sustainable ways to mitigate the degradation of water quality are being researched all over the world. Phytoremediation is one of the serious efforts towards the sustainability. Most of the aquatic macrophytes are naturally occurring and well adapted for their surroundings. Aquatic macrophytes have the capability to remove excessive nutrient load from the water that otherwise cause eutrophication of the water body. Aquatic macrophytes absorb nutrient mineral ions from water column and influence metal retention indirectly by acting as traps for particulate matter, by slowing the water current and favoring sedimentation of suspended particles. Aquatic macrophytes also reduce sediment resuspension by offering wind protection. The use of aquatic macrophyte for treatment of wastewater to mitigate variety of pollution level is one of the most researched issues all over the world. Aquatic plant species are very specific for the uptake of nutrients. Owing to this specificity, the selection of the aquatic plant species is one of the skilled tasks prior to the design of a water treatment facility. An effort has been made in this review to cover the most researched aquatic flora for mitigation purposes and their possible use in a mesocosm as the selection of an appropriate aquatic plant specie reduce the time and cost of the treatment processes.

Keywords Aquatic macrophytes · Water quality · Nutrient ions · Metals mesocosm · Selection of species

1 Introduction

The Human Development Report (2006) of UNDP has focused on the global water crisis as one of the most serious problems facing by the humanity today. In many Asian countries and elsewhere the demand for potable water doubles every 10–15 years, not only because of the rising domestic consumption but also due to the increasing needs of industry. The

J. Srivastava (✉)
Department of Environmental Sciences, Chhatrapati Shahu Ji Maharaj University, Kanpur 208024, UP, India
e-mail: jks_345@rediffmail.com

A. Gupta
Department of Agricultural Chemistry, National Taiwan University, Taipei 106-17, Taiwan

H. Chandra
Department of Environmental Microbiology, Gayatri College of Biomedical Sciences, Dehradun, UK, India

principal sources of water for human use are lakes, rivers, soil moisture and relatively shallow groundwater basins. The usable portion of these sources is less than 1% of all freshwater and only 0.01% of all water on Earth. Although, water quality is an important issue and the subject of much legislation, sometimes the quantity is more important than quality in determining the extent and type of development possible in a given geographic location. Water quality problems can often be as severe as those of water availability but less attention has been paid to them, particularly in developing countries. Many countries do not have sufficient water supplies to meet demand, as a result of which, aquifer depletion due to over exploitation is common. Moreover, the scarcity of water is accompanied by deterioration in the quality of available water due to heavy pollution load and environmental degradation.

Water quality in lakes and reservoirs is subjected to the natural degradation, processes of eutrophication and the impacts of human activities. Sources of pollution include untreated sewage, chemical discharges, petroleum leaks and spills, dumping in old mines and pits, and agro-chemicals that are washed off from farm fields. The principal chemical constituents of surface water cause enrichment of the water if exceed the threshold limit (Table 1). These ions are required for the growth of micro- and macro-organisms. Phosphorus (P) is generally considered as the limiting nutrient ion, playing the key role in eutrophication (Zhou et al. 2001; Varjo et al. 2003) and is one of the main factors in phytoplanktonic growth (Correll 1998). Visible effects of eutrophication are development of plankton scum and rooted plant biomass, amplified growth of algae, enhanced organic loading, death of fishes, increase in sedimentation, and reduction of water transparency (Klapper 1991).

Table 1 Principal chemical constituent of surface water

Anions[a]	Threshold level[b]	Cations[a]	Threshold level[b]
HCO_3^-	200 mgl^{1-}	Ca^{2+}	75.0 mgl^{1-}
SO_4^{2-}	200 mgl^{1-}	Mg^{2+}	30.0 mgl^{1-}
Cl^-	200 mgl^{1-}	Na^+	50.0 mgl^{1-}
NO_3^-	45.0 mgl^{1-}	K^+	10.0 mgl^{1-}
PO_4^{3-}	0.25 mgl^{1-}	Zn^+	5.0 mgl^{1-}

[a] Tchobanoglous and Schroeder (1985)

[b] As per Indian standards IS: 2490

Although nitrogen contamination rarely exceeds levels of potential health risk, consuming water having high concentrations of nitrates can cause infant methaemoglobinaemia or blue-babysyndrome (Sampat 2000). Enriched water provides favorable conditions for pathogenic microorganisms to multiply. Direct consumption of such water can cause water borne diseases. Because existing surface water sources are widely polluted, ground water is the main fresh water source for aquaculture. Consequently, several areas have faced ground subsidence as a result of over-withdrawal of ground water, therefore it is essential to reuse the wastewater after the treatment to lessen the overburden on the natural resources of water. In addition, aquatic macrophytes absorb and accumulate the nutrient ions in the tissues (DeBusk et al. 1995; Mahujchariyawong and Ikeda 2001). Aquatic macrophyte influence metal retention indirectly by acting as traps for particulate matter, by slowing the water current and favoring sedimentation of suspended particles (Kadlec 2000). Aquatic macrophyte also reduces sediment resuspension by offering wind protection (Brix 1997). Large aquatic macrophytes possess the ability to breakdown the human and animal derived pollutants in the water (Kadlec and Knight 1996). Having the outlines of the issues associated with the degraded water quality, the role of aquatic macrophytes (floating and submerged) in managing the water quality, has been discussed in this review.

2 The wetlands and their role in improving water quality

Wetlands are transition areas between land and water bodies, characterized by shallow water overlying waterlogged soil as well as interspersed submerged, emergent or floating vegetation. The capability of wetlands for decontamination of waste water has long been recognized in natural wetlands in many parts of the world (Godfrey et al. 1985; Mitsch and Gosselink 1993; Nahlik and Mitsch 2006). Major mechanisms of pollutant removal in wetlands depend on sedimentation, adsorption on the root surface and absorption by the aquatic macrophytes (Hutchinson 1975; Serra et al. 2004). Macrophytes create conditions for the sedimentation of suspended solids (SS) and prevent erosion by reducing the velocity of the water in wetlands. Macrophytes in association with the aquatic micro-organisms and periphytons enhance the uptake of nutrients from the water (Vymazal 2002). Periphyton potentially removes metal cations (Scinto and Reddy 2003) and nutrient anions such as PO_4^{3-} and NO_3^- by direct absorption from the water column (Khatiwada and Polprasert 1999). The macrophytes transport approximately 90% of the oxygen available in the rhizosphere. This stimulates both aerobic decomposition of organic matter and promotes the growth of nitrifying bacteria (Scholz 2006; Lee and Scholz 2007).

3 Aquatic macrophytes

Aquatic macrophytes are limited to the macroscopic flora including aquatic spermatophytes, pteridophytes and bryophytes. Schwarz and Haves (1997) also described the charophytes as aquatic macrophyte. Growth forms of macrophytes usually classifies them in four group systems; emergent macrophytes (e.g., *Phragmites australis, Typha latifolia*), floating-leaved macrophytes (e.g., *Nuphar luteum*), free-floating macrophytes (e.g., *Eichhornia crassipes*) and submerged macrophytes (e.g., *Myriophyllum spicatum*). The accumulation of nutrients in macrophyte tissues determines the cleaning ability of these plants (Figs. 1 and 2). The amount of accumulated nutrients depends on the physiological capacity for further uptake and biomass of aquatic macrophytes which vary with the species (Pieczynska 1990). In most aquatic ecosystems, attention has been focused on the cycling of N and P, most likely to limit primary producers and perhaps heterotrophic micro-orgaisms (Pace et al. 1991; Suberkropp and Chauvet 1995; Smith 1998; Rosemond et al. 2002) (Table 2). Aquatic macrophytes act as substratum for the growth of periphyton communities composed of complex assemblages of cyanobacteria, eubacteria, diatoms and eukaryotic algae (McCormick and O'Dell 1996).

4 Floating aquatic macrophyte (FAM)

Tropical wetlands are dominated by floating aquatic macrophytes whereas the emergent macrophytes are

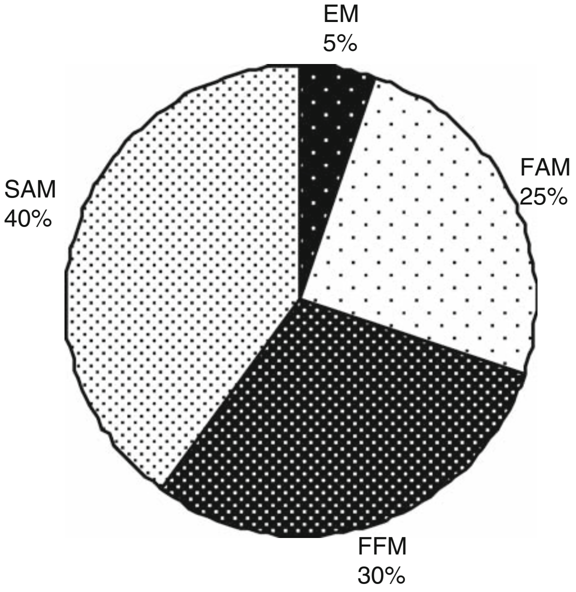

Fig. 1 The nutrient ion removal efficiency of aquatic macrophytes (EM = Emergent macrophyte, FAM = Floating aquatic macrophyte, FFM = Floating aquatic macrophyte, SAM = Submerged aquatic macrophytes)

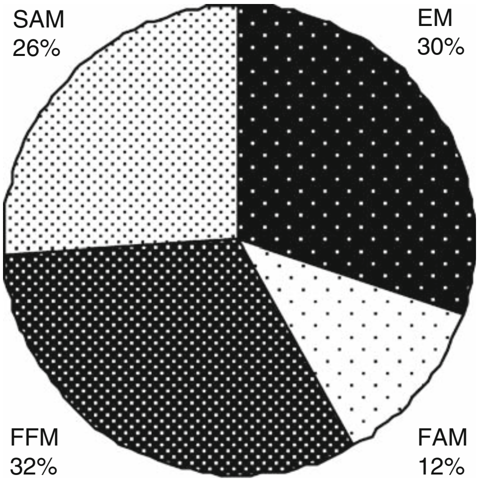

Fig. 2 The metal ion removal efficiency of aquatic macrophytes (EM = Emergent macrophyte, FAM = Floating aquatic macrophyte, FFM = Floating aquatic macrophyte, SAM = Submerged aquatic macrophytes)

common in temperate wetlands (Nahlik and Mitsch 2006). Floating-leaved aquatic macrophytes potentially remove and recover the nutrient anions and metal cations from water and wastewaters (Kadlec 2000). Haslem (1978) provide a classification of the water

Table 2 Tabulated chart for the selection of some common aquatic plant species in tropical climate on the basis of removal efficacy of ions

Aquatic plants	Conditions of temperature and pH for optimal growth	Order of removal of N and P	Growth in mesocosm	References[d]
Eichhornia cressipes	10–40°C, 7–9 pH	N → P	++++	Reddy and DeBusk (1985); Sooknah and Wilkie (2004)
Azolla spp.	10–22°C, 7.0–8.5 pH	N	+++	Lejeune et al. (1999)
Ceratophyllum demersum	10–40°C, 6.8–9.0 pH	P → N	++	Tracy et al. (2003)
Chara spp.[c]	10–40°C, 6.8–9.0 pH	N → P	+++	Kufel and Kufel (2002); Vermeer et al. (2003)
Hygrophila polysperma	10–30°C 5–7 pH	N, P	++++	Doyle et al. (2003)
Ipomoea aquatica	15–45°C, 6–7 pH	P → N	+++	Sinha et al. (1996), Göthberg et al. (2002)
Lemna spp.	5,7–29°C, 6.9–7.8 pH	N → P	++	DeBusk et al. (1995)
Ludwigia repens	10–30°C, 5–7 pH	N, P	++	Doyle et al. (2003)
Pistia stratiotes	15–35°C, 6–9 pH	$NH_4 \rightarrow NO_3 \rightarrow P$	−−−[b]	Aoi and Hayashi (1996), Sooknah and Wilkie (2004)
Potamogeton spp.	10–40°C, 7.0 pH	N	++[a]	La-Montagne et al. (2003), Fritioff et al. (2005)
Salvinia herzogii	10–22°C, 7.0–8.5 pH	N	+++	Maine et al. (2004)

The temperature and pH conditions are the essential favorable conditions next to the nutrient loading and other physical parameters of water for the optimum growth of the macrophytes; however the conditions mentioned above may change depending upon the local applied conditions

[a] Plants usually survive only for few (1–3) days

[b] Plants need special conditions of light to survive

[c] Algae; + indicates the extent of growth in mesocosm

[d] For further studies

bodies on the basis of the occurrence of FAMs as their distribution is related to the habitat richness. FAMs prevent submerged photosynthesis and affect the oxygen exchange between the atmosphere and water column, resulting in low dissolved oxygen levels in the water. The floating plants also serve as a secondary carbon source to the decomposers and are important component in nitrate–nitrogen removal via denitrification (Hamersley et al. 2001). FAM, because of their high productivity, high nutritive value and ease of stocking and harvesting (Boyd 1974) are suitable in engineered wetlands to improve the quality of water (Sooknah and Wilkie 2004). Free floating plants are partly superior to the submerged aquatic macrophytes as their removal requires neither extensive filtration equipment nor they produce significant disruption to the water body (Sternberg et al. 1999). Wetlands dominated by the floating aquatic macrophytes are well documented by DeBusk and Reddy (1987), Brix and Schierup (1989), Reed et al. (1995), and Vymazal et al. (1998).

4.1 Brief introduction to the most common FAMs

The most common floating (rooted and free floating) macrophytes include *Eichhornia crassipes* (Mart.) Solms commonly known as water hyacinth, a floating aquatic weed belonging to the family Pontederiaceae. *E. crassipes* is one of the most extensively researched aquatic weeds for its potential in the biomass production (Reddy 1984); for its detrimental affects on the quality of water (Gopal 1987); for the nutrient uptake (Imaoka and Teranishi 1988); and for the metal uptake through the root systems (Zaranyika et al. 1995; DeBusk et al. 1995). Next to the *E. crassipes* is the group of duckweeds belonging to the family of free floating-leaved aquatic monocotyledon macrophytes Lemnaceae including various species of genera Lemna for e.g., *Lemna obscura, Lemna minor, Lemna majus*, and *Lemna gibba*. *Lemna* spp. have been widely studied for the uptake of P and N from the water by DeBusk et al. (1995). *Pistia stratiotes* (L.) is a floating perennial commonly called water lettuce belonging to the family Araceae. *P. stratiotes* is not a winter-hard plant, having a minimum growth temperature of 15°C (Kasselmann 1995). In general the specific growth rate of *P. stratiotes* is slightly higher as compared to the *E. crassipes* in dry season. However, the rainy spell reduces the growth of the *P. stratiotes* because of the lower solar radiation which is needed for its growth (Aoi and Ohba 1995). *P. stratiotes* has been well studied for the removal of nitrogen from water by Aoi and Hayashi (1996). Water spinach *(Ipomea aquatica)* also known as swamp cabbage belonging to the family Convolvulaceae and is a common floating aquatic macrophyte in southeast Asia. *I. aquatica* has been extensively researched for the metal uptake by Sinha et al. (1996); Göthberg et al. (2002). Water ferns including *Azolla filiculoides and Azolla caroliniana* belonging to the family Azollaceae, *Salvinia molesta* belonging to the family Salviniaceae have great potential to affect water chemistry. *A. filiculoides* is commonly found specie, appears on the surface of eutrophic, warm, still waters (ponds, swamps) of temperate regions and in winters of tropical regions. It has smaller plant units (frond size, 1–5 cm) and lives often in symbiosis with cyanobacteria *Anabaena azollae* (Nostocaceae) and fix atmospheric nitrogen within the dorsal leaf cavities. Some more examples of floating-leaved aquatic macrophytes are *Hygrophila polysperma, Ludwigia repens, Hydroctyle umbellate, Nuphar variegatum, Spirodela polyrhiza.*

4.2 Nutrient mitigation from water by FAMs

Aquaculture is an important industry in most of the developing countries. The wastewater generated from the aquaculture industries contains a lot of organic matter which causes the nutrient enrichment of the natural water system. Nutrient removal is essential for aquaculture for reuse of the water. Growth of *E. crassipes* is favored by the nutrient status of water in particular with nitrogen, phosphorus and potassium content. (Mahujchariyawong and Ikeda 2001). The overall requirement of P is very low of *E. crassipes* (Reddy et al. 1990) however; *E. crassipes* is reported to assimilate up to 777 mg N m^{-2} day^{-1} and 200 mg P m^{-2} day^{-1} during the rooting, flowering and at high temperature conditions (DeBusk et al. 1995). Lateral roots of *E. crassipes* are longer and denser at low P while the stem girth decreases at low P availability (Xie and Yu 2003). Duckweeds show great promise for water containing nitrogenous pollution. Minimum growth of *L. obscura* has been reported in the absence of N in the growth medium. In such conditions nitrogen is made available to the plant by the nitrogen fixing micro-organisms living in the fronds. Phosphorous removal by the *Lemna* spp. is not significant however; few reports suggest employing of this macrophyte (Culley and Epps 1973; Corradi et al. 1981; Devi et al. 1996) for the removal of nutrients from polluted water. Voluminous literature is available on the usages of duckweeds for water quality improvement and nutrient removal (Al-Nozaily et al. 2000a, b; Cheng et al. 2002a; El-Shafai et al. 2004). *Pistia stratiotes* is reported to reduce the ammonium ions from the water as it utilizes NH_4–N prior to NO_3–N as nitrogen source and does not switch on the utilization of NO_3–N until NH_4–N gets consumed entirely (Aoi and Hayashi 1996). The only demerit of *P. stratiotes* is that it does not grow at higher COD levels (Sooknah and Wilkie 2004). Haller et al. (1974) reported higher survival rate of *P. stratiotes* at higher levels of EC (electrical conductivity) having a killing strength >4000 µS/cm. This indicates that *P. stratiotes* withstand higher salinity conditions keeping the dissolved oxygen at a level of saturation. *P. stratiotes* are superior in productivity as compared to other small aquatic weeds such as *Lemna spp* (Reddy et al. 1983). Next to *P. stratiotes* is *Hygrophila polysperma* a fast growing stem plant with bit red-brown leaves and commonly occur in the water of 5–7 pH (Doyle et al. 2003). It is a native of Asia but also occurs in the wild of North America. *H. polysperma* produces adventitious roots at stem nodes providing the plant with vegetative reproduction strategy through fragmentation. This ability of asexual reproduction is a characteristic feature associated with invasive non-native species (Kolar and Lodge 2001) making it tolerant for the environmental stresses. The plant is most commonly found in waters with pH between 5 and 7 and its leaves are adapted to draw CO_2 directly from the water. *H. polysperma* is difficult to control because it is relatively resistant to herbicides and regrows extremely rapidly following harvesting (Sutton 1999). Integrated systems for the treatment of water whereby the waste water is treated with wetland species (aquatic and subaquatic macrophytes) is a common practice in most of the developing countries

(Lin et al. 2002) however; the efficiency is still a issue to be investigated thoroughly. An integrated system for wastewater treatment using duckweed has been developed for nutrient removal. After harvesting, the duckweed is used in aquaculture (El-Shafai et al. 2004).

4.3 Metal removal by FAMs

Bioaccumulation of essential and non-essential metal ions by aquatic macrophytes is well documented (Vesk and Allaway 1997; Khan et al. 2000). Studies on pollutant bioaccumulation in macrophytes are aimed at assessing removal efficiency of metals and bioaccumulation processes by aquatic macrophytes (Table 3). *E. crassipes* has the ability to absorb and accumulate metal ions, organic and inorganic substances through its roots (Pinto et al. 1987). *Lemna minor* shows a high growth rate and is well investigated for the removal of heavy metals from the water column (Nasu and Kugimoto 1981; Jain et al. 1990; Wang 1990; Wahaab et al. 1995; Maine et al. 2001). Sternberg et al. (1999) reported that *L. minor* can remove 70–80% Pb (lead) by its viable biomass. Highest aluminum (Al) uptake is also reported by *L. minor* (Goulet et al. 2005) growing in an engineered wetland. Researches have also shown the uptake of metals like Ni, Cd and Zn by various species of *Lemna* (Noraho and Gaur 1995; Miretzky et al. 2006). The Floating-leaved aquatic macrophytes including *P. stratiotes* has a high growth rate and have been extensively used to remove metals like Zn, Ni, and Cd from the water column (Sridhar 1986) however; lower biomass of *P. stratiotes* was reported by Miretzky et al. (2006) when grown in water containing metal ions of Cd, Ni, Cu, Zn and Pb as compared to *Spirodela intermedia* and *Lemna minor*. In nature inorganic Hg is biochemically transformed into an organic form methyl-Hg which is a potential toxicant (Boening 2000) and can be taken up by aquatic macrophytes e.g., *Ipomoea aquatica* (Göthberg et al. 2002). *I.* aquatica can accumulate higher contents of metals such as Fe, Cu, Cr, Cd, Mn, Hg and Pb (Sinha et al. 1996). *Ipomea carnea*, an amphibious plant, has potential to phyto-extract the cadmium from marshy areas (Ghosh and Singh 2005). *Salvinia molesta* commonly called the 'Kariba weed' has been found well adapted for the removal of Cr (III) from the wastewaters (Maine et al. 2004). *Azolla caroliniana* acts as biofilter as it bind heavy metals and is helpful in the purification of waters polluted by Hg and Cr (Bennicelli et al. 2004). *Azolla caroliniana* is also called as biological pesticide as it controls the growth of mosquitoes and weeds (Wagner 1997). Major shortcomings of aquatic macrophytes in metal removal are the lower surface area of leaves.

5 Submerged aquatic macrophytes (SAMs)

Submerged aquatic vegetation form a horizontal ecotone between land and open water and vertically between the sediments and overlying water. This underwater forest plays a central role in the ecosystem

Table 3 Removal of metal ions by some common aquatic macrophytes

Common macrophytes	Metal/s	Removing efficiency (%)	References
Eichhornia cressipes	Fe → Cu → Zn→ Cd	80.0	Sahu et al. (2007), Schneider et al. (1999), Prakash et al. (1987)
Azolla spp.	Hg	93.0	Kamal (2004)
Ceratophyllum demersum	Pb → Zn → Cu	80.0	Keskinkan et al. (2004)
Ipomoea aquatica	Hg	90.0	Götheberg et al. (2002)
Lemna spp.	Pb	90.0	Gazi and Steven (1999)
Ludwigia repens	Hg	99.8	Pilon-smith and Pilon (2002)
Pistia stratiotes	Cd → Hg → Cr	85–90.0	Maine et al. (2001)
Potamogeton spp.	Pb → Zn	70.0	Schneider et al. (1999)
Salvinia herzogii	Cr	70.83	Maine et al. (2004)

(→) Symbolize the preference of removal, Removal efficiency is based on the total possible removal of metals from given treatment, Metals mentioned are reported in the literature however; these plants are able to take up other metals too affecting the nutrient cycling in lakes (Qiu et al. 2001). Submerged plants can maintain clear water state by various buffering mechanisms such as bicarbonates utilization, luxuriant uptake of nutrient ions and allelopathy, and provide refugia for the large bodied cladocera, which are highly efficient harvesters of phytoplankton. Two well defined procedures are said to involve in the uptake of nutrients and metals by the submerged aquatic macrophytes from the water. First the indirect mechanisms involve the stimulation of oxygenation of the sediment coupled with nitrification–denitrification (Rysgaard et al. 1994) and also by providing substratum to the micro-organisms involved in the process of metal accumulation (Eriksson and Weisner 1997). Second is direct effect of submerged macrophytes on the cycling of metals and nutrients is their uptake e.g., nitrification, limited by ammonium (NH_4^+) ions uptake by *Potamogeton perfoliatus* (L.) and *Elodea nuttalli* (Planch) St. John (Caffrey and Kemp 1990). Submerged aquatic macrophytes provide substratum to the periphytons account for maximum uptake of N and P from water (Dierberg et al. 2002). Rooted submerged macrophytes can take up nutrients both from the sediment pore water (Barko and Smart 1980) and from the overlying water (Ozimek et al. 1993). SAMs have several impacts on water chemistry as they utilize dissolved CO_2 and HCO_3^- ions in the water and promote the co-precipitation of P with available $CaCO_3$ (DeBusk et al. 1989; McConnaughey et al. 1994).

5.1 Brief introduction to the most common SAMs

Some of the most common submerged (rooted submerged and submerged) macrophytes include *Hydrilla verticillata* belonging to the family Hydrocharitaceae, which is native to the warmer areas of Asia. Hydrilla is highly polymorphic (Verkleij et al. 1983; Pieterse et al. 1985). Although it occurs in temperate areas, it tends to be more widespread in tropical areas of the world. *Ceratophyllum demersum* (Coontail or hornwort) is a completely submerged plant and commonly seen in ponds, lakes, ditches, and quiet streams (Johnson et al. 1995). Apart from the submerged macrophytes, an alga which has very important role in water chemistry is *Chara* (Musk grass) belonging to the family Characeae a group of the most commonly found algae in the shallow waters of tropical wetland including *C. tomentosa, C. najas, C. hispida*, and *C. aspera*. *Chara* is not found in wetlands dominated by emergent macrophytes. *Chara* and related genera such as *Nitella* and *Tolypella* are classed as alga yet they have a life form resembling that of higher submerged plants. Ecologically *Chara* is classes along with the submerged producers (Odum 1996). Extensive studies of the growth pattern and nutrient uptake from the water by the charophytes in particular of *Chara* spp. has been carried out by Kufel and Kufel (2002).

5.2 Uptake of nutrients by SAMs

Submerged macrophytes are an important ecosystem component affecting nutrient cycling in lakes. SAM communities exhibit phosphorus (P) removal mechanisms e.g., *Chara* spp. (Dierberg et al. 2002). *Chara* spp. can take up nitrogen as NH_4^+ and NO_3^- from the water significantly (Vermeer et al. 2003) which causes the reduction of Characean biomass because of the increased levels of N in the cells (more than 2%). Reports of Forsberg (1964) suggest the *Chara* spp. as a potential accumulator of P. The growth of *Ceratophyllum demersum* is favored by moderate to high nutrient level in the water (Johnson et al. 1995). It does not produce roots, instead it absorbs all the nutrients it requires from the surrounding water. Species such as *Najas guadalupensis, Ceratophyllum demersum, Chara* spp. and *Potamogiton illininoensis* are reported to have capability to remove the different chemical species of P (e.g., total phosphorous, soluble reactive phosphorus, PO_4^{3-}) (Dierberg et al. 2002). *Chara* spp. has special affinity for N and *C. demersum* has it for P. *Chara* spp. is also able to take up both ammonium and nitrate ions from water and sediments (Vermeer et al. 2003). Submerged plants can also detoxify the toxic metabolites such as methyl-Hg (Clarkson 1994) which is degraded by fresh water algae a submerged macrophyte *Elodea densa* (Simon and Boudou 2001). The plants like *Hydrilla* can use free carbon dioxide from surrounding water when it is available and can switch to bicarbonate utilization under favorable conditions i.e., high pH and high carbonate concentration (Salvucci and Bowes 1983).

5.3 Uptake of metal ions by SAMs

Submerged plants are useful in reducing heavy metal concentrations in water, as the biomass of their shoot can accumulate large amounts of heavy metals (Rai et al. 1995; Jackson 1998; Fritioff et al. 2005). Everard and Denny, (1985) reported the uptake of metal such as Pb by the submerged aquatic species specifically by the mosses (Aufwuch). The increased uptake of metals is caused by the increased concentration of metal ions in the surroundings of submerged aquatic macrophytes. pH, redox potential, temperature and salinity in the aquatic surrounding largely affect the metal uptake by submersed plants. In the aquatic environment, the Cu adsorption on the algal surface (*Dunaliella tertilecta*) increases with increasing temperature (Gonzalez-Davila et al. 1995). In a study, *Elodea canadensis* (Michx.) showed unusual ability to remove Pb under high salinity conditions while *Potamogeton natans* (L.) found to have great promise for Zn and Cd (Fritioff et al. 2005). Significant uptake of metals with the increase of biomass of submerged plants such as *E. canadensis* that grows faster to yield more biomass is a well established fact. *C. demersum* act as effective biosorbent for Zn, Pb and Cu metals (Table 3) under diluted conditions (Keskinkan et al. 2004). *C. demersum*, *Wolffia* spp., and *H. verticillata* are used as markers to assess the level of heavy metal pollution in aquatic bodies. Tripathi et al. (1995) demonstrated the light dependency for metabolic energy for the transport of Cd^{2+} in *C. demersum.* Cadmium influx in the plants is more in the light than in dark.

6 Constructed wetlands (Mesocosm)

Constructed wetlands are the well accepted and most preferable ways to treat the waste water all over the world particularly for the developing world. The researches carried out on constructed wetlands in last two decades have yielded comprehensive understanding on the bioremediation. However; Knowledge of the functioning of constructed wetlands is not as advanced as to provide detailed predictive models, since they depend on biological characteristics such as inter-specific competition and tolerance to a residual liquid of changing characteristics (Cole 1998; Hadad et al. 2006). Constructed wetlands are the miniature of natural conditions especially of a natural wetland. Macrophytes are assumed to be the main biological component of a constructed wetland (Hadad et al. 2006). The major components of constructed wetland systems are the reeds and aquatic vegetation such as *Phragmites australis*, *Vetiveria zizanioides*, *Scirpus* spp., *Typha* spp., *Iris* spp., *Glyceria* spp. *Lemna* spp., *Arundo donax, Salix nigra, Populus fremontii* and the rhizosphere organisms. Smaller sized wetlands (mesocosms) have significant wildlife potential. Figure 3 shows a simple horizontal surface flow constructed wetland. Large sized wetlands may not only be driven by the desire to attract wildlife but may also be advantageous in terms of treatment. Treatment wetland systems can remove significant amounts of suspended solids, organic matter, nitrogen, phosphorous, trace elements, and micro-organisms contained in wastewater (Kadlec and Knight 1996). Small constructed wetlands do not generally perform well at phosphorous removal (Cooper and Green 1995). The constructed wetlands are also used as controlled environment for the removal of xenobiotics such as pesticides e.g., Cheng et al. (2002b), demonstrated the removal of xenobiotics from polluted water by a multifunctional constructed wetland. Major mechanisms involved in such mesocosms are the hydraulic detention time (HDT) and volumetric flow rate (VFR) of water. More the HDT and least VFR provide maximum exposure of water to the root surface of the plant providing sufficient time for the uptake of the

Fig. 3 A prototype of horizontal flow constructed wetland

nutrient ions and other chemical changes. The study of wetlands also include the efficiency to remove xenobiotics from polluted water in a twin shaped (Vertical flow chamber and reverse vertical flow chamber) constructed wetland. Recently significant work has been performed by the Eco-auditing group National Botanical Research Institute Lucknow India on the treatment of waste water with aquatic macrophytes and the grasses like *Vetiveria zizanioides* and *Phragmites karka* growing in a constructed wetland. The results showed (unpublished data) significant reduction in BOD, PO_4^{3-} and bacterial count.

6.1 Future prospects of constructed aquatic systems

The results of earlier research reports (Reddy and Smith 1987; Dierberg and Brezonik 1983; DeBusk et al. 1995; Brix 1997; Dierberg et al. 2002; Sooknah and Wilkie 2004; Deaver 2005; Nahlik and Mitsch 2006) show the potential of macrophytes to grow in mesocosm and to mitigate the nutrient ions and metals from water and waste waters. However; not a significant work is reported so far on the handling the biomass generated as a result of usages of aquatic macrophytes in the constructed wetlands for the purposes of pollution mitigation. A comprehensive study of potential aquatic macrophytes and their combination for the treatment of waste water in mesocosm is much required by the industrialist and for the aqua-culturists for the reuse of water for various purposes.

7 Conclusion

Studies from all over the world show that both submerged and free-floating macrophytes have a high capability to improve water quality by removing heavy loads of nutrients and toxic metals from the water. Researchers have made it clear that the macrophytes can reduce the concentrations of nutrient ions such as P and N significantly in a controlled environment for e.g., in an integrated system called constructed wetland. The selection of the aquatic plant species is one of the tricky tasks prior to the designing of a treatment facility. The utility of aquatic macrophytes for the simulated conditions, to improve the water quality has always been a question of much research. The available information regarding an ideal combination of species to meet the standards of water quality is still to be completed.

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