Role of Phosphate in Eutrophication of water bodies and its Remediation

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Abstract: Phosphate is an essential, non-renewable and limiting nutrient. Phosphate reaches the aquatic system by point and non-point sources from terrestrial ecosystem. Phosphate in excess induces serious ecological consequences in aquatic ecosystems leading to eutrophication. Eutrophication enhances algal growth with the production of toxins harmful to aquatic and other living forms. In order to eradicate eutrophication, discharge limits for phosphate in wastewaters have been set forth globally. Phosphate removal from point sources can be controlled by source- separation, diversion, improvised drainage systems and treatment of wastewater by physical, chemical and biological methods. The removal of phosphate from non-point sources can be addressed by building buffer zones, riparian belts, and constructed wetlands. The methods such as filtration, adsorption, precipitation, growing macrophytes and floating bed systems are adopted to remove phosphate from water column in aquatic system whereas phosphate leaching from sediment is arrested by sediment capping and sealing.

Keywords: phosphate, eutrophication, source-separation, buffer zones, riparian belts, floating beds.

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1 Introduction

Phosphorus is an essential nutrient for all living beings and plays a major role in the cellular metabolic activities (Kornberg et al. 1999). Although phosphate is a major nutrient and finds wider application in many industrial and agricultural sectors, it is considered as a potent contaminant of aquatic system. The elimination of phosphate through point and non-point sources increases the riverine load of phosphorus resulting in eutrophication, hypoxia and water quality depletion (Filippelli 2008). Phosphate in the range of 0.1-5.6 μg/L could trigger eutrophication, limiting the primary productivity of aquatic ecosystem (Bowman et al. 2007). About 30-40% of the lakes and reservoirs have been affected by eutrophication globally (UNEP 2005). Most of the inland water bodies in India are degraded due to encroachments, eutrophication, and silt (CPCB 2016). Eutrophication in aquatic system can be controlled by restricting the load of one of the key nutrient elements, either nitrate or phosphate, which acts as the limiting factor for algal growth in the aquatic ecosystem (Smith et al. 1999).

2 Phosphorus as a nutritional element

Phosphorus is a natural element present in the rocks, soils, and organic material. Phosphorus is an essential nutrient for all living beings. The different forms of organic phosphorus in biological sources are orthophosphates (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$), organic phosphate (nucleic acids, phospholipids, inositol phosphates, phosphoamides, phosphoproteins, sugar phosphates, amino phosphoric acids, organic condensed phosphates) and inorganic phosphates (polyphosphates) (Majed et al. 2012). They are essential for the cellular functions such as phosphate and energy storage, sequestration and storage of cations, pH buffering, formation of membrane channels for active biomolecule uptake, cell envelope formation and function, gene activity control, regulation of enzyme activities (Kornberg et al. 1999), stress response (Alcantara et al. 2014), survival and stationary phase adaptation (Rao et al. 2009).

3 World Phosphate reserves

Phosphate rock exists both in sedimentary (70-80%) and igneous rock deposits (10-20%) across the world. World phosphate rock production capacity is expected to increase by 2% per year by 2020. Major producers of global phosphate rock (75%) are China (81 mmt), US (28.1 mmt), Morocco (28 mmt), and Russia (11.2 mmt) (Heffer & Prudhomme, 2015). World consumption of P2O5 in all the sectors is expected to increase from 44.5 million tonnes in 2016 to 48.9 million tonnes by 2020 (Jasinki 2017). Majority of the mined phosphate rock (90%) is used for food

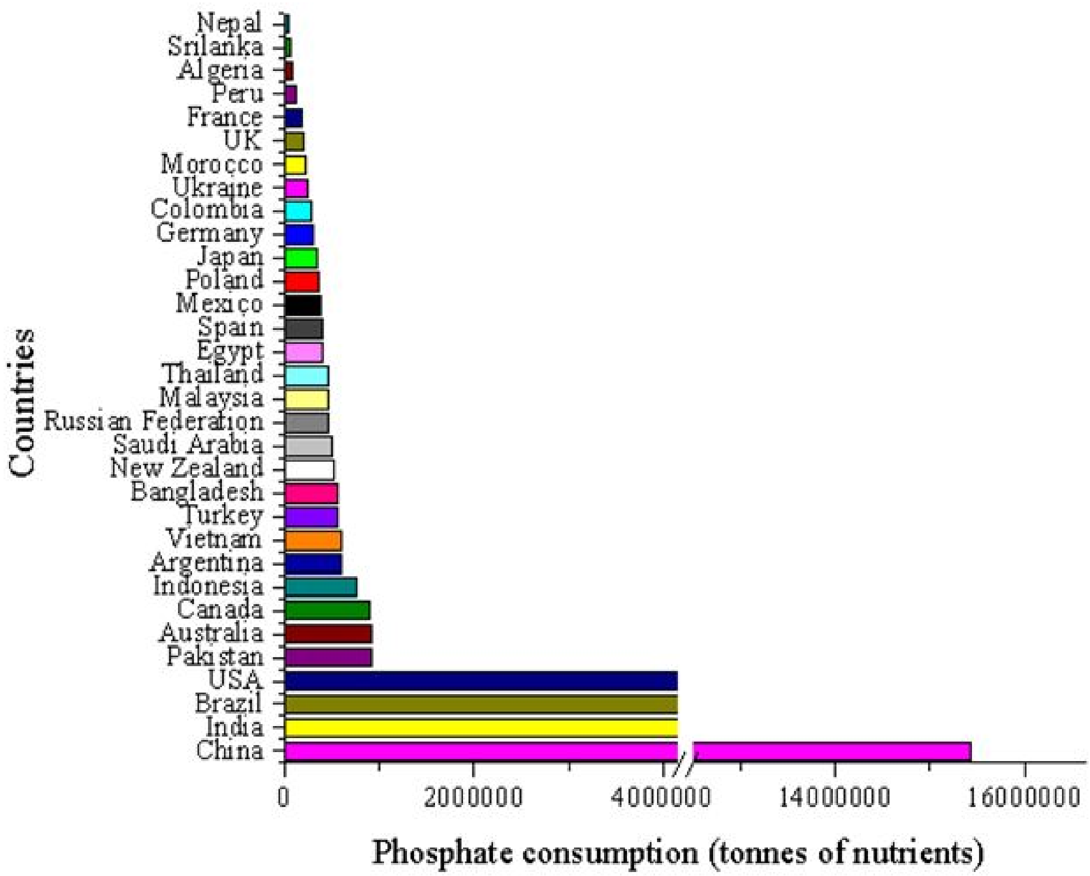

Figure 1: Global phosphate consumption

production as fertilizer (approx. 82%) and feed additives (approx. 7%) and only the residual fraction (9-10%) is used for non-food related industrial purposes (Schroder et al. 2010). China and India are the largest consumers of phosphorus fertilizers demanding 34% and 19% of global consumption (Fig. 1). An increase in fertilizer demand by 1.7% per annum from 2012/13 to 2019/20 is expected with a moderate increase in phosphate demand by 1.8% per annum (Heffer & Prudhomme, 2015).

4 Phosphate weathering from rocks

Earths crust contains about 1200 mg P/kg, a majority of which are present in rocks and the remaining in soil ranging from 200 to 800 mg P/kg (Tiessen 2008). Phosphate exists in the form of apatite (fluorapatite, hydroxyapatite and chlorapatite) in rocks. These are less soluble but weathering, a natural process mediated by physical and chemical agents generates soluble phosphorus (Smil 2000). Natural weathering releases 0.05-1.0 kg P/ha/year by direct means and 5.0 kg/ha/year by less direct means (Newman 1995). An estimate of 20 Mt P/year (Ruttenberg 2003) and 13 Mt of P/year (Carpenter & Bernett 2011) is weathered from rocks to the soil. The phosphorus rich deposits of Eocene volcanic rock have caused the Black Lake (soluble rock phosphate (SRP) ¿ 250 μg P/ L) in the interior of British Columbia to become eutrophic without direct human influence (Murphy et al. 1983). Save River which is a source of drinking water in Zimbabwe has been contaminated by the soluble phosphate from igneous rocks (apatite and calcite) at Dorowa (Meck et al. 2010). Phosphate mining waste rocks dumped in the Xiangxi river bay, China releases phosphorus (2.6 mg/L) when the pH changes from weak alkalinity and neutral to acidic conditions (Jiang et al. 2016).

5 Phosphate weathering and leaching from soil

In soil, phosphorus occurs both in organic and inorganic forms. The phosphorus source in soil is apatite minerals and weathered by reaction with dissolved carbon dioxide as follows (Filippelli 2002).

$$Ca_5(PO_4)_3OH + 4CO_2 + 3H_2O \longrightarrow 5Ca^{2+} + 3HPO_4^{2-} + 4HCO_3^{4-}$$

The total phosphorus in Indian soil varies from 130-1310 ppm (Raychaudhuri & Dattur 1964), and 165-1377 ppm (Dhir 1956) with inorganic and organic phosphorus contributing 54-84% and 16-46% of total phosphate. Since the Indian soil has low to medium phosphate fertility (Table 1), phosphate fertilization is practiced to increase the crop yield (Tomar 2000). Several factors such as soil type, phosphorus content, dosage of phosphate fertilization, plant uptake, exchange capacity, water logging, rainfall and runoff determine leaching of phosphate from soil to aquatic system (Rashmi et al. 2016).

Table 1: Total phosphate in Indian soils (Kanwar & Grewal 1990)

States	Soil type	Total P (ppm)	States	Soil type	Total P (ppm)
Assam	Acidic soil	175-1220	Rajasthan	Desert and plains	479-812
Bengal	Acidic soil	131-1120	Tamil Nadu	Alluvial soil	276-628
Bihar	Alluvial soil	175-436		Laterite soil	183-1304
Uttar Pradesh	Alluvial soil	100-760		Black soil	311-494
Karnataka	Black soil	61-982		Red soil	152-640
Shimla	Acidic hill soil	850-1800			

6 Phosphate contamination from agricultural runoff

Agriculture is the principal livelihood and the largest economic sector that contributes to about 22% of GDP in India. A net loss of phosphorus from the worlds cropland is estimated at about 10.5 mmt P/year equivalent to one half of phosphorus extracted each year (Liu et al. 2008). The highest phosphorus loss is found in agriculturally intensive regions and the diffuse loss is estimated to be 1 kg/ha in Europe (EEA report 2005). Of the total loading of phosphorus to Danube river, 44% is from agricultural activities (Negulescu 2003). The total loss of phosphorus from agricultural field runoff varied from 0.689 to 27.291 kg/ ha (Lal & Mishra 2015). The chemical fertilizer residues in borewell and channel water samples near certain agricultural fields at Mysore district of Karnataka, India showed diammonium phosphate (DAP) in the range of 4.31 to 9.59 ppm (Divya & Belagali 2012).

7 Phosphate contamination from atmospheric deposition

The major sources of atmospheric phosphorus are from the volcanic eruption, agricultural and mining activities, dust aerosols, fuel combustion, sewage sludge and compost heaps (Boehme et al. 2011). The entry of phosphorus to the lake ecosystem occur by two ways (i) rain or snowfall, known as wet deposition and (ii) gaseous and particulate-wind transported particles, or dry deposition (Anderson & Downing 2006; Zhai et al. 2009). The total annual transfer of phosphorus from the atmosphere is estimated to be 3.7 Tg a^{-1}, of which about 85% gets deposited on land and freshwater (Tipping et al. 2014). The atmospheric input of phosphorus to Lake Udaisagar, India was 0.48-1.65 Kg/ha through dry deposition and 1.10-3.80 Kg/ha by wet deposition. Similarly Baghdara lake, India received atmospheric phosphate inputs of 0.8-1.86 Kg/ha by dry deposition and 1.60-4.10 Kg/ha by wet deposition (Verma & Pandey 2016). The atmospheric deposition of phosphate in the river Ganga, India increased 1.5-2.0 fold from 2007 to 2011 ranging from 0.3-3.3 Kg ha^{-1} y^{-1}, reflecting a 1.5-fold increase in the riverine dissolved reactive phosphorus (DRP) (Pandey et al. 2013). Atmospheric P deposition has led to 1.5-fold increase in nutrients (NO_3^-, NH_4^+, PO_4^{-3}) from 1999 to 2008 in six freshwater lakes namely, Baghdara, Bari, Fatehsagar, Govardhansagar, Pichhola and Udaisagar which increases primary productivity in the lake thereby deteriorating the water quality and shifting carbon balance of the ecosystem in the long run (Pandey & Pandey 2014).

8 Phosphate contamination from sewage

The nutrient discharge from municipal wastewater treatment plants was 75% due to the population density and anthropogenic activities and the inputs from industrial sources was 17%. The five states namely Maharashtra, Tamil Nadu, Uttar Pradesh, Delhi, and Gujarat accounts for 50% of the total sewage generated. The treatment capacity (67%) of the total sewage generated in the country exists in the states of Maharashtra, Gujarat, Delhi, and Uttar Pradesh. The direction under Water (Prevention and control of Pollution) Act, 1974 clearly defines the treatment and utilization of sewage for controlling pollution in the receiving water bodies. The inland water bodies in India covers a total land area of about 1,00,000 ha. The long-term assessment of water quality data revealed that 275 rivers out of 445 rivers are polluted (CPCB 2016). Indian lakes such as Chilika, Loktak, and Keoladeo are put on Montreux record of lakes which needs immediate remedial measures to reduce its high degree of pollution and ecological deterioration due to eutrophication, non-dredging and silt. The water quality monitoring programme such as Global Environmental Monitoring System (GEMS), Monitoring of Indian National Aquatic Resources System (MINRAS), Yamuna Action Plan (YAP) and Ganga Action Plan (GAP) comprises monitoring stations of 2500 covering 28 states and 6 union territories across the country. It is estimated that 0.6 million tonnes of nitrogen and 0.1 million tonnes of phosphorus reach the east and west coastal waters of the country through channels (Jayatilake 2013).

9 Phosphate contamination from industrial effluents

India has 32 major fertilizer complexes with the production capacity of 53,80,000 and 1, 45,09,000 tonnes of nitrogenous and phosphate fertilizers (Thakkar 2013). A number of plants (14) with installation capacity for 5.88 lakh tonnes of nitrogenous and 3.22 lakh tonnes of phosphatic fertilizers are located in Tamil Nadu, in which 5.6 lakh tonnes nitrogenous fertilizers and 3.31 lakh tonnes of phosphatic fertilizers are manufactured (Prabakaran 2003). A phosphate fertilizer plant with 100 tonnes capacity discharges 3,000 to 6,000 m^3 effluent/d. The phosphate released from different processing units such as gypsum filtration unit, cooling water, boiler blow down waste, condenser waste of fertilizer industry ranges from 10-30 mg/L, 10-50 mg/L, 5-50 mg/L, and 400-2500 mg/L respectively (Wang et al, 2006). In laundry and detergent industries, approximately 1.0-1.7 million tonnes/yr of phosphate are used in detergents worldwide. The annual consumption of phosphate-containing laundry detergents in India is 2.88 million tonnes and the total outflow of phosphate is estimated to be 146 thousand tonnes per year (Kundu et al. 2015). The total inorganic phosphate was found to be 2,520 mg P/kg in dairy manure, 24,250 mg P/kg in poultry manure and 30,127 mg P/kg in swine manure (Sharpley and Moyer 2000). The total phosphate in cattle-manure compost ranged from 12.1 to 18.4 g/kg, and poultry manure compost ranged from 17.7-19.7 g/kg (Takahashi 2013). The dissolved inorganic phosphorus leaching from dairy manure (71 mg/L), poultry manure (75 mg/L), swine slurry (74 mg/ L), poultry litter (57 mg/L), dairy compost (42 mg/L), and poultry compost (34 mg/L) were recorded during simulated rainfall (Sharpley & Moyer 2000). In fish farming, 69-86% of dietary phosphate is excreted (Lazzari & Badisserotto 2008). Meat production in India is estimated to be 6.3 million tonnes accounting for about 3% of the total meat production globally (220 million tonnes). A slaughterhouse generated 1,210 m^3 to 2,059 m3 raw wastewater containing 78.5-89% of TP in the form of orthophosphate (Johns et al. 1995).

10 Eutrophication in aquatic ecosystem

The point and non-point sources of phosphate contamination increase the riverine load of phosphorus resulting in eutrophication (Filippelli 2008). Eutrophication means the enrichment of nutrients in water leading to an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and the quality of the water concerned (OSPAR 2003). The aquatic ecosystem is classified as (1) Oligotrophic (water with poor nutrient status and productivity); (2) mesotrophic (water with moderate nutrient status and productivity) and (3) Eutrophic (water with rich nutrient status and high productivity) based on the nutrient status and productivity (Naeem et al. 2014). The trophic status of the water body is determined based on their nutrient concentration and primary productivity (Table 2). Algae compose its bioplasm by sunlight and inorganic substances through photosynthesis and the process of eutrophication is described as follows (Yang et al. 2008).

$$106\,CO_2 + 16\,NO_3^- + HPO_4^{2-} + 122\,H_2O + 18\,H^+ \xrightarrow{\text{Energy + Microelement}} C_{106}H_{263}O_{110}N_{16}P + 138\,O_2 \quad \text{(bioplasm of algae)}$$

Table 2: Critical values for N and P in eutrophicated water

Eutrophic status	TP (µg/L)	TN (µg/L)	Primary productivity (mg C/m²/day)
Oligotrophic water	5-10	250-600	5-300
Mesotrophic water	10-30	500-600	300-1000
Eutrophic water	30-100	1000-2000	>1000
Hypereutrophic water	>100	>2000	>1000

(Source: Richardson et al. 2007)

Eutrophication disturbs the intrinsic equilibrium of aquatic ecosystem with the release of algal and cyanobacterial toxins, and alteration in the existing aquatic biodiversity (Roy et al. 2013). The physical changes such as decline in dissolved oxygen leading to anoxia and release of nutrients from sediments, chemical changes such as increase in pH due to consumption of CO2 for photosynthesis, and the biological changes such as modification in biological community occur due to eutrophication (Beklioglu 1999). The algal toxins, and the microcystins are considered to be potent hepatotoxin (Codd 1995; Dawson 1998) and tumor promoter (Matsushima et al. 1992). The outbreak of blue-green algal bloom in Taihu Lake created Wuxi water crisis. Most of the Indian lakes have become eutrophic due to the discharge of untreated wastewater and input of nutrients by point and non-point discharges (Table 3).

11 Consequences of Eutrophication

Eutrophication disturbs the intrinsic equilibrium of aquatic ecosystem with the release of algal and cyanobacterial toxins, increase of planktivorous fish population and decrease in economically important fish populations such as percid, clupeid and salmonids (Roy et al, 2013). Cultural eutrophication leads to the reduction in seagrass (Zostera marina) population due to direct nitrate inhibition, light limitation and unfavourable biogeochemical alterations. Bioaccumulation of toxin in sea mammals leads to hepatotoxic shellfish poisoning (HSP) in human upon consumption (Miller et al, 2010). The algal blooms contain algae such as Microcystis which releases microcystins. Microcystins act as a tumour promoter (Matushima et al. 1992) and potent hepatotoxin (Codd 1995; Dawson 1998).

Table 3 List of eutrophicated lakes in India

S.No.	Lake/ Reservoir/ River	City/ District/ State	Area/ storage capacity	Depth	TN/ Nitrate	TP	Phytoplanktons/ Trophic status	Period of Analysis	Reference
1.	Kodaikanal Lake	Tamil Nadu	21.45 km^2	11.5 m	1.05 ± 0.17 to 2.14 ± 0.29	0.41 ± 0.04 to 0.82 ± 0.03	*Navicula cuspidate Microcystis aeruginosa*	Oct 2008 – Sep 2009	Singh and Balasingh 2009.
2.	Ramsagar reservoir	Madhya Pradesh	140.097 ha		0.011- .033	0.013-0.054	Mesotrophic	2003-2005	Garg et al. 2009.
3.	Anchar Lake	Jammu and Kashmir		0.71-1.73 m	0.13 – 0.32	0.28 - 0.51	Eutrophic	2010-11	Ahangar et al. 2012.
4.	Pili Reservoir	Uttar Pradesh	162 km^2	18.29 m	0.04- 0.58	0.13- 0.19	Eutrophic	2013	Nagma and Khan 2015.
5.	Morna Lake	Madhya Pradesh			0.023	0.038	Cyanophyceae, Bacillariophyceae	2009	Abdar 2013.
6.	Kankaria lake	Gujarat	251709 cm^2	16-17 ft	1.26- 3.28	0.12- 0.56	*Cylinderospermum sp. Microcystis sp.*	Mar 2009-Feb 2010.	Verma et al. 2011.
7.	Raipur reservoir	Madhya Pradesh			0.623 ± 0.04	0.086 ± 0.05	Eutrophic	2009-2011	Saxena and Saksena 2012.
8.	Morna reservoir	Sangli district, Maharashtra	85.5 km^2		0.011-0.034	0.022-0.055	Mesotrophic	2007-2009	Abdar 2013.
9.	Suchendrum pond	Kanyakumari Tamil Nadu			0.08-1.34	0.28-0.98	Eutrophic	2010	Balasingh and Vincy 2015
					0.31-1.64	0.32-0.88		2011	

Table 3 List of eutrophicated lakes in India (Contd..)

S.No.	Lake/ Reservoir/ River	City/ District/ State	Area/ storage capacity	Depth	TN/ Nitrate	TP	Phytoplanktons/ Trophic status	Period of Analysis	Reference
10.	Ooty Lake		23 ha	12m	3.82-16	0.02- 0.04			
11.	Kodaikanal Lake		26.3 ha	11.50m	1.26-16.87	0.005- 0.59			
12.	Yercaud Lake		11.5 ha	4m	2.8- 5.77	0.005- 0.59			
13.	Pulicat Lake		250-450 km^2	1-10m	11.56- 29.7	0.11- 2.83			
14.	Poondi Lake	Tamil Nadu	91 million cubic meter		10.15- 41.1	0.04- 2.89	Eutrophic	2012-2015	Rajamanickam and Nagan 2016.
15.	Redhills Lake		93 million m^3		13.3- 23.2	0.05-3.06			
16.	Veeranam Lake		41.23 million m^3		3.2 - 10.56	0.005- 0.06			
17.	Porur Lake		1.3 million m^3		7.34- 23.2	0.03- 2.1			
18.	Harsi reservoir	Gwalior, MP	777.5 m^2	29-26 m	0.027-0.222	0.004-0.032		2011	Pawaiya et al. 2014.
19.	Porur Lake	Chennai, TN			0.08	1.1			
20.	Husain Sagar Lake	Hyderabad, Andhra Pradesh			0.05	3.6	Eutrophic	2011	Chandra et al. 2012.
21.	Vihar Lake	Mumbai, Maharashtra	5.7sq. km.	5 m	0.04	1.25			

sTable 3 List of eutrophicated lakes in India (Contd..)

S.No.	Lake/ Reservoir/ River	City/ District/ State	Area	Depth	TN/ Nitrate	TP	Phytoplanktons/ Trophic status	Period of Analysis	Reference
22.	Tighra reservoir	Gwalior, Madhya Pradesh			0.029	0.007	Oligo-mesotrophic	2007-2008	Uchchariya and Saksena 2012.
					0.035	0.01		2008-2009	
23.	Savitri reservoir	Raigad district, Maharashtra			0.058-0.315	0.011- 0.04		2012-2013	Lianthuamluaia et al. 2013.
24.	Kalamba lake	Kolhapur city, Maharashtra			1.21 ± 0.08	0.1 ± 0.06	Eutrophic	2011-2012	Jadhav et al., 2013
25.	Rankala Lake				3.1 ± 0.08	1.96± 0.10			
26.	Kotitirth Lake				4.0 ± 0.56	1.64± 0.07			
27.	Rajaram Lake				1.77 ± 0.09	1.57± 0.11			
28.	Shivaji University (SU) Lake 1				0.71 ± 0.11	1.35± 0.32			
29.	SU - Lake 2				0.84 ± 0.23	1.78± 0.50			
30.	Deliya lake	Mehsana district, Gujarat	19 ha		-	0.019-0.193	Eutrophic	2011	Joshi and Patel 2012.

12 Treatment technologies for phosphate removal at point sources

Phosphate removal from point sources is essential before discharge of wastewaters into aquatic systems. The treatment option for phosphate removal includes (1) chemical (precipitation, adsorption), (2) physical (filtration for particulate phosphorus, membrane technologies) and (3) biological which include assimilation by plants (rooted or floating plants), algae (attached or planktonic), cyanobacteria, and microbe (enhanced biological phosphorus removal (EBPR), biological nutrient removal (BNR) methods (Strom 2006) (Table 4). Metal salts such as alum, sodium, aluminate, ferric chloride, ferric sulfate, lime etc. are used for removal of phosphate by flocculation. Many factors such as influent phosphorus level, wastewater suspended solids, alkalinity, chemical costs, handling facility, disposable methods, and compatibility with other treatment operations affect chemical method of phosphate removal. More reliable, environmental friendly, economically feasible and easily operated method for phosphate removal is Enhanced biological Phosphate removal process (EBPR). The other process include phostrip where the phosphate rich wastewater from anaerobic zone is treated with magnesium/ potassium salt for phosphate and ammonia removal as struvite. Biological Nutrient Removal (BNR) systems include anoxic zone after anaerobic-aerobic zone for the removal of nitrate including nitrification-denitrification in its process along with phosphate removal.

Table 4: Effect of various treatment operations and processes on phosphorus removal

Treatment operation/ process	**Removal of phosphorus entering system (%)**
Conventional treatment	
Primary	10-20
Activated-sludge	10-25
Trickling filter	8-12
Rotating biological contactors	8-12
Biological phosphorus removal	70-90
Combined biological nitrogen and phosphorus removal	70-90
Chemical removal with lime and metal salts	70-90
Physical removal	
Filtration	20-50
Reverse osmosis	90-100
Carbon adsorption	10-30

(Tertiary treatment of domestic wastewater, Dr. Alaadin A. Bukhari, Centre for Environment and Water research institute, KFUPM)

13 Mitigation of phosphate contamination by non-point sources

The studies on different types of soils for on agronomic and environmental basis such as soil phosphate sorption and desorption, phosphate bioavailability and leaching indicates high risk soils which can be remediated by effective management practices (Sharpley, 1995). Accelerated eutrophication of surface waters can be controlled by effective management systems such as identification of soil phosphate levels, watershed management and remedial strategies, runoff and erosion control, P-source management based on eutrophic rather than agronomic consideration, regular soil and aquatic phosphate tests, and landowner options to utilize P efficiently (Sharpley et al, 1994). Agricultural best management practices such as conservation tillage, contour farming, strip cropping, buffer zones, cover crops and conservation crop rotations, nutrient management, manure storage facilities, integrated pest management, precision farming, terraces, vegetated waterways, and diversions, sediment detention structures, constructed wetlands, stream fencing and off-stream water supplies, rotational grazing help in the control of nonpoint source phosphate pollution (Mostaghimi et al, 2000). The reduction of pollution by riparian zones, buffer strips, conservation tillage, terracing, contour tillage, cover crops, retention ponds, and vegetated constructed wetlands is under practice (Carpenter et al, 1998).

The management practices such as input management of nutrient application, controlling and trapping nutrient run-off at the edge of the field and in the primary aquatic system has been implemented and practised in the Missippi river basin as a part of improving water quality in the Mississipi river basin (Kroger et al, 2012). Gulf hypoxia action plan for reducing, mitigating and controlling hypoxia in the Northern Gulf of Mexico and the GOMA Governors Action Plan II for healthy and resilient coasts for development and implementation of nutrient reduction to Gulf of Mexico led to 45% reduction of nutrient load in the river basin. Agricultural drainage ditches reduced 43.92 $\pm$3.12% influent phosphates to receiving water bodies and hence can be adopted for mitigating P from runoffs and stromflows (Kroger et al, 2008). Constructed wetlands have been successful in treating agricultural runoffs by being vegetated with aquatic plants able to assimilate and filter nutrients. Menon and Holland, 2013 removed 77% phosphate by vegetating constructed wetland with either monoculture or mixed culture of J. effuses and C.lurida. Apart from plant uptake other actions such as surface adsorption on soil, precipitation, and microbial immobilization also plays a major role in removing P in constructed wetlands (Vymazal 2007). Agricultural best management practices (BMPs) such as tillage management, wetlands, winter rice field management, subsurface drainage, and vegetated drainage ditches had nutrient reductions from 15% to 100% in Lower Mississippi Alluvial Valley (LMAV) (Kroger et al, 2008), 78-91% P removal in Iowa (Lee et al, 2003), 78-100% in Illinois (Schoonover et al, 2005), 27 97% in Scandinavia (Uusi-Kamppa et al, 2000) and 56-67% in Georgia (Lowrance and Sheridan, 2005).

14 Phosphate mitigation in aquatic ecosystem

When the aquatic ecosystem gets stratified and hypolimnion becomes anoxic, nutrients (dissolved reactive phosphate and ammoniacal-nitrogen) diffuse into the water column (Burger et al, 2007). Phosphate release from sediments can be controlled y (i) physical approaches such as artificial destratification, hypolimnetic aeration, enhanced lake flushing, and dredging/discing and (ii) geochemical approaches such as application of alum and iron as flocculation agents, and other products as capping materials that may be physical (eg. Sand, gravel, clay) or active barrier (chemical or biochemical materials) (Hickey and Gibbs, 2009). The waste products such as red ochre and black ochre, gypsum, sander dust, mag dust, vermiculite, and lanthanum bentonite product were used for phosphate sorption studies of lake sediment in UK (Spears et al, 2013). The biological removal of phosphate using planted float technology has gained increasing attention as an alternative in-situ treatment for nutrient removal in natural (Zhu et al, 2011) and seminatural water systems. The polyethylene foam made floating bed vegetated with Canna indica, Accords calamus, Cyperus alternifolius, and Vetiveria zizanioides removed COD, TN, TP and Chla in the range of 15-3%, 25-4%, 16-42%, 29-88% at Three Gorges Reservoir region of China (Bu and Xu, 2013).

15 Conclusion

Phosphate though an essential element, its excess availability in aquatic ecosystem raises serious concerns over ecological degradation and hence requires a check. The legislative action plans and directives are set forth to limit phosphate entry into aquatic ecosystem and cleanup of degraded ecosystem worldwide. The eutrophication in aquatic ecosystems can be controlled by restricting the load of either nitrate or phosphate which acts as the limiting factor for plant growth. The point source phosphate contamination can be controlled by source separation, diversion, improvised drainage systems and treatment options. The non-point source pollution can be controlled by effective management system viz. identification of soil phosphate levels, phosphate source management based on eutrophic rather than agronomic consideration, regular soil and aquatic phosphate tests, landowner options to utilize phosphate efficiently, runoff and erosion control, watershed management and remedial strategies.

References

1. Abdar, MR 2013, Assessment of water quality and major threats of Morna Reservoir in Western ghats (M.S) India, Pollution research, 3(2), 35-41.

2. Ahangar, IA, Saksena, DN & Mir, AF 2012, Limnological studies, assessment of nutrients, trophic status and major threats to Anchar Lake, Kashmir, International Journal of Science and knowledge, 1(1), 3-16.

3. Alcantara, C, Blasco, A, Zuniga, M & Monedero, V 2014, Accumulation of polyphosphate in Lactobacillus spp. and its involvement in stress resistance, Applied Environmental Microbiology, 80(5), 1650-1659.

4. Anderson, KA & Downin, JA 2006, Dry and wet atmospheric deposition of nitrogen, phosphorus and silicon in agricultural region, Water, Air and Soil Pollution, 176, 351-374.

5. Balasingh, GSR & Vincy, W 2015, Physico-chemical features of a migratory visited pond in the freshwater environment of Kanyakumari district, Indian Journal of Fundamental and applied life sciences, 5(2), 139-145.

6. Beklioglu, M 1999, A review on the control of eutrophication in deep and shallow lakes, Turkish Journal of Zoology, 23, 327-336.

7. Boehme, J, Schulhauser, R & Bejankiwar, R 2011, Atmospheric deposition of phosphorus to freshwater lakes, Working draft for IJCs Lake Erie Ecosystem Priority (LEEP) by GLRO (Great Lakes Regional Office), 1-25.

8. Bowman, MF, Chambers, PA & Schindler, DW 2007, Constraints on benthic algal response to nutrient addition in oligotrophic mountain rivers, River research and applications, 23(8), 858-876.

9. Bu F and Xu X, 2013. Planted floating bed performance in treatment of trophic river water. Environmental Monitoring and Assessment 185(11), 9651-62.

10. Burger D, Hamilton DP, Pilditch CA, Gibbs MM, 2007. Benthic nutrient fluxes in a eutrophic, polymictic lake. Hydrobiologia 584(1), 13-25.

11. Burger D, Hamilton DP, Pilditch CA, Gibbs MM, 2007. Benthic nutrient fluxes in a eutrophic, polymictic lake. Hydrobiologia 584(1), 13-25.

12. Carpenter, SR, Caraco, NF, Correll, DL, Howarth, RW, Sharpley, AN & Smith, VH 1998, Nonpoint pollution of surface waters with phosphorus and nitrogen, Ecological applications, 8, 559-568.

13. Carpenter, RS & Bennett, EM 2011, Reconsideration of the planetary boundary for phosphorus, Environmental Research Letters 6(1), 1-12.

14. Chandra, S, Singh, A & Tomar, PK 2012, Assessment of water quality values in Porur Lake Chennai, Hussain Sagar Hyderabad, and Vihar Lake Mumbai, India, Chemical ScienceTransactions 1(3),508-515.

15. Codd, GA 1995, Cyanobacterial toxins: occurrence, properties and biological significance, Water Science and Technology 32, 149156.

16. CPCB 2016, Bulletin, vol. 1, pp. 1-26. Available from: http://www.cpcb.nic.in/upload/Latest/ 123- SUMMARY BOOK-FS.pdf.

17. Dawson, RM 1998, The toxicology of microcystin, Toxicon, vol. 36, pp. 953962.

18. Dhir, RP 1956, Phosphorus status of major Indian soils, Thesis Assoc, IARI, New Delhi.

19. Divya, J & Belagali, SL 2012, Effect of extensive use of chemical fertilizers on nitrate and phosphate enrichment in water resources of selected agricultural areas of T. Narasipura taluk, Mysore district, Karnataka, India, Proceedings of International conferences SWRDM 2012 held at Department of Environmental studies, Shivaji University, 43-47.

20. EEA, 2005, A report on Source apportionment of nitrogen and phosphorus inputs into the aquatic environment, Report no.7, 1-52.

21. Filippelli, GM 2002, The Global phosphorus cycle (Chapter 10) Phosphates Geochemical, geobiological, and materials importance, Mathew J. Kohn, Rakovan John, and John M. Hughes, Editors, Mineralogical society of America (Paul H. Ribbe, Series editor), Geochemical society (Jodi J. Rosso, Series Editor), Reviews in Mineralogy and Geochemistry, 48, 391-425.

22. Filippelli, GM 2008, The global phosphorus cycle: Past, present, and future, Elements, 4, 89-95.

23. Garg, RK, Rao, RJ & Saksena, DN 2009, Water quality and conservation management of Ramsagar reservoir, Daita, Madhya Pradesh, Journal of Environmental Biology, 30(5), 909-916.

24. Heffer, P & Prudhomme, M 2015, Fertilizer Outlook 2015-19, International fertilizer Industry association 83rd IFA annual Conference Istanbul, Turkey, 25-27 May 2015.

25. Hickey CW, and Gibbs MM, 2009. Lake sediment phosphorus release management Decision support and risk assessment framework. New Zealand Journal of Marine and Freshwater Research, 43, 819-856.

26. Jadhav, AS, Patil, VN & Raut, PD 2013, Systematic Investigation of Hydrochemical characteristics of six different lakes in and around Kolhapur city, Maharashtra, India, European Academic Research, 1(8), 2036-2050.

27. Jasinski, SM 2017, Phosphate rock, US Geological survey, Mineral Commodity Summaries, pp. 124-125, Available from: https://minerals.usgs.gov/minerals/pubs/commodity/ rock/mcs-2017-phosp.pdf.

28. Jayatilake, SMDPA, Nutrient loading and eutrophication of coastal waters of the South Asian seas a scoping study, 1-56.

29. Jiang, L, Liang, B, Xue, Q & Yin, C 2016, Characterization of phosphorus leaching from phosphate waste rock in the Xiangxi river watershed, Three Gorges reservoir, China, Chemosphere 150, 130-138.

30. Johns, M, Harrison, ML, Hutchinson, PH & Beswick, P 1995, Sources of nutrients in wastewater from integrated cattle slaughterhouses, Water Science Technology, 32(12), 53-58.

31. Joshi, HV & Patel, RS 2012, Studies on the Physico-chemical status of two lakes-Deliya lake and Malap lake, under biotic stress of Visnagar Taluka in Mehsana district, Gujarat, India, International Journal of Scientific and Research Publications, 2(9), 1-8.

32. Kornberg, A, Rao, NN & Ault-Riche, D 1999, Inorganic polyphosphate: a molecule of many functions, Annual Review of Biochemistry, 68, 89-125.

33. Kroger R, Holland MM, Moore MT, Cooper CM, 2008. Agricultural drainage ditches mitigate phosphorus loads as a function of hydrological variability. J Environ Qual.37(1): 107-13.

34. Kroger R, Czarnecki JMP, Tank J, and Christopher S, 2015.et al, 2015. Implementing innovative drainage management practices in the Mississippi River Basin to enhance nutrient reductions. Journal of the American Water Resources Association 51(4), 1020-1028.

35. Kundu, S, Vassanda, C, M, Rajendiran, S, Ajay & Subba Rao, A 2015, Phosphates from detergents and eutrophication of surface water ecosystem in India, Current Science, 108(7), 1320-1325.

36. Lal, M & Mishra, SK 2015, Characterization of Surface runoff, soil erosion, nutrient loss and their relationship for agricultural plots in India, Current World Environment, 10(2), 593-601.

37. Lazzari, R & Baldissrotto, B 2008, Nitrogen and phosphorus waste in fish farming, Bulletin of Fisheries Institute, Sao Paulo, 34(4), 591-600.

38. Lee KH, Isenhart TM, and Schiltz RC, 2003. Sediment and nutrient removal in an established multi-species riparian buffer. Journal of Soil and ater Conservation 58(1), 1-8.

39. Lianthuamluaia, Landge, AT, Purushothaman, CS, Deshmukhe, G & Ramteke, KK 2013, Assessment of seasonal variations of water quality parameters of Savitri reservoir, Poladpur, Raigad district, Maharashtra, The Bioscan, 8(4), 1337-1342.

40. Liu, Y, Villalba, G, Ayres, RU & Schroder, H 2008, Global phosphorus flows and environmental impacts from a consumption perspective, Journal of Industrial Ecology, 12(2), 229-247.

41. Lowrance R and Sheridan JM, 2005. Surface runoff water quality in a Managed Three Zone riparian buffer, Journal of Environmental quality 34(5), 1851-59.

42. Majed, N, Li, Y & Gu, AZ 2012, Advances in techniques for phosphorus analysis in biological sources, Current opinion in Biotechnology 23, 1-8.

43. Matsushima, NR, Ohta, T, Nishiwaki, S, Suganuma,M, Kohyama, K, Ishiwaka, T, Carmichael, WW & Fujiki, H 1992, Liver tumor promotion by the cyanobacterial cyclicpeptide toxin microcystin-LR, Journal of Cancer Research and Clinical Oncology, 118, 420424.

44. Meck, ML, Atlhopheng, J, Masamba, WRL & Ringrose, S 2010, Pollution implications of Save River water from weathering and dissolution of metal hosting minerals at Dorowa phosphate mine, Zimbabwe, Physics and Chemistry of the Earth, Parts A/B/C, 35(13-14), 679-685.

45. Menon R and Holland MM, 2013. Phosphorus retention in constructed wetlands vegetated with Juncus effuses, Carex lurida, and Dichanthelium acuminatum var. acuminatum, Water Air Soil Pollut 224; 1602-05.

46. Miller MA, Kudela RM, Mekebri A, Crane D, Oates SC, et al, 2010. Evidence for a novel marine harmful algal bloom cyanotoxin (microcystin) transfer from land to sea otters. PLoS one 5(9), e12576.

47. Mostaghimi S, Brannan KM, Dillaha III TA, and Bruggeman AC, 2000. Chapter 10. Best Management practices for Nonpoint source pollution control, Agricultural nonpoint source pollution watershed management and hydrology Kevin M. Brannan, Adriana C. Bruggeman, Theo A. Dillaha, and Saied Mostaghimi, Edited by Adel Shirmohammadi and William F. Ritter CRC Press 2000.

48. Murphy, TP, Hall, KJ & Yesaki, I 1983, Co-precipitation of phosphate with calcite in a naturally eutrophic lake, Limnology and Oceanography, 28(1), 56-59.

49. Naeem, M, Idrees, M, Masroor, M, Khan, A, Moinuddin & Ansari, AA 2014, Task of mineral nutrients in Eutrophication. Eutrophication: causes, consequences and control, vol. 2, edited by Abid A. Ansari and Sarvajeet Singh Gill, 223-237.

50. Nagma & Khan, MA 2015, Observations on ichthyofauna and water quality of Pili reservoir in district Bijnor of Uttar Pradesh, International journal of fisheries and aquatic studies, 2(6), 106-112.

51. Negulescu, ALC 2003, APRA Project The reduction of pollution generated by agricultural activities in Romania.

52. Newman, EI 1995, Phosphorus inputs to terrestrial ecosystems, Journal of Ecology, 83(4), 713-726.

53. OSPAR 2003, Strategies of the OSPAR Commission for the protection of the Marine Environment of the North East Atlantic (Reference number 2003-21) In: OSPAR Convention for the protection of the marine environment of the North East Atlantic: Ministerial Meeting of the OSPAR Commission Bremen: 25 June, vol. Annex 31 (Ref. B-4.2).

54. Pandey, J, Singh, AV, Singh, A & Singh, R 2013, Impacts of changing atmospheric deposition chemistry on nitrogen and phosphorus loading to Ganga river (India), Bulletin of Environmental contamination and toxicology, 91, 184-190.

55. Pandey, J & Pandey, U 2014, Atmospheric deposition of nutrients shifts carbon capture and storage trends in freshwater tropical lakes in India, Environmental control in biology, 52(4), 211-220.

56. Pawaiya, N, Sharma, DK & Khushwah, MKS 2014, Study on Physico-chemical parameters of Harsi reservoir Dabra, Gwalior district, Madhya Pradesh, International Journal for Scientific research and development, 2(8), 406-410.

57. Prabakaran, S 2003, Chapter 3 Evolution of fertilizer industry in Tamil Nadu A study, Thesis submitted for Doctor of Philosophy to University of Madras, 89-129.

58. Rajamanickam, & Nagan, S 2016, A study on water quality status of major lakes in Tamil Nadu, International Journal of Research in Environmental science, 2(2), 9-21.

59. Rao, NN, Gomez-Garcia, MR & Kornberg, A 2009, Inorganic polyphosphate: essential for growth and survival, Annual Review of Biochemistry 78, 605-647.

60. Rashmi, I, Biswas, AK, Parama, VRR, Athifa, M & Ramteke, L 2016, Soil testing indices for phosphorus leaching in selected vertisol and inceptisol of India, Proceeding of National Academy of Sciences of India, Section B Biological sciences, DOI 10.1007/s40011-016-0823-y, 1-8.

61. Raychaudhuri, SP & Datta, NP 1964, Phosphorus and potassium status of Indian soils, Indian Council of Agricultural Research, Rev. Ser. No. 36, 1-44.

62. Richardson, CJ, King, RS, Qian, SS, Vaithiyanathan, P, Qualls, RG & Stow, CA 2007, Estimating ecological thresholds for phosphorus in the Everglades, Environmental science and Technology, 41(23), 8084-8091.

63. Roy, K, Chari, MS & Gaur, SR 2013, Eutrophication in Lentic systems and its impact on Fisheries, International Journal of Research in Fisheries and aquaculture, 3(4), 170-175.

64. Ruttenberg, KC 2003, The Global Phosphorus cycle, Treatise on Geochemistry, 8, 585-643.

65. Saxena, M & Saksena, DN 2012, Water quality and trophic status of Raipur reservoir in Gwalior, Madhya Pradesh, Journal of Natural Science Research, 2(8), 82-96.

66. . Schoonover JE, Williard KWJ, Zaczek J, Mangun JC, and Carver AD, 2005. Nutrient attenuation in agricultural surface runoff by riparian buffer zones in Southern Illinois, USA. Agroforestry Systems, 64(2), 169-180.

67. Schroder, JJ, Cordell, D, Smit, AL & Rosemarin, A 2010, Sustainable use of phosphorus, report 357, Wageningen: Plant Research International BV, available from: http://ec.europa.eu/environment/natres/pdf/sustainable use phosphorus.pdf.

68. Sharpley AN, Chapra S, Wedepohi R, and Sims JT, 1994. Managing Agricultural phosphorus for protecting surface waters: Issues and options, Journal of Environmental quality 23(3), 437-451.

69. . Sharpley, AN 1995, Soil phosphorus dynamics: agronomic and environmental impacts, Ecological Engineering 5(2-3), 261-279.

70. Sharpley, AN & Moyer, B 2000, Phosphorus forms in manure and compost and their release during simulated rainfall, Journal of Environmental quality 29, 1462-1469.

71. Singh, RP & Balasingh, GSR 2011, Limnological studies of Kodaikanal Lake (Dindugal District), in special reference to phytoplankton diversity, Indian Journal of Fundamental and Applied Life sciences 1(3), 112-118.

72. Smil, V 2000, Phosphorus in the environment: Natural flows and Human Interferences, Annual Review of Energy and Environment 25, 53-88.

73. Smith, VH, Tilman, GD & Nekola, JC 1999, Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems, Environmental pollution 100, 179-196.

74. Spears BM, Meis S, Anderson A, Kellou M, 2013. Comparison of phosphate (P) removal properties of materials proposed for the control of sediment p release in UK lakes. Science o the Total Environment. 442(1), 103-110.

75. Strom, PF 2006, Technologies to remove phosphorus from wastewater, Invited presentation for water quality trading, 91st Annual Meeting, NJWEA, Atlantic City, NJ.

76. Takahashi, S 2013, Phosphorus characterization of manure composts and combined organic fertilizers by a sequential-fraction method, Journal of plant nutrition and soil science 176, 494-496.

77. Thakkar, A 2013, Analysis of air pollution parameters of fertilizer industries specially reference to G.S.F.C.Vadodara, Gujarat, International journal of Theoretical and applied sciences 5(2), 109-113.

78. . Tiessen, H 2008, Chapter 1 - Phosphorus in the global environment. The ecophysiology of Plant-phosphorus Interactions, PJ White, and JP Hammond (eds.), Springer Science Business Media BV.

79. Tipping, E, Benham, S, Boyle, JF, Crow, P, Davies, J, Fischer, U, Guyatt, H, Helliwell, R, Blake, JL, Lawlor, AJ, Monteith, DT, Rowe, EC & Toberman, H 2014, Atmospheric deposition of phosphorus to land and freshwater, Environmental Science: Processes & Impacts 16(7),1608-1617.

80. Tomar, NK 2000, Dynamics of phosphorus in soils, Journal of the Indian society of soil science 48, 640-672.

81. Uchchariya, DK & Saksena, DN 2012, Study of nutrients and trophic status of Tighra reservoir, Gwalior (Madhya Pradesh), India, Journal of Natural sciences Research 2(8), 97-110.

82. UNEP 2005, Millenium Ecosystem Assessment Synthesis Report, The United Nations Environment Programme.

83. Uusi-Kamppa J, Braserud B, Jansson H, et al, 2000. Buffer zones and constructed wetlands as filters for agricultural phosphorus. Journal of Environmental quality, 29(1), 151-158.

84. Verma, PU, Chandawat, DK & Solanki, HA 2011, Seasonal variation in Physicochemical and phytoplankton analysis of Kankaria Lake, Life sciences leaflets 19, 842-854.

85. Verma, A & Pandey, J 2016, Atmospheric deposition coupled runoff driven shifts in nutrients and trophic status of two fresh water tropical lakes of India, International Journal of Lakes and Rivers 9(1), 1-10.

86. Vymazal, J 2008, Constructed wetland for wastewater treatment: A review, Proceedings of Taal 2007: The 12th Word Lake Conference, Sengupta M and Dalwani R (Edts), 965-980.

87. Wang, LK, Hung,YT, Lo, HH & Yapijakis, C 2006, Chapter 9 - Treatment of phosphate industry wastes, Waste treatment in the process industries, Taylor and Francis group, CRC Press, 399-453.

88. Yang X, Wu X, Hao H, He Z, 2008. Mechanisms and assessment of water eutrophication. J Zhejiang Univ Sci B, 9(3), 197-209.

89. Zhai, S, Yang, L & Hu, W 2009, Observations of Atmospheric nitrogen and phosphorus deposition during the period of algal bloom formation I Northern Lake Taihu, China, Environmental Management 44, 542-551.

90. Zhu L, Li Z, and Ketola T, 2011. Biomass accumulations and nutrient uptake o plants cultivated on artificial floating beds in Chinas rural area. Ecological Engineering, 37(10), 1460-1466.