4 Phytoremediation of Eutrophic Waters

Abid Ali Ansari, Subrata Trivedi, Fareed Ahmad Khan, Sarvajeet Singh Gill, Rubina Perveen, Mudasir Irfan Dar, Zahid Khorshid Abbas, and Hasibur Rehman

4.1 Introduction

Water is an indispensable resource and essential life supporting factor. On the hydrological map of the world, eutrophication is one of the great issues causing degradation of freshwater ecosystems. The excessive nutrient enrichment of waters results in change of oligotrophic water bodies into mesotrophic, eutrophic, and finally hypertrophic. The major nutrient sources for enrichment of aquatic ecosystems are sewage, household detergents, and industrial discharges, runoff from agriculture, construction sites, and urban areas. Eutrophication is a threat for water used in fisheries, recreation, industry, and drinking as it causes increased growth of cyanobacteria and aquatic macrophytes resulting in low oxygen, death, and decomposition of aquatic flora and fauna (Ansari and Gill 2014).

The water is an essential life supporting matter in every cell of an organism. It enters into the living organisms via absorption or ingestion. It circulates between biotic and abiotic components of the ecosystem. The misuse and reckless over consumption has resulted into the fast depletion of water resources. The nutrient enrichment of the water bodies caused from the natural and man-made sources is depleting the water resources at a faster pace. The eutrophication is a kind of nutrient enrichment process of any aquatic body which results in an excessive growth of phytoplankton (Ansari and Khan 2014).

A.A. Ansari, Ph.D. (✉) • S. Trivedi, M.Phil., Ph.D. • Z.K. Abbas, Ph.D.
H. Rehman, Ph.D.
Department of Biology, Faculty of Science, University of Tabuk, Tabuk 71491, Saudi Arabia
e-mail: aansari@ut.edu.sa; aaansari40@gmail.com

F.A. Khan, M.Phil., Ph.D. • R. Perveen, M.Phil., Ph.D., Student
M.I. Dar, Ph.D., Student
Department of Botany, Environmental Physiology Laboratory, Aligarh Muslim University, Aligarh 202002, UP, India

S.S. Gill
Centre for Biotechnology, Maharshi Dayanand University, Rohtak, Haryana, India

The common household detergents are the major anthropogenic source of phosphorus input into the nearby water bodies and sewage treatment plants (Ansari and Khan 2014). Eutrophication refers to natural or artificial addition of nutrients to water bodies and its effects on the aquatic life. When the effects are undesirable, eutrophication may be considered a form of pollution. Based on nutrient status and productivity, an aquatic system can be classified into the following three types: (1) Oligotrophic: water with poor nutrient status and productivity; (2) Mesotrophic: water with moderate nutrient status and productivity; (3) Eutrophic: water with rich nutrient status and high productivity (Naeem et al. 2014).

The European Union (EU) Water Framework Directive (WFD) given directions to prevent deterioration, protect aquatic ecosystems and to promote the sustainable use of water (Andersen et al. 2006). Hypoxia is one of the common effects of eutrophication in aquatic ecosystems and is becoming an increasingly prevalent problem worldwide. The causes of hypoxia are associated with nutrient inputs from both point and non-point sources. Eutrophication may be defined as the sum of the effects of the excessive growth of phytoplankton, benthic algae, and macrophytes leading to imbalanced primary and secondary productivity caused by nutrient enrichment. Most studies about eutrophication primarily focused on dissolved nutrients assimilated rapidly by aquatic plants. The role of complex organic nitrogen leading to the eutrophication of tropical waters has been largely overlooked although nitrogen occurs predominantly as organic nitrogen, due to a higher rate of decomposition of organic matter (Berman and Bronk 2003). The sources of nitrogen in the environment serve to enhance plant growth, and nitrogen acts as a pollutant in water bodies, becoming a serious problem worldwide. The elevated concentrations of ammonium nitrate and other forms of nitrogen enhance the eutrophication of aquatic ecosystems (Glibert et al. 2004; Zhang et al. 2007; Naeem et al. 2014).

A.A. Ansari et al. (eds.), *Phytoremediation: Management of Environmental Contaminants, Volume 2*,
DOI 10.1007/978-3-319-10969-5_4,

The domestic waste (rich in phosphate and nitrate) when discharged in water bodies makes them highly productive or "eutrophic." Nutrient enrichment is the starting point of eutrophication in any water body and is followed by uncontrolled growth of primary producers which depletes oxygen owing to decomposition of algal organic matter. Lakes and ponds in many Indian cities are the important sources of freshwater for various purposes and recharge the underground water resources. (Fareed et al. 2014).

Phytotechnologies involving use of plants for pollutant removal gained importance during the last two decades. Over the past many years phytoremediation technology has become an effective method for environmental cleaning due to the plants ability to accumulate the contaminants at the concentration level thousands times higher than background one. Phytoremediation is treatment technology that takes advantage of fact that certain species of plants flourish by accumulating contaminants present in the water. Phytoremediation refers to the natural ability of certain plants called hyper-accumulators or bio-accumulators to degrade or render harmless contaminants in water (Dar and Kumawat 2011). The floating macrophytes are applied most often for treatment of sewage released from different industrial sources and may consider as efficient tool for contaminated waters. The plants are capable to remove many toxic substances from water reservoirs, acquiring the pollutants from waters as food elements, basically through root system using the products of decomposition for their viability (Jamuna and Noorjahan 2009).

Development of aquatic plant systems for nutrient recovery from eutrophic water is essentially required to control eutrophication. The performance of phytoremediation system depends upon many factors such as growth performances of the plants selected for phytoremediation, their nutrient removal potential, efficiency to grow in experimental environment. In order to develop high-efficient nutrients phytoremediation systems aquatic plant species in combinations can be used (Ansari et al. 2014).

Contaminants like heavy metals, nonessential metals, crude oil, inorganic and organic substances and their derivatives could be mitigated in phytoremediation projects running across the globe as it is considered a clean, cost-effective, and environment friendly technology. Aquatic plants propagate rapidly by consuming dissolved nutrients from water and are excellent for harvesting nutrients within a short period of time and for the treatment of waste water by absorbing various nutrients like phosphates, calcium, magnesium, chloride from the waste water (Ansal et al. 2010). By harvesting the plants, nutrients can be permanently removed from the system. During the phytoremediation using aquatic plants an increase in pH value of water occurs usually which supports the growth of aquatic plants interne restoring the aquatic ecosystems (Patel and Kanungo 2010; Kaur et al. 2010). Changes in climate, particularly pH, temperature, and light affect the sustainability of phytoremediation systems (Ansari et al. 2011c, 2014; Feuchtmayr et al. 2009). Aquatic plants are highly capable to remove many organic nutrients which they convert into the substance of the plants as their biomass (El-Kheir et al. 2007).

Nitrogen and Phosphorus are the macronutrients required for the growth and physiological development of plants as they are major components of many metabolic and structural compounds in plant cells. These nutrients play a significant role in the synthesis of chlorophylls, protoplasm, and nucleic acids, and act as the backbone for ATP. Nitrogen deficiency causes decreased cell division and expansion, chlorophyll deficiency, and prolonged dormancy. Nitrogen is an essential plant nutrient for healthy growth and reproduction. An increase in availability of N usually boosts life production, such as increasing the abundance of primary producers in a water body (Camago and Alonso 2006). Aquatic plants can utilize various chemical forms of nitrogen ranging from simple inorganic nitrogen compounds such as ammonium and nitrate to organic nitrogen forms such as polymeric proteins (Paungfoo-Lonhienne et al. 2008). Among all the forms of nitrogen, ammonium and nitrate are the most common ionic (reactive) forms of dissolved inorganic nitrogen in aquatic ecosystems. Nitrogen is present naturally due to atmospheric deposition, surface and groundwater runoff, geological deposits, biological nitrogen fixation, and biodegradation of organic matter (Rabalais 2002).

Various free-floating aquatic macrophytes were studied for their possible use in the removal of different ionic form of nutrients (Gunnarsson and Petersen 2007; Malik 2007) as these free-floating aquatic plants have very high growth rates and rapidly utilize the available nutrients in the water (Malik 2007). The plants having high growth rates provide a good estimation of their nutrient removal capacity form eutrophic waters (Agunbiade et al. 2009). Plants with high bio-productivity are preferred for phytoremediation systems as they can utilize more nutrients to support rapid plant growth (Liao and Chang 2004; Gujarathi et al. 2005; Malik 2007).

Many waters of developed nations have experienced widespread and rapid eutrophication due to the increase in supply of organic matter during the last half of the twentieth century. An aquatic system takes thousands of years to become eutrophic which is a natural process. However, a high rate of nutrients inputs due to anthropogenic activities significantly enhances the condition in a very short period of time (Ansari and Khan 2002, 2006a, b, 2007, 2014). The nutrient input to waters from various sources causes eutrophication and are responsible for degradation of aquatic ecosystems (Ansari and Khan 2009b) and plant biodiversity. The environmental factors viz. nutrients, temperature, pH, dissolved oxygen, carbon dioxide, light within an aquatic ecosystem have a major role in controlling eutrophication in aquatic bodies and limiting the growth and development of aquatic plants (Lau and Lane 2002; Shen 2002; Khan and Ansari 2005; Khan et al. 2014).

In this experiment mono, bi, tri, tetra, and penta-cultures of some free-floating aquatic macrophytes *Eichhornia*, *Lemna*, *Salvinia*, *Spirodela*, and *Wolffia* were applied for the treatment of eutrophic waters. The selected plant species were grown in artificial nutrient media for 21 days to investigate their nutrient removal potential in order to develop sustainable nutrient phytoremediation systems for eutrophic waters. Selecting aquatic free-floating macrophytes would not only result in greater nutrient removal from eutrophic waters but also help to reduce other pollutants and to mitigate the other effects of eutrophication. Hence, in this study some free-floating aquatic macrophytes have been selected to determine their nutrient removal ability under controlled conditions, and to establish the phytoremediation systems for eutrophic waters.

4.2 Materials and Methods

Plants selected for this experiment were collected from freshwater bodies, washed thoroughly in lab and cultured for 1 week to acclimatize the experimental conditions. The experiments were conducted in large earthen pots of size 40 × 25 cm (diameter × depth) containing 15 L of freshwater with macronutrients 1 mL/L (Tables 4.1 and 4.2). The experimental pots were placed in a greenhouse in which had average conditions of 30/25 °C day/night temperatures, 65–85 % relative humidity, 12-h photoperiod. Natural irradiance (Photosynthetically Active Radiation, PAR) was provided to the plants and the light levels were maintained at 650 Gmol quanta m^{-2} s^{-1} by supplementing with artificial lighting. Growth medium in all the sets were maintained at pH 7, measured regularly with a pH meter (Elico Limited, Hyderabad) and NaOH or HCl were added to the growth medium to maintain the pH level.

Before inoculation to experimental pots the plants were disinfected by immersing them in NaClO (1 % v/v) and then rinsed with distilled water. The final volume (15 L) of the growing medium in the experimental pots was maintained using distilled water. The initial values of total fresh weight were made uniform and 100 g of each plant species transferred from the maintained stock to each experimental pot. The plants were placed in a nutrient-free solution for 3 days to elicit starvation-induced maximal removal response before transfer. Earthen pots of each treatment were maintained in triplicate.

The experiments were terminated after 21 days. Plants removed from the experimental pots and some part of fresh material was taken for chlorophyll-a estimation following the method of Zhao (2000). And rest of the fresh material was dried at 80 °C in order to obtain dry matter. The nitrogen and phosphorus contents in dry matter of aquatic plants were determined using the method of Lindner (1944) and Fiske and Subba-Row (1925) respectively. The parameters dry matter, nitrogen, phosphorus, and chlorophyll-a contents in aquatic plants used in this experiment was taken separately from each plant and an average was taken according to their combination as mono, di, tri, tetra, and penta-culture species used to develop a phytoremediation system for eutrophic waters. Water samples were collected from a depth of 5–10 cm below the water surface and 25 mL of water sample was collected each time in sterile, screw-capped plastic bottles measuring 50 mL. To minimize turbidity, samples were filtered with a Whatman No. 42 filter paper before storage. After filtration, the samples were refrigerated at 4 °C and analyzed following APHA (2005) within a week of collection. All the data obtained from the research were analyzed statistically for significance following Dospekhov (1984).

Table 4.1 Composition of stock solution of macronutrients added to freshwater used as growth medium

Macronutrients	g/L
$NH_4H_2PO_4$	0.23
KNO_3	1.02
$Ca(NO_3)$	0.492
$MgSO_4 \cdot 7H_2O$	0.49

Table 4.2 Physicochemical characteristics of freshwater used as growth medium

Physicochemical characteristics	mg/L (Except pH and turbidity)
pH	7.1
Turbidity	12 (NTU)
Dissolved oxygen	7.4
Calcium	15.7
Magnesium	21.8
Potassium	9.3
Chloride	55.7
Phosphate	0.07
Nitrate	0.61

NTU nephelometric turbidity unit

4.3 Results

With the increasing interest related to the use of plants for phytoremediation of Nitrates and Phosphates rich waters, aquatic plants like *Eichhornia*, *Salvinia*, *Spirodela*, *Lemna*, *Wolffia* were selected in this study as they offer great potential for phytoremediation, reproduce vegetatively at a very rapid rate, and have relatively high rate for uptake of nutrients. All the plants showed their high potential to remove nitrate and phosphate from eutrophic waters.

4.4 Percent Nutrients (Nitrates and Phosphates) Removal from Eutrophic Waters

In mono-culture (one plant species) phytoremediation system the nutrient removal potential was in order of *Eichhorni a* < *Spirodela* < *Lemna* < *Wolffia* < *Salvinia* where *Eichhornia* remove maximum 63 % nitrates and 55 % phosphates from eutrophic waters. In di-culture (two plant species) phytoremediation systems, nutrient removal potential was in order of *Eichhornia* + *Salvinia* < *Lemna* + *Spirodela* < *Eichhornia* + *Spirodela* < *Eichhornia* + *Lemna* < *Spirodela* + *Salvinia* < *Eichhonia* + *Wolffia* < *Wolffia* + *Salvinia* < *Lemna* + *Salvinia* < *Spirodela* + *Wolffia* < *Lemna* + *Wolffia* but maximum potential was shown by *Eichhornia* + *Salvinia* which can remove up to 75 % nitrates and 62 % phosphates. Highest nutrient removal potential was observed in tri-culture (three plant species) phytoremediation system of *Eichhornia* + *Lemna* + *Spirodela* which removes 92 % nitrates and 78 % phosphates from nutrient media (Figs. 4.1 and 4.2, and Table 4.3).

However, in tri-culture phytoremediation systems nutrient removal potential was in the following order: *Eichhornia* + *Lemna* + *Spirodela* < *Lemna* + *Spirodela* + *Wolffia* < *Salvinia* + *Eichhornia* + *Spirodela* < *Eichhornia* + *Lemna* + *Salvinia* < *Wolffia* + *Salvinia* + *Eichhornia* < *Spirodela* + *Wolffia* + *Eichhornia* < *Eichhornia* + *Lemna* + *Wolffia* < *Wolffia* + *Salvinia* + *Lemna* < *Lemna* + *Spirodela* + *Salvinia* < *Spirodela* + *Wolffia* + *Salvinia*. In tetra-culture (four plant species) phytoremediation systems the nutrient removal potential was in order of *Salvinia* + *Eichhornia* + *Lemna* + *Spirodela* < *Spirodela* + *Wolffia* + *Salvinia* + *Eichhornia* < *Eichhornia* + *Lemna* + *Spirodela* + *Wolffia* < *Lemna* + *Spirodela* + *Wolffia* + *Salvinia* < *Wolffia* + *Salvinia* + *Eichhornia* + *Lemna* and maximum was 88 % for nitrates and 75 % for phosphates of *Salvinia* + *Eichhornia* + *Lemna* + *Spirodela*. The penta-culture (five plant species) (using a combination of *Eichhornia* + *Lemna* + *Spirodela* + *Wolffia* + *Salvinia*) phytoremediation system efficiently removes 85 % nitrate and 81 % of phosphate from the eutrophic water (Figs. 4.1 and 4.2, and Table 4.3).

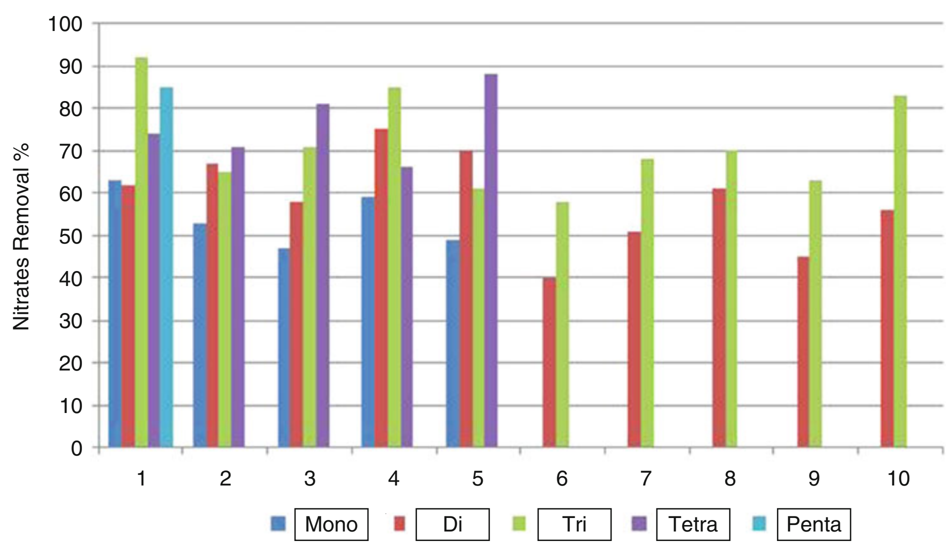

Fig. 4.1 Nitrates removal potential of free-floating aquatic macrophytes grown in mono, di, tri, tetra, and penta-cultures species phytoremediation systems

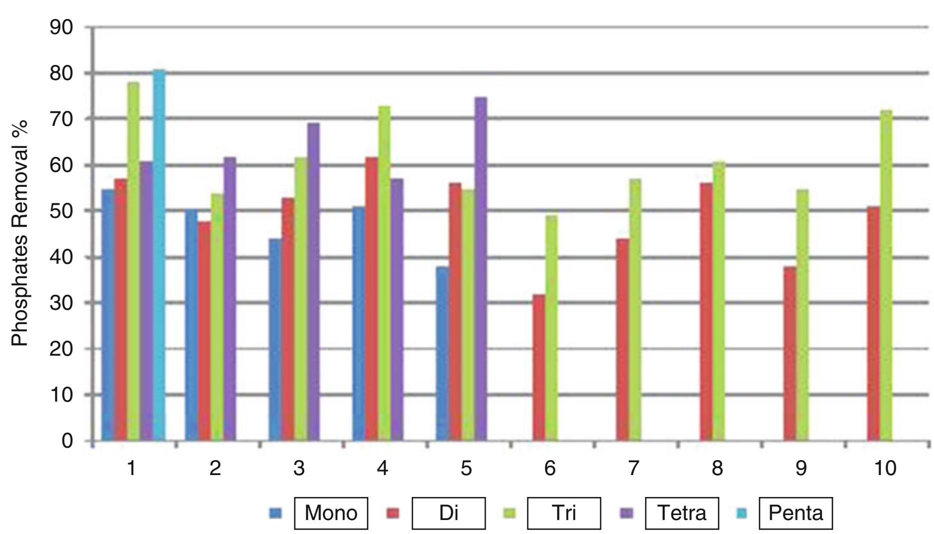

Fig. 4.2 Phosphates removal potential of free-floating aquatic macrophytes grown in mono, di, tri, tetra, and penta-cultures species phytoremediation systems

Table 4.3 Percent nutrients (Nitrates and Phosphates) removal from eutrophic waters by mono, di, tri, tetra, and penta-culture species phytoremediation systems

Mono-culture (single species)			Di-culture (two species)			Tri-culture (three species)			Tetra-culture (four species)			Penta-culture (five species)		
	% Nutrient Removal			% Nutrient Removal			% Nutrient Removal			% Nutrient Removal			% Nutrient Removal	
	N	P		N	P		N	P		N	P		N	P
E	63	55	E+L	62	57	E+L+Sp	92	78	E+L+Sp+W	74	61	E+L+Sp+W+Sa	85	81
L	53	50	E+Sp	67	48	E+L+W	65	54	L+Sp+W+Sa	71	62			
Sa	47	44	E+W	58	53	E+L+Sa	71	62	Sp+W+Sa+E	81	69			
Sp	59	51	E+Sa	75	62	L+S+W	85	73	W+Sa+E+L	66	57			
W	49	38	L+Sp	70	56	L+Sp+Sa	61	55	Sa+E+L+Sp	88	75			
			L+W	40	32	Sp+W+Sa	58	49						
			L+Sa	51	44	Sp+W+E	68	57						
			Sp+Sa	61	56	W+Sa+E	70	61						
			Sp+W	45	38	W+Sa+L	63	55						
			W+Sa	56	51	Sa+E+Sp	83	72						

E = *Eichhornia*, L = *Lemna*, Sa = *Salvinia*, Sp = *Spirodela*, W = *Wolffia*

4.5 Percent Nutrient Uptake by Aquatic Plants from Eutrophic Waters

In mono-culture (one plant species) phytoremediation system the nitrogen and phosphorus uptake was highest (7.2 and 0.85 %) in *Eichhornia*. In di-culture (two plant species) phytoremediation systems, nitrogen and phosphorus uptake was highest (7.6 and 0.95 %) in *Eichhornia* + *Salvinia*. Highest (8.3 and 0.97 %) nitrogen and phosphorus was observed in *Eichhornia* + *Lemna* + *Spirodela* tri-culture (three plant species) phytoremediation system (Figs. 4.3 and 4.4, and Table 4.4).

In tetra-culture (four plant species) phytoremediation systems the nutrient uptake was maximum (7.25 and 0.88 %) in *Salvinia* + *Eichhornia* + *Lemna* + *Spirodela*. The penta-culture (five plant species) phytoremediation system *Eichhornia* + *Lemna* + *Spirodela* + *Wolffia* + *Salvinia* efficiently took up nitrogen and phosphorus (6.9 and 0.79 %); however, other systems were more efficient in taking up the nutrients from eutrophic waters (Figs. 4.3 and 4.4, Table 4.4).

4.6 Dry Weight Accumulation and Chlorophyll-a Content in Aquatic Plants Grown in Eutrophic Waters

In mono-culture (one plant species) phytoremediation system the dry matter accumulation and chlorophyll-a content were highest (335 and 1.34 mg/g of fresh matter) in *Eichhornia*. In di-culture (two plant species) phytoremediation systems, dry matter accumulation and chlorophyll-a content were highest (338 and 1.41 mg/g of fresh matter) in *Eichhornia* + *Salvinia*. Highest (342 and 1.40 mg/g of fresh matter) dry matter accumulation and chlorophyll-a content were observed in *Eichhornia* + *Lemna* + *Spirodela* tri-culture (three plant species) phytoremediation system (Figs. 4.5 and 4.6, and Table 4.5).

In tetra-culture (four plant species) phytoremediation systems dry matter accumulation and chlorophyll-a content was maximum (324 and 1.28 mg/g of fresh matter) in *Salvinia* + *Eichhornia* + *Lemna* + *Spirodela*. In penta-culture (five plant species) phytoremediation system (*Eichhornia* + *Lemna* + *Spirodela* + *Wolffia* + *Salvinia*) efficiently accumulate dry matter and chlorophyll-a content (328 and 0.87 mg/g of fresh matter), however, other systems were more efficient in accumulating dry matter and chlorophyll-a content grown in eutrophic waters (Figs. 4.5 and 4.6, Table 4.5).

4.7 Discussion

The study indicates that under controlled conditions multi-species phytoremediation systems are more efficient in removing the nutrients from eutrophic waters than the mono-species phytoremediation systems. However, in all types of phytoremediation systems tri-culture phytoremediation system (*Eichhornia* + *Lemna* + *Spirodela*) showed its highest efficiency and may be used for lowering high nutrient levels in eutrophic water. Freshwater aquatic plants are highly capable to remove nitrates and phosphates from waters but the response may be species dependent (Sooknah and Wilkie 2004; Zhang et al. 2009; Konnerup and Brix 2010). Aquatic plants are highly sensitive to pH, temperature and nutrient concentration of the growing media. Nitrate and phosphate removal potential of selected aquatic plants were studied in

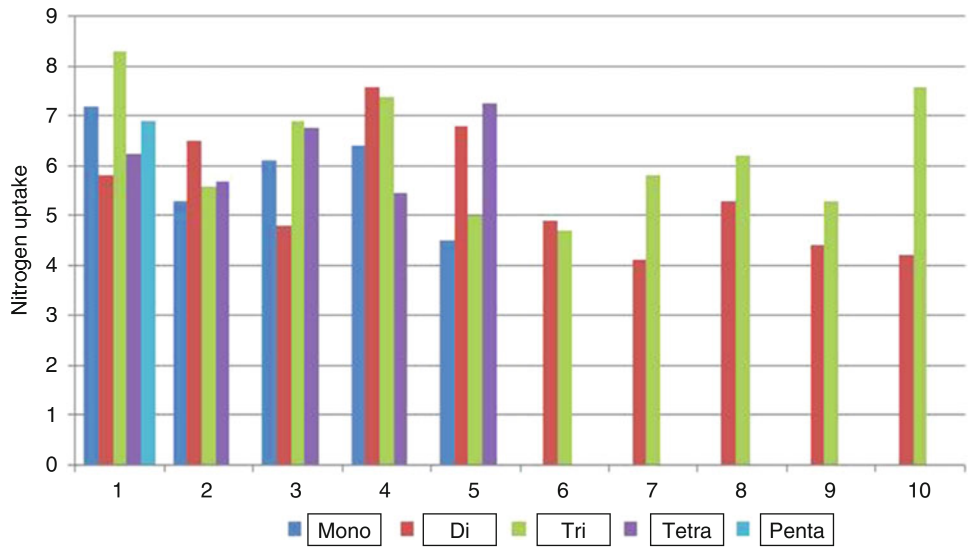

Fig. 4.3 Nitrogen uptakes (mg/100 mg of dry matter) by free-floating aquatic macrophytes grown in mono, di, tri, tetra, and penta-cultures species phytoremediation systems

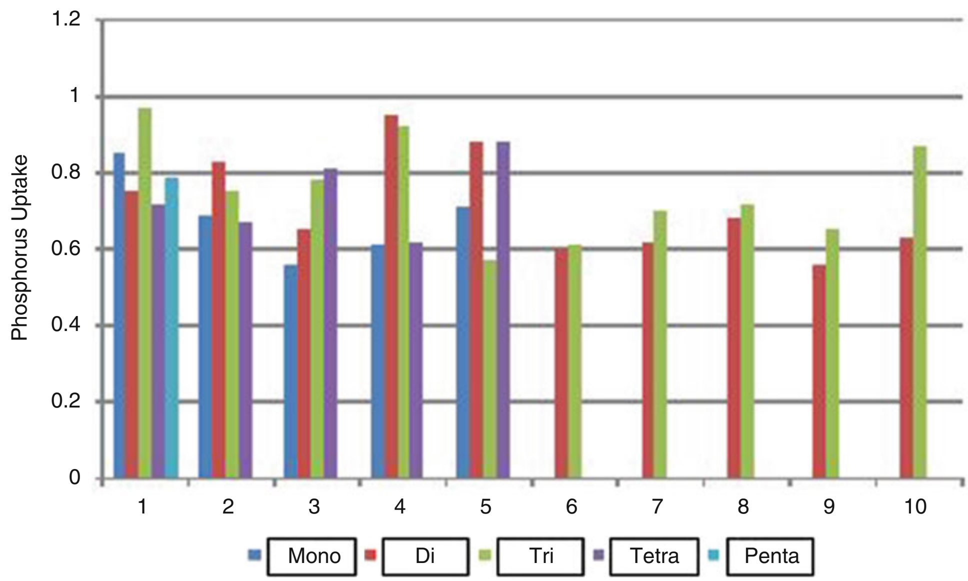

Fig. 4.4 Phosphorus uptakes (mg/100 mg of dry matter) by free-floating aquatic macrophytes grown in mono, di, tri, tetra, and penta-cultures species phytoremediation systems

Table 4.4 Nutrient (Nitrogen and Phosphorus) uptake (mg/100 mg of dry matter) by aquatic plants grown in mono, di, tri, tetra, and penta-culture species phytoremediation systems

Mono-culture (single species)			Di-culture (two species)			Tri-culture (three species)			Tetra-culture (four species)			Penta-culture (five species)		
	% Nutrient uptake			% Nutrient uptake			% Nutrient uptake			% Nutrient uptake			% Nutrient uptake	
	N	P		N	P		N	P		N	P		N	P
E	7.2	0.85	E+L	5.8	0.75	E+L+Sp	8.3	0.97	E+L+Sp+W	6.25	0.72	E+L+Sp+W+Sa	6.9	0.79
L	5.3	0.69	E+Sp	6.5	0.83	E+L+W	5.6	0.75	L+Sp+W+Sa	5.67	0.67			
Sa	6.1	0.56	E+W	4.8	0.65	E+L+Sa	6.9	0.78	Sp+W+Sa+E	6.75	0.81			
Sp	6.4	0.61	E+Sa	7.6	0.95	L+S+W	7.4	0.92	W+Sa+E+L	5.47	0.62			
W	4.5	0.71	L+Sp	6.8	0.88	L+Sp+Sa	5.0	0.57	Sa+E+L+Sp	7.25	0.88			
			L+W	4.9	0.60	Sp+W+Sa	4.7	0.61						
			L+Sa	4.1	0.62	Sp+W+E	5.8	0.70						
			Sp+Sa	5.3	0.68	W+Sa+E	6.2	0.72						
			Sp+W	4.4	0.56	W+Sa+L	5.3	0.65						
			W+Sa	4.2	0.63	Sa+E+Sp	7.6	0.87						

E = *Eichhornia*, L = *Lemna*, Sa = *Salvinia*, Sp = *Spirodela*, W = *Wolffia*

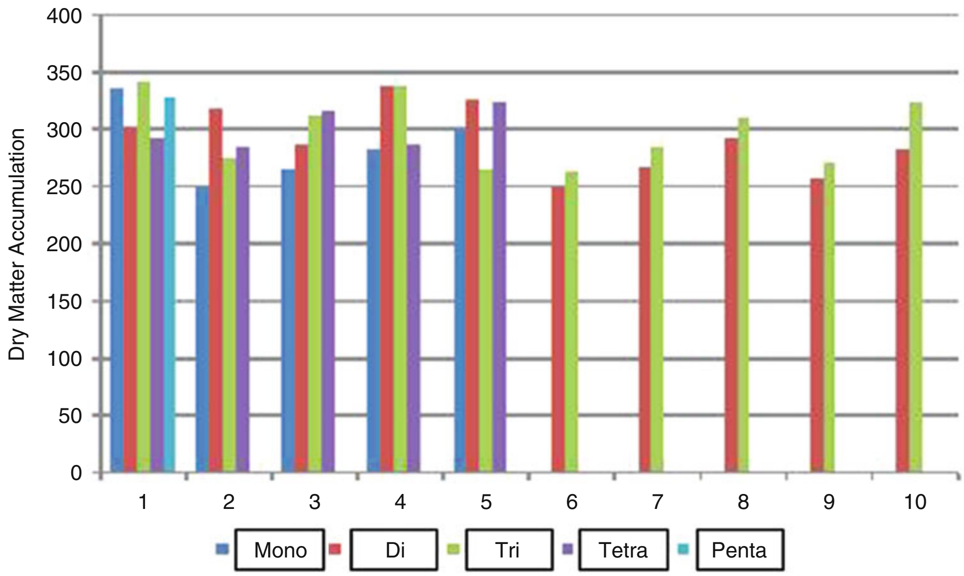

Fig. 4.5 Dry matter accumulation (mg/g of fresh matter) of free-floating aquatic macrophytes grown in mono, di, tri, tetra, and penta-cultures species phytoremediation systems

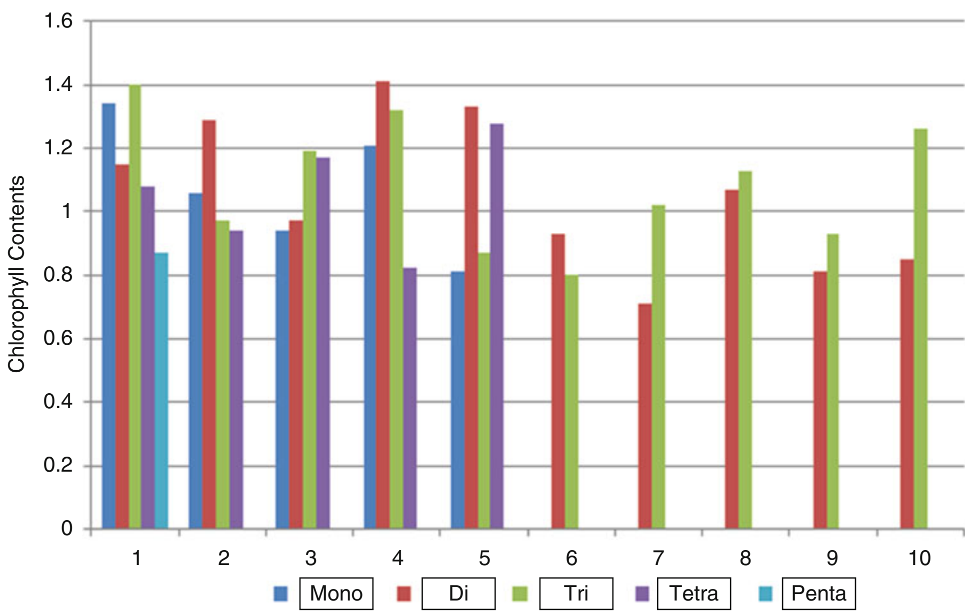

Fig. 4.6 Chlorophyll-a contents (mg/g of fresh matter) in free-floating aquatic macrophytes grown in mono, di, tri, tetra, and penta-cultures species phytoremediation systems

Table 4.5 Dry matter and chlorophyll-a contents (mg/g of fresh matter) in aquatic plants grown in mono, di, tri, tetra, and penta-culture species phytoremediation systems

Mono-culture (single species)			Di-culture (two species)			Tri-culture (three species)			Tetra-culture (four species)			Penta-culture (five species)		
	DM	Chl-a		DM	Chl-a		DM	Chl-a		DM	Chl-a		DM	Chl-a
E	335	1.34	E+L	302	1.15	E+L+Sp	342	1.40	E+L+Sp+W	292	1.08	E+L+Sp+W+Sa	328	0.87
L	250	1.06	E+Sp	318	1.29	E+L+W	275	0.97	L+Sp+W+Sa	284	0.94			
Sa	265	0.94	E+W	287	0.97	E+L+Sa	313	1.19	Sp+W+Sa+E	316	1.17			
Sp	282	1.21	E+Sa	338	1.41	L+S+W	337	1.32	W+Sa+E+L	287	0.82			
W	301	0.81	L+Sp	326	1.33	L+Sp+Sa	265	0.87	Sa+E+L+Sp	324	1.28			
			L+W	250	0.93	Sp+W+Sa	264	0.80						
			L+Sa	267	0.71	Sp+W+E	285	1.02						
			Sp+Sa	293	1.07	W+Sa+E	310	1.13						
			Sp+W	258	0.81	W+Sa+L	271	0.93						
			W+Sa	282	0.85	Sa+E+Sp	324	1.26						

E = *Eichhornia*, L = *Lemna*, Sa = *Salvinia*, Sp = *Spirodela*, W = *Wolffia*, DM = Dry matter, Chl = Chlorophyll mono, bi, tri, tetra, and penta-culture species phytoremediation systems to investigate the best combination to develop a sustainable phytoremediation system for eutrophic water. Free-floating aquatic macrophytes are highly capable for morphological and physiological adaptations to aquatic environment. They have very high potential to take up and accumulate nutrients through their roots, stems, and leaves and can remove different ionic forms of nutrients especially of nitrogen and phosphorus from aquatic ecosystems (Smith 2007; Ansari and Khan 2006a, 2011, 2013; Ansari and Gill 2014).

Growth responses of aquatic plants reflect the primary productivity which has been considered as a strong indicator of eutrophication (Smith 2007; Ansari and Khan 2006a). The significant enhancement in dry matter, chlorophyll-a, nitrogen, and phosphorus in selected aquatic plants is a direct effect of composition of growth medium (Smith 2007). Waste water containing different forms of nutrients when discharged into the aquatic ecosystems changes the natural quality and quantity of water bring about corresponding changes in natural flora and fauna of the ecosystem (Azzurro et al. 2010).

Contamination of water has become one of the most serious problems of today's civilization. Phytoremediation is cost effective technique that uses plants to remediate contaminants from waste water. According to World Health Organization approximately 1.1 billion people do not have access to safe drinking water and within 15 years, three-fourths of the world's population will face the same problem. Contamination of water by different pollutants alters ecosystem structure and function. As such there has been a great deal of research into finding cost effective methods for the removal of contaminants to improve the quality of water (Abdel-Ghani and El-Chaghaby 2008; Al-Anber and Matouq 2008). Phytoremediation is a very useful and cost-effective, eco-friendly, and efficient technology in which aquatic plants are used to remediate contaminated water. There are several species of aquatic plants known for their phytoremediation abilities for polluted waters (Riffat et al. 2007; Nouri et al. 2009, 2011). Potential utility for phytoremediation of nutrients by aquatic macrophytes like *Eichhornia crassipes*, *Salvinia natans*, *Spirodela polyrrhiza*, *Lemna minor*, etc. has been tested (Ansari and Khan 2011, 2013; Sooknah and Wilkie 2004; Zimmels et al. 2006; Lu et al. 2010).

Phytoremediation systems using aquatic macrophytes are the major options that have been applied for simultaneously handling of wastewater with the nutrients used for poultry and aquacultural projects (Naphi et al. 2003; Ansal et al. 2010). Aquatic macrophytes may produce many generations of progeny over a very short period of time and multiply their biomass and can remove more than 75 % of total phosphorus and nitrogen in a eutrophied water body (Ansari and Khan 2008, 2009a; Cheng et al. 2002). The use of plants for nutrient uptake is especially valuable because following site remediation, it is possible to identify practical and value-added uses for the plant material (Cheng et al. 2002; Fang et al. 2007; Gulcin et al. 2010).

Phytoremediation systems depend on many factors, including retention time, season, temperature, pH, diversity of species, nutrients loading, hydraulic regimes, plant harvesting, light intensity, etc. (El-Shafai et al. 2007; Ansari and Khan 2009a; Lu et al. 2010). Light reduction in the water column and enhanced organic matter load into the sediments are two main consequences of eutrophication (Olive et al. 2009). Temperature is important environmental factor directly related with the functioning of an aquatic ecosystem (Ansari et al. 2011b). pH controls absorption of nutrients and biochemical reactions taking place in living organisms (Ansari et al. 2011a). The potential of aquatic plants for phytoremediation of various pollutants in water has been determined (Xia and Xiangjuan 2006; Mishra et al. 2007). Aquatic plants are reported for their efficiency to remove about 60–80 % nitrogen (Fox et al. 2008) and about 69 % of potassium from water (Zhou et al. 2007). The pH and temperature significantly control the bio removal of nutrients from waters using aquatic plants (Uysal and Fadime 2009).

A recent meta-analysis examined the effects of nutrients on absolute and relative production of large aquatic ecosystems and found rise in productivity due to increasing eutrophication (Faithfull et al. 2011). A global climate change also enhances freshwater eutrophication (Dokulil and Teubner 2011). Some major problems that humanity is facing in the twenty-first century are related to water quantity and/or water quality issues (UNESCO 2009). Thousands of aquatic ecosystems around the world are suffering due to the excessive inputs of nutrients from human-related uses of the land causing changes in their ecological structure and function (Moss et al. 2011; Esteves 2011).

Many lake managers have adopted the options of increasing macrophytes abundance in order to restore the quality of eutrophic waters (Lau and Lane 2002). The process of eutrophication is directly related with discharge of nutrients in household wastes and sewages, industrial wastes, agricultural and urban runoffs (Ansari and Khan 2006a). A strict control on effluents from the different nutrient sources can mitigate the problem of eutrophication (Stone 2011). The nutrient removal by waste water treatments before release and biological control using free-floating macrophytes may be the cost effective measures to control the eutrophication in aquatic ecosystem.

4.8 Conclusions

Multi-species phytoremediation systems are more efficient in removing the nutrients from eutrophic waters than the mono-species phytoremediation systems. However, in all types of phytoremediation systems tri-culture phytoremediation system (*Eichhornia* + *Lemna* + *Spirodela*) were showed highest efficiency in lowering high nutrient levels from eutrophic waters. By removing the rapidly growing free-floating aquatic macrophytes, absorbing high nutrient contents especially nitrates and phosphates from the growing medium, and replacing old with fresh plants at regular intervals, the eutrophic aquatic ecosystem can be restored. This is a preliminary experiment to investigate the nutrients (N and P) removal potential of various free-floating aquatic macrophytes in different combinations. Further we will study the growth of selected aquatic plants (in mono, bi, tri, tetra, and penta-species culture) in response to varying pH, light, temperature, and nutrient concentrations of growing medium. To develop a sustainable nutrient phytoremediation system to improve the quality of eutrophic waters, all the selected plants (in different combinations) will be tested in natural environmental conditions.

References

Abdel-Ghani NT, EI-Chaghaby GA (2008) The use low cost, environmental friendly materials for the removal of heavy metals from aqueous solutions. Curr World Environ 3:31–38

Agunbiade FO, Olu-Owolabi BI, Adebowale KO (2009) Phytoremediation potential of *Eichhornia crassipes* in metal contaminated coastal water. Bioresour Technol 100:4521–4526

Al-Anber ZA, Matouq MAD (2008) Batch adsorption of cadmium ions from aqueous solution by means of olive cake. J Hazard Mater 151:194–201

Andersen JH, Schluter L, Rtebjerg G (2006) Coastal eutrophication: recent developments in definitions and implications for monitoring strategies. J Plankton Res 28:621–628

Ansal MD, Dhawan A, Kaur VI (2010) Duckweed based bio-remediation of village ponds: an ecologically and economically viable integrated approach for rural development through aquaculture. Livest Res Rural Dev 22:129

Ansari AA, Gill SS (eds) (2014) Eutrophication: causes, consequences and control, vol 2. Springer, The Netherlands, p 262

Ansari AA, Khan FA (2002) Nutritional status and quality of water of a waste water pond in Aligarh showing blooms of *Spirodela polyrrhiza*. J Ecophysiol Occupat Health 2:185–189

Ansari AA, Khan FA (2006a) Studies on the role of selected nutrient sources in the eutrophication of fresh water ecosystem. Nat Env Poll Tech 5:47–52

Ansari AA, Khan FA (2006b) Growth responses of *Spirodela polyrrhiza* to selected detergent at varying temperature and pH conditions. Nat Env Poll Tech 5:399–404

Ansari AA, Khan FA (2007) Eutrophication studies in some freshwater ponds of Aligarh. Ind J Appl Pure Bio 22:21–26

Ansari AA, Khan FA (2008) Remediation of eutrophied water using *Lemna minor* in a controlled environment. Afr J Aquat Sci 33:275–278

Ansari AA, Khan FA (2009a) Remediation of eutrophied water using *Spirodela polyrrhiza* L. Shleid in controlled environment. Pan Am J Aquat Sci 4:52–54

Ansari AA, Khan FA (2009b) Eutrophication studies on Jeffery canal of Aligarh. International Conference on Emerging Technologies in Environmental Science and Engineering. Oct 26–28, Aligarh Muslim University, Aligarh, India, pp. 845–849

Ansari AA, Khan FA (2011) Nutrients phytoremediation of eutrophic waters using *Eichhornia crassipes* in a controlled environment. Int J Environ Sci 2:241–246

Ansari AA, Khan FA (2013) Response of *Eichhornia crassipes* to eutrophic waters receiving nutrients from various sources. Int J Environ Sci 4:39–45

Ansari AA, Khan FA (2014) Household detergents causing eutrophication in freshwater ecosystems. In: Ansari AA, Gill SS (eds) Eutrophication: causes, consequences and control, vol 2. Springer, The Netherlands, pp 139–163

Ansari AA, Gill SS, Khan FA (2011a) Eutrophication: threat to aquatic ecosystems. In: Ansari AA, Gill SS, Lanza GR, Rast W (eds) Eutrophication: causes, consequences and control. Springer, The Netherlands, pp 143–170

Ansari AA, Gill SS, Khan FA, Varshney J (2011b) Aquatic plant diversity in eutrophic ecosystems. In: Ansari AA, Gill SS, Lanza GR, Rast W (eds) Eutrophication: causes, consequences and control. Springer, The Netherlands, pp 247–263

Ansari AA, Gill SS, Lanza GR, Rast W (eds) (2011c) Eutrophication: causes, consequences and control, vol 1. Springer, The Netherlands, pp 143–170

Ansari AA, Gill SS, Khan FA, Naeem M (2014) Phytoremediation systems for the recovery of nutrients from eutrophic waters. In: Ansari AA, Gill SS (eds) Eutrophication: causes, consequences and control, vol 2. Springer, The Netherlands, pp 239–248

APHA (2005) Standard methods for the examination of water and wastewater, 21st edn. APHA, AWWA and WEF, New York, NY, 1368 pp

Azzurro E, Matiddi M, Fanelli E, Guidetti P, La Mesa G, Scarpato A, Axiak V (2010) Sewage pollution impact on Mediterranean rocky-reef fish assemblages. Mar Environ Res 69:390–397

Berman T, Bronk DA (2003) Dissolved organic nitrogen: a dynamic participant in aquatic ecosystems. Aquat Microb Ecol 31:279–305

Camago JA, Alonso A (2006) Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: a global assessment. Environ Int 32:831–849

Cheng J, Landesman L, Bergmann BA, Classen JJ, Howard JW, Yamamoto YT (2002) Nutrient removal from swine lagoon liquid by *Lemna minor* 8627. Am Soc Agri Eng 45:1003–1010

Dar SH, Kumawat DM (2011) Sewage treatment potential of water hyacinth (*Eichhornia crassipes*). Res J Environ Sci 5:377–385

Dokulil MT, Teubner K (2011) Eutrophication and climate change: present situation and future scenarios. In: Ansari AA, Singh Gill S, Lanza GR, Rast W (eds) Eutrophication: causes consequences and control. Springer, Dordrecht, pp 1–16

Dospekhov BA (1984) Field experimentation. Mir Publications, Moscow, 351 pp

El-Kheir WA, Ismail G, El-Nour A, Tawfik T, Hammad D (2007) Assessment of the efficiency of duckweed (*Lemna gibba*) in wastewater treatment. Int J Agricul Bio 5:681–689

El-Shafai SA, El-Gohary FA, Nasr FA, Van der Steen NP, Gijzen HJ (2007) Nutrient recovery from domestic wastewater using a UASB-duckweed ponds system. Bioresour Technol 98:798–807

Esteves FA (2011) Fundamentos derd limnologia, 3rd edn. Interciência, Rio de Janeiro, p 790

Faithfull CL, Bergström AK, Vrede T (2011) Effects of nutrient and physical lake characteristics on bacterial and phytoplankton production: a meta-analysis. Limnol Oceanogr 56:1703–1713

Fang YY, Babourina O, Rengel Z, Yang XE, Pu PM (2007) Ammonium and nitrate uptake by the floating plant *Landoltia punctata*. Ann Bot 99:365–370

Feuchtmayr H, Moran R, Hatton K, Connor L, Heyes T, Moss B, Harvey I, Atkinson D (2009) Global warming and eutrophication: effects on water chemistry and autotrophic communities in experimental hypertrophic shallow Lake Mesocosms. J Appl Ecol 46: 713–723

Fiske CH, Subba-Row Y (1925) The colorimetric determination of phosphorus. J Bio Chem 66:375–400
Fox LJ, Struik PC, Appletona BL, Rule JH (2008) Nitrogen phytoremediation by water hyacinth (*Eichhornia crassipes* (Mart.) Solms). Wat Air Soil Poll 194:199–207
Glibert PM, Heil CA, Hollander D, Revilla M, Hoare A, Alexander J, Murasko S (2004) Evidence for dissolved organic nitrogen and phosphorus uptake during a cyanobacterial bloom in Florida Bay. Mar Ecol-Prog Ser 280:73–83
Gujarathi NP, Haney BJ, Linden JC (2005) Phytoremediation potential of *Myriophyllum aquaticum* and *Pistia stratiotes* to modify antibiotic growth promoters, tetracycline, and oxytetracycline, in aqueous wastewater systems. Int J Phytoremediat 7:99–112
Gulcin I, Kirecci E, Akkemik E, Topal F, Hisar O (2010) Antioxidant, antibacterial and anticandidal activities of an aquatic plant: duckweed (*Lemna minor* L. Lemnaceae). Turk J Biol 34:175–188
Gunnarsson CC, Petersen CM (2007) Water hyacinths as a resource in agriculture and energy production: a literature review. Waste Manag 27:117–119
Jamuna S, Noorjahan CM (2009) Treatment of sewage waste water using water hyacinth *Eichhornia* sp and its reuse for fish culture. Toxicol Int 16:103–106
Kaur L, Gadgil K, Sharma S (2010) Effect of pH and lead concentration on phytoremoval of lead from lead contaminated water by *Lemna minor*. Am Eur J Agric Environ Sci 7:542–550
Khan FA, Ansari AA (2005) Eutrophication: an ecological vision. Bot Rev 71:449–482
Khan FA, Naushin F, Rehman F, Masoodi A, Irfan M, Hashmi F, Ansari AA (2014) Eutrophication: global scenario and local threat to dynamics of aquatic ecosystems. In: Ansasri AA, Gill SS (eds) Eutrophication: causes, consequences and control, vol 2. Springer, The Netherlands, pp 17–28
Konnerup D, Brix H (2010) Nitrogen nutrition of *Canna indica*: effects of ammonium versus nitrate on growth, biomass allocation, photosynthesis, nitrate reductase activity and N uptake rates. Aquat Bot 92:142–148
Lau SSS, Lane SN (2002) Biological and chemical factors influencing shallow lake eutrophication: a long-term study. Sci Tot Env 3:167–181
Liao SW, Chang WL (2004) Heavy metal phytoremediation by water hyacinth at constructed wetlands in Taiwan. J Aquat Plant Manage 42:60–68
Lindner RC (1944) Rapid analytical methods for inorganic constituents of plant tissues. Plant Physiol 19:76–89
Lu Q, He ZL, Graetz DA, Stoffella PJ, Yang X (2010) Phytoremediation to remove nutrients and improve eutrophic storm waters using water lettuce (Pistia stratiotes L.). Environ Sci Poll Res 17:84–96
Malik A (2007) Environmental challenge - opportunity: the case of water hyacinth. Environ Int 33:122–138
Mishra KK, Rai UN, Prakash O (2007) Bioconcentration and phytotoxicity of Cd in *Eichhornia crassipes*. Env Monitor Assess 130: 237–243
Moss B, Kosten S, Meerhoff M, Battarbee RW, Jeppesen E, Mazzeo N, Havens K, Lacerot G, Liu Z, De Meester L, Paerl H, Scheffer M (2011) Allied attack: climate change and eutrophication. Inl Water 1:101–105
Naeem M, Idrees M, Khan MMA, Moinuddin MA, Ansari AA (2014) Task of mineral nutrients in eutrophication. In: Ansari AA, Gill SS (eds) Eutrophication: causes, consequences and control, vol 2. Springer, The Netherlands, pp 223–237
Naphi I, Dalu J, Ndamba J, Gijzen HJ (2003) An evaluation of duckweed based pond systems an alternative option for decentralized treatment and reuse of wastewater in Zimbabwe. Water Sci Technol 48:115–122
Nouri J, Khorasani N, Lorestani B, Karami M, Hassani AH, Yousefi N (2009) Accumulation of heavy metals in soil and uptake by plant species with Phytoremediation potential. Environ Earth Sci 59:315–323
Nouri J, Lorestani B, Yousefi N, Khorasani N, Hasani AH, Seif S, Cheraghi M (2011) Phytoremediation potential of native plants grown in the vicinity of Ahangaran lead-zinc mine (Hamedan Iran). Environ Earth Sci 62:639–644
Olive I, Garcıa-Sanchez MP, Brun FG, Vergara JJ, Perez-Llorens JL (2009) Interactions of light and organic matter under contrasting resource simulated environments: the importance of clonal traits in the seagrass *Zostera noltii*. Hydrobiologia 629:199–208
Patel DK, Kanungo VK (2010) Phytoremediation potential of Duckweed (*Lemna minor* L: a tiny aquatic plant) in the removal of pollutants from domestic wastewater with special reference to nutrients. Bioscan 5:355–358
Paungfoo-Lonhienne C, Lonhienne TGA, Rentsch D, Robinson N, Christie M, Webb RI, Gamage HK, Carroll BJ, Schenk PM, Schmidt S (2008) Plants can use protein as a nitrogen source without assistance from other organisms. Proc Natl Acad Sci U S A 105:4524–4529
Rabalais NN (2002) Nitrogen in aquatic ecosystems. Ambio 31:102–112
Riffat S, Arefin MT, Mahmud R (2007) Phytoremediation of boron contaminated soils by naturally grown weeds. J Soil Nature 1:01–06
Shen DS (2002) Study on limiting factors of water eutrophication of the network of rivers. J Agricul Life Sci 28:94–97
Smith VM (2007) Using primary productivity as an index of coastal eutrophication: the unit of measurement matter. J Plant Res 29:1–6
Sooknah RD, Wilkie AC (2004) Nutrient removal by floating aquatic macrophytes cultured in anaerobically digested flushed dairy manure wastewater. Ecol Eng 22:27–42
Stone R (2011) China aims to turn tide against toxic lake pollution. Science 333:210–211
UNESCO (2009) The United Nations world water development report 3: water in a changing world. UNESCO, Par is
Uysal Y, Fadime T (2009) Effect of pH, temperature, and lead concentration on the bioremoval of lead from water using *Lemna minor*. Int J Phytoremediat 11:591–608
Xia H, Xiangjuan M (2006) Phytoremediation of ethion by water hyacinth (*Eichhornia crassipes*) from water. Bioresour Technol 97:1050–1054
Zhang X, Liu P, Yang Y, Chen W (2007) Phytoremediation of urban wastewater by model wetlands with ornamental hydrophytes. J Environ Sci China 19:902–909
Zhang Z, Rengel Z, Meney K (2009) Kinetics of ammonium, nitrate and phosphorus uptake by *Canna indica* and *Schoenoplectus validus*. Aquat Bot 91:71–74
Zhao SHJ (2000) Detection of chlorophyll pigment. In: Zou Y (ed) Manual of plant physiology experiment. Chinese Agriculture Press, Beijing, pp 72–75
Zhou W, Zhu D, Tan L, Liao S, Hu H, David H (2007) Extraction and retrieval of potassium from water hyacinth (*Eichhornia crassipes*). Bioresour Technol 98:226–231
Zimmels Y, Kirzhner F, Malkovskaja A (2006) Application of *Eichhornia crassipes* and *Pistia stratiotes* for treatment of urban sewage in Israel. J Environ Manage 81:420–428