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Ecological wastewater treatment system: Management approach to solve sanitation and water problems

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Abstract

Wastewater contains various types of pollutants, such as nutrients, solids, organic carbon, metals, inorganic salts, pathogens, etc. Therefore, effective wastewater treatment is crucial for public health as well as for environmental concern. On the other hand, water management with limited water resources is a great challenge in most countries. The freshwater shortage is seriously affecting the economic and social growth of developing nations. An ecological wastewater treatment system is a concept towards ecologically and economically sounds wastewater management. Water and organic nutrients in wastewater consider as a resource and can reuse and recycle in agriculture. The study reviewed the principles and concepts of the ecological wastewater treatment system and a case study of the ecological treatment system by growing economic vegetation. A hybrid constructed wetland (CW) system was used to investigate the performance. The CW system showed high removal efficiency for TP (total phosphorus), NH4 (ammonium), and TN (total nitrogen). The removal efficiencies were 97 %, 75 %, and 64 % for TP, NH4–N, and TN, respectively. Ecological wastewater treatment system is cost-effective, and energy-saving also offers nutrients recycling, water reuse, recreation activities, and vegetation growth.

Introduction

Water is crucial and plays an important role for humans as well as other living forms. Recently freshwater pollution increase with the expansion of industrialization and economic growth lead to the deficiency of freshwater for human consumption [1]. Freshwater resources are limited, and water circulates between the spheres of the environment (lithosphere, atmosphere, hydrosphere, and biosphere) to maintain life (**Fig. 1**). Global warming led to alterations of the amplitude of the continental and global runoff by alteration of the global hydrological cycle as well as by altering temporal and spatial changes in precipitation [2]. These changes exert great effects on the ecological ecosystem and the agronomy development as well as economy, particularly in dry and semiarid regions. The main purpose of wastewater treatment is to remove the pollutant load and protection of environmental components in a manner commensurate with community health and socio-economic concerns [3].

Worldwide more than 2.4 billion people living without access to suitable hygienic amenities and are worst among rural inhabitants [4]. In most of the developing countries, over 90 % of wastewater discharge untreated and pollute water bodies and coastal areas. On the other hand, in many countries, farmers are facing shortages of water and nutrients in agriculture practices. Therefore, it is a need of time to implement sustainable and economically efficient wastewater treatment approaches, that can provide reusing and recycling of water and nutrients.

Sustainable wastewater treatment and reuse

Recently many countries facing severe water shortages and imbalance, and water imbalance in demand versus supply is because of uneven distribution of precipitation, global warming, changes in weather patterns, and an increase in water need for irrigation [5]. To overcome this issue, serious attention must be given to wastewater reclamation and reuse. A sustainable and appropriate wastewater treatment system is necessary for developing nations to overcome water and wastewater-related issues. Adopting an efficient, simple, and economical wastewater management plan is important to efficiently manage and, in some instances, the reuse of wastewater for the benefit of communities [6].

Reclaimed wastewater can be used for several alternatives including agricultural irrigation. As a wastewater treatment technology, constructed wetland qualifies as a substitute approach for water shortage areas. The constructed wetlands are "engineered structures that have been designed and built to utilize the natural processes occurring in natural wetland but in controlled manners for treatment of wastewater" [7]. Wastewater contains organic matter in the form of nitrogen and phosphorus and would serve as nutrients for plants and is valuable for agriculture purposes [8]. Wastewater treatment methods vary from conventional systems to decentralize manners. The centralized wastewater treatment system is based on treatment wastewater from a large population, and it needs a large infrastructure with a pipes network. Whereas, decentralized wastewater treatment systems used for small communities and treatment occurred near to generation point [9].

Constructed wetland: A multifunctional approach

Most of the conventional wastewater treatment technologies are not sustainable and difficult to build because of the large cost. The centralized wastewater treatment system was initially perceived as an optimal solution to control water pollution but is unsuitable and expensive to build in low-income areas. The constructed wetland is a suitable alternative compare to other systems because of cost-effective, and has almost no energy consumption [10]. A constructed wetland treatment system can provide economical, effective and aesthetically acceptable onsite wastewater treatment [11]. Another application of constructed wetland is reusing of water and nutrients by growing economic vegetation and this approach can reduce the gap between demand and supply for food and water [12].

Constructed wetland

Constructed wetlands are being used all over the world and play a significant part in wastewater treatment methods by providing different wastewater treatment, runoff treatment, sludge treatment, and floodwater retention [13-17]. Although CWs relatively a new concept for wastewater treatment,

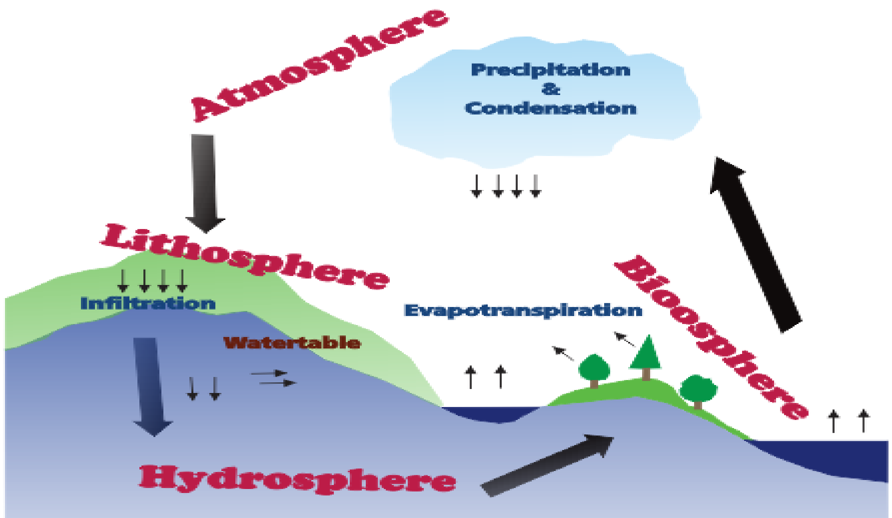

Fig. 1: Describing the movement of water between environmental components

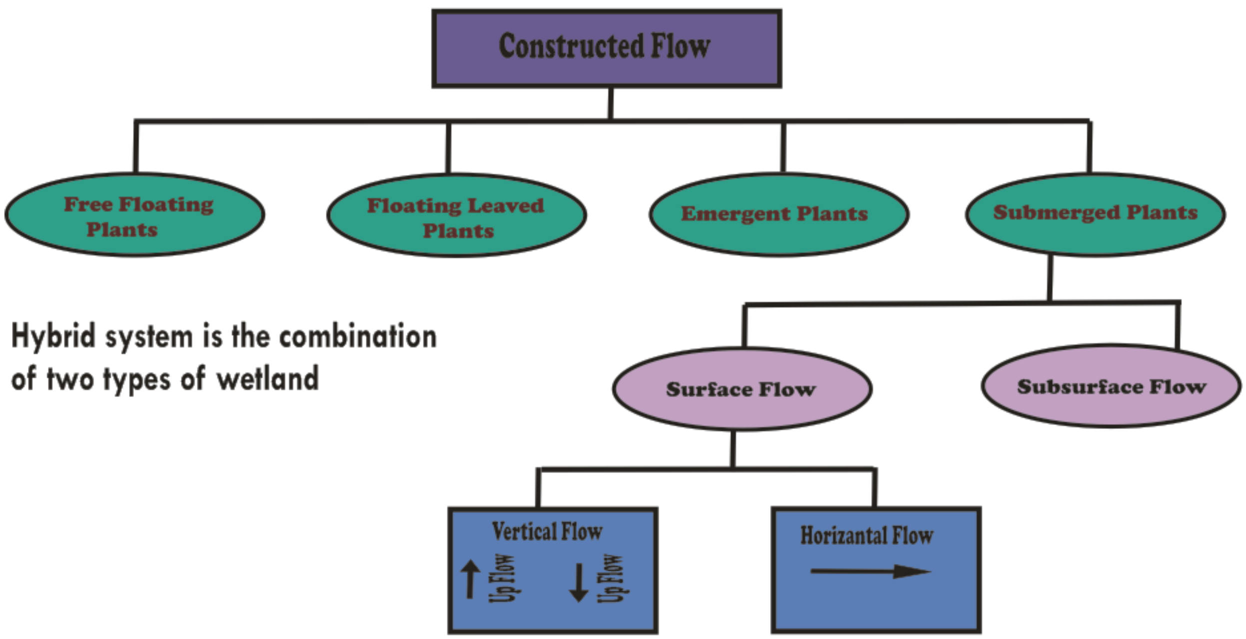

Fig. 2: Classification of Constructed Wetland

however, interest in the application of CW has become widespread [18].

Constructed wetland types

The constructed wetlands can be categorized based on hydrology (Surface flow or subsurface flow), flow path (vertical or horizontal), and vegetation (free-floating, emergent, submerged, or floating leaves) (**Fig. 2**).

Constructed Wetland Removal Mechanisms

Constructed wetlands are simple in terms of construct but biologically very complex, rely on physical, biological, and microbial, as well as the chemical process for removal of BOD, TSS, nutrients (N and P) metals, organic pollutants, and pathogens in wastewater [19]. Like any other ecosystem, all living and nonliving components in CW systems are interrelated and can increase or limit any process. The removal mechanism that takes place in CWs can be biotic (microbial or plant uptake) or abiotic (physical/chemical). The microbial communities have an important role in CWs and the mechanism used for pollutant removal depends on specific contaminants and conditions of the site (**Table 1**).

Table 1: The Mechanism occur in the constructed wetland system

Pollutants	Removal Mechanism
Nitrogen	Ammonia volatilization, Ammonification, Nitrate ammonification, Nitrification, Denitrification, plant uptake, Fixation
Phosphorus	Soil Accretion, Adsorption and Precipitation, Plant uptake, Microbial uptake
Pathogens	Filtration, Sedimentation, Absorption, Predation
Metals	Adsorption, Precipitation, Complexation, Sedimentation, Plant uptake

Materials and Methods

A hybrid constructed wetland system (CFW = constructed floating treatment wetlands and HSFCW = horizontal subsurface flow constructed wetland) was established in Southeast University, Wuxi Campus, China for the research study. Each bed of the hybrid system was concrete made with epoxy lined, measurement was 2.5 m length × 0.3 m width × 0.5 m height (**Fig. 3**). The polyethylene foam board was in CFW as floating mats by perforating holes of 2 cm for each plant, whereas the HCFW bed was packed with a 10 cm layer of large gravel in the bottom as a supporting layer, in the middle 25 cm layer of ceramsite, and on the top 10 cm of small gravel. The experiment was performed in a natural environment from August to October and real wastewaters were used. *Ipomoea aquatica forsk* (*I. aquatica*; common name water spinach) and *Zizania latifolia* (*Z. latifolia*; common name Manchurian wild rice) plant species were selected to grow in the hybrid system by keeping in mind economic value, easy availability, and aesthetic worth. The hydraulic load and hydraulic retention times were 0.2 m.d ̄1 and 1.25 d, respectively, whereas, sampling was carried out twice a week. pH and DO were measured by PH100 and DO200 probes (YSI), respectively, while, Standard methods [20] were used to analyze other parameters.

Results and Discussion

The concentration and removal efficiencies of TP, NH_4-N, and TN in the hybrid systems are shown in **Fig. 4-6**. The total removal efficiency of the CW hybrid system during the study time was 97%, 75%, and 64 % for TP, NH_4-N, and TN, respectively. The mean, minimum and maximum concentrations of nutrients in CW are shown in **Table 2**. The TP concentration in influent was between 1.2 to 3.2 mg/ L^{-1} with average value 2.33 ± 0.5 mg/ L^{-1} and after treatment, the effluent TP concentration was 0.0517 to 1.1274 mg/ L^{-1}. The removal efficiency for TP in the system reached up to 97%. The ammonium concentrations in the influent and effluent were 7.13 to 20.13 and 2.92 to 9.18 mg/ L^{-1}, respectively, with 29 – 75 % removal efficiency. Whereas the average effluent concentration of TN was 7.23 – 24.05 and removal efficiency reached up to 64 %.

In the present study, a pilot-scale hybrid constructed wetland systems were used and nutrient removal was found to be adequate and higher than that reported by previous authors [21-23]. The substrate is the primary phosphorus storage pool in CW, however, some may be discharged to the water column under less reducing conditions [24]. Meanwhile, P has been released into the CW system and making it more difficult to predict phosphorus removal.

According to [25] overall phosphorus removal was between 65 to 240 percent, and effluent phosphorus concentration was higher than influent. The lower removal of phosphorus efficiencies in the constructed wetland is generally credited to the substrate [26, 27]. An identical trend in the removal efficiencies of NH_4 and TN was observed. NH_4 removal was more noticeable in initial samples but restrained in the latter samples. The same observations were found out in TN removal and this is because of low DO (dissolved oxygen) concentration as shedding and shelter of plants reduce the oxygen diffusion in the water column [28]. In constructed wetland DO influence the biochemical processes which determine the fate of NH_4 and TN, furthermore, biotransformation of nutrients and other substances can be affected by oxidative and reductive conditions in the system. Oxygen in the CWs system can be transferred from influent, directly dissolve from the atmosphere, or through plant tissues [29].

The nitrogen removal processes in constructed wetlands are nitrification, denitrification, volatilization, sorption, desorption, fragmentation, and plant uptakes to become part of biomass [30]. Nitrogen to biomass is one of the very important processes that occur in the CWs system [31]. However, the physical and chemical properties of the substrate in the CWs system determine the living communities of microbes and other organisms in addition to absorbing nutrients and contaminants

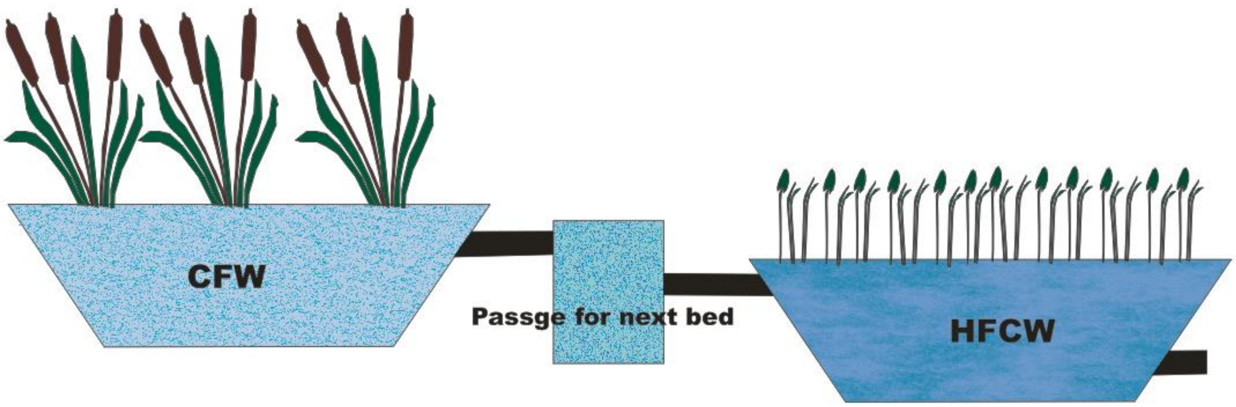

Fig. 3: Schematic diagram showing the hybrid constructed wetland; CFW is constructed floating treatment wetlands and HFCW is horizontal flow constructed wetlands.

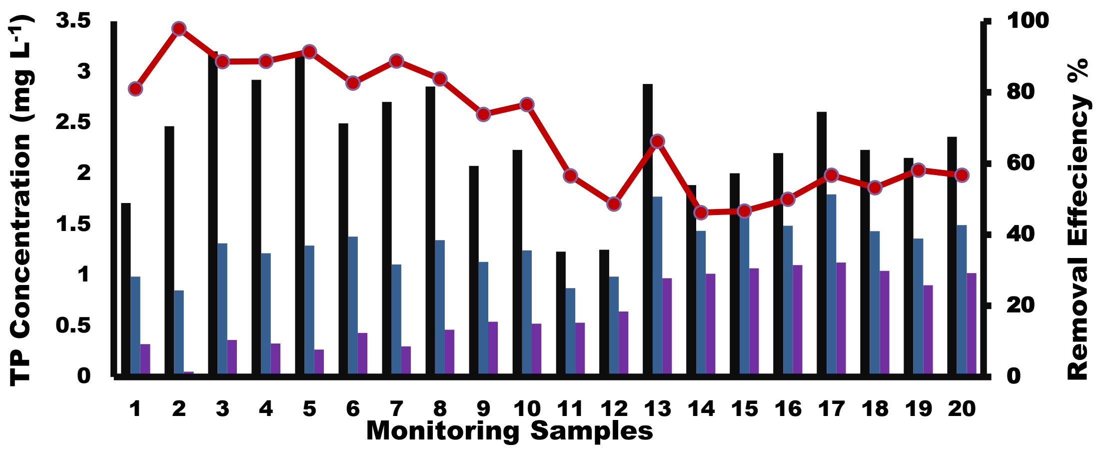

Fig. 4: Variation in TP concentration and removal efficiency during minoring period in CW

Influent | CFW Effluent
Effluent | Removal Efficiency

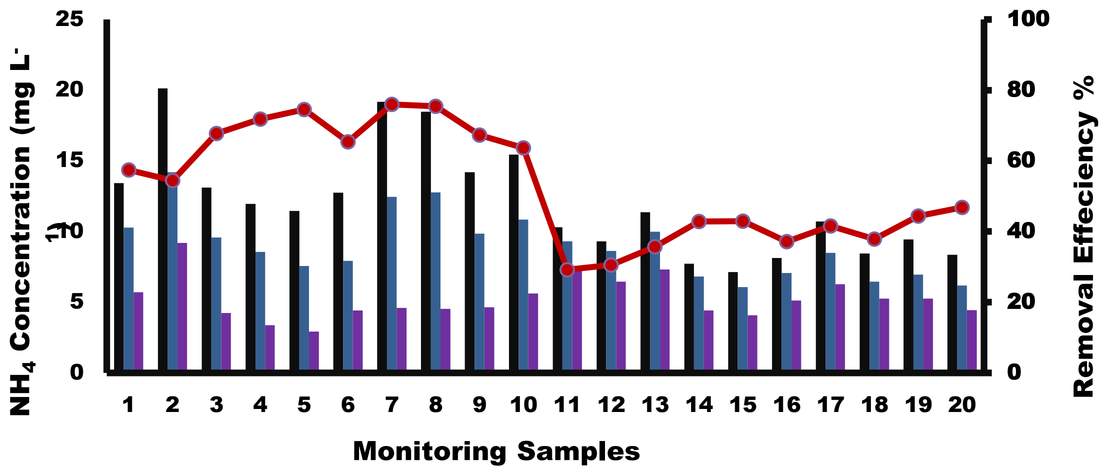

Fig.5: Variation in NH_4 concentration and removal efficiency during minoring period in CW

Influent | CFW Effluent
Effluent | Removal Efficiency

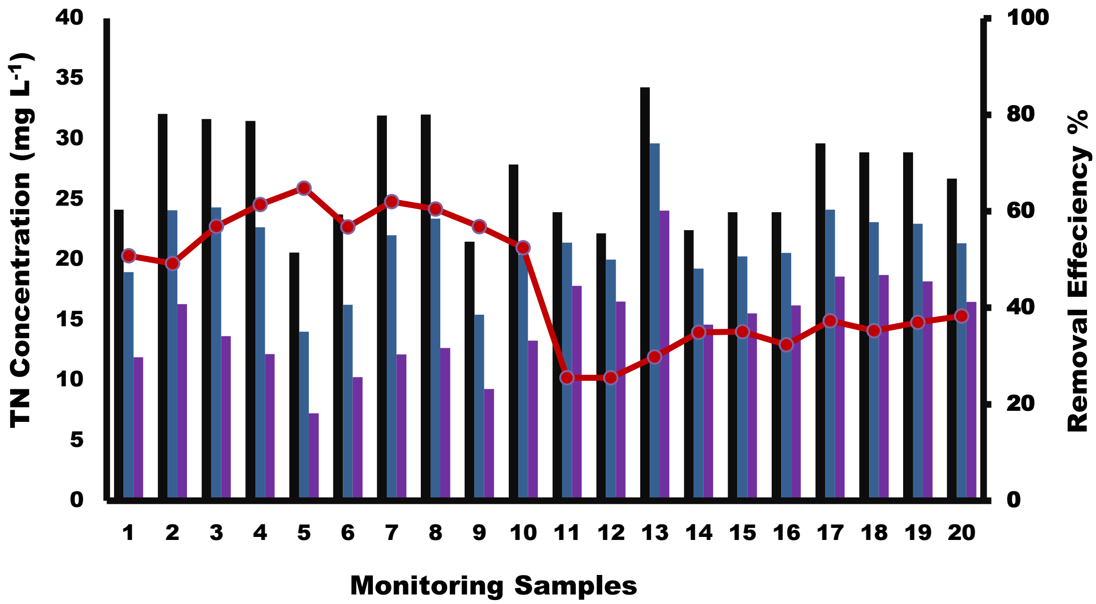

Fig. 6: Variation in TN concentration and removal efficiency during minoring period in CW

Influent | CFW Effluent
Effluent | Removal Efficien

Table 2: Statistical analysis for values of nutrients

Parameters	Influent			HCW Effluent			Effluent			Removal rate		
	Min	Max	Mean ± sd**	Min	Max	Mean ± sd**	Min	Max	Mean ± sd**	Min	Max	Mean ± sd**
	mg L^{-1}									%age		
TP	1.232	3.205	2.33 ± 0.555	0.8531	1.797	1.306 ± 0.265	0.0517	1.1274	0.6520 ± 0.34	0.462	0.979	0.696 ± 0.174
NH_4	7.136	20.133	12.052 ± 3.851	6.062	14.21	9.00 ± 2.293	2.922	9.183	5.256 ± 1.478	0.292	0.759	0.531 ± 0.159
TN	20.571	34.272	27.089 ± 4.278	14.021	29.64	21.211 ± 3.511	7.236	24.05	14.776 ± 3.87	0.254	0.648	0.451 ± 0.132

Here, ** is the P value <0.001. whereas TN = total nitrogen; NH_4–N = ammonium; TP = total phosphorus.

[32]. The composition of beds in the CWs system directly affects nutrient removal as a substrate provides habitat and rooting medium for plants and living communities [33].

Conclusion

The alarming scarcity of water in different countries of the world demands the adoption of an integrated approach to managing the water and wastewater treatment strategies. Conventional wastewater treatment methods are neither sustainable nor economical solutions. In third-world countries, often there is a lack of established sanitation infrastructure and a shortage of funds limit to adopt conventional wastewater systems. The traditional wastewater treatment systems are only based on disposal and need to be transformed into a more suitable, sustainable, and economical system that is based on the conservation of nutrients and water resources in wastewater. In comparison with other wastewater treatment processes, the CWs system offers a more economical and sustainable wastewater treatment system.

Conflict of interest

The authors declare no conflict of interest.

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