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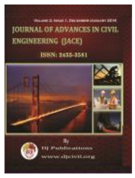

REVIEW ARTICLE

Constructed Wetlands and Water Hyacinth Macrophyte as a Tool for Wastewater Treatment: A Review

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ABSTRACT

This paper is an attempt to study the water treatment processes with special emphasis on construction wetlands (CW's). Wastewater is a growing concern in different developed countries. Hence treatment of wastewater has gained much importance. There are different levels of water treatment of which constructed wetlands come under secondary level. The types of constructed wetlands include free water surface CW's, CW's with horizontal subsurface flow, CW's with vertical subsurface flow and hybrid CW's. A comparison is done for both the surface flow types. Macrophytes form an important part of constructed wetlands and in this paper the effectiveness of a bio-hedge based water hyacinth system is emphasized. An outline of the sand filtration technique is also provided. The different factors that are to be removed from the waste water and the mechanisms used for their removal are also concentrated.

Keywords: Wastewater, Constructed wetlands, Water hyacinth, Nutrients, Removal mechanisms.

1. INTRODUCTION

Wastewater treatment can be defined as that process which converts the water which is unsuitable for any useful processes in to an effluent that can be reused for suitable purposes. In simple words it means removal of contaminants from wastewater. The system that can be employed for such a purpose can be called a wastewater treatment plant. The treatment process may vary for municipal and industrial wastewaters. The main aim of this process can be regarded as reduction of water pollution in a broad view.

1.1. Waste water

Waste water as the term defines contain unused and unwanted products from various industrial as well as domestic processes. It poses a threat to all the living organisms living in an ecosystem if left untreated.

1.2. Contents

[1]The contents of waste water include faecal sludge, kitchen waste, hospital waste, waste from commercial industries, agricultural waste etc., Pathogenic microorganisms, heavy metals, organic pollutants and micro pollutants are the ingredients of these contents and can harm plant, animal and human life.

1.3. History

[2]In early days waste in the nature was acted upon and decayed by microorganisms. The amount of contaminants in the waste is reduced by biodegradation, plant and animal intake and so on. In such a scenario the need for waste water treatment was not much considered. Gradually the scenario began to change by directing the wastewater to public water ways [3]. Again the scenario became worse when this wastewater was transported to lakes and rivers. Meantime the concentration of waste also increased in water due to rapid urbanization. The marine life was threatened by these changes. The disturbing fact was that in many of the cities this water was used as the primary source.

1.4. Effects of untreated wastewater

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The contents of wastewater can deplete oxygen content and thereby make fishes unable to survive in the aquatic environment. Water can be over fertilized leading to the extinction of some species. Bacteria, viruses and pathogens may lead to many water borne diseases which makes water consumption a fearful task.

The culminations of all these effects lead to the idea of wastewater treatment.

1.5. Levels of wastewater treatment

[4]There are three levels of waste water treatment viz primary, secondary and tertiary treatments.

1.5.1. Primary treatment

It mainly focuses on solid objects which are suspended in wastewater. Biochemical Oxygen Demand (BOD) of the wastewater is considerably reduced in this step. It is also known as mechanical treatment.

1.5.2. Secondary treatment

The organic matter which is let off in the primary treatment is taken care off in this stage. This stage is accomplished by microorganisms consuming and feeding on this organic matter and make use of them for their own sustenance and development. It is also known as biological treatment. Examples of secondary treatment include constructed wetland systems, sludge process and trickling filters. This stage is also known as biological treatment as biological activity is at the core of this treatment process.

1.5.3. Tertiary treatment

This stage is more related with the technical processing of waste water. It requires expensive systems and trained plant operators. Example of a tertiary water treatment process include the removal of nitrogen and phosphorous from wastewater which has undergone the secondary treatment process.

The beginning of wastewater treatment methods was marked by the process of filtration. Later new technologies arose and made wastewater treatment process more effective.

2. BACKGROUND AND RELATED WORK

Wastewater sources can be multifarious and each contributes to the hazardous contents of water in different ways. The major constituent of municipal wastewater is suspended solid matter. It is the home for bacteria and pathogens. A single stage of treatment process may not be effective since the amount of contaminants is high. Additional steps need to be implemented for removing the content effectively. Constructed wetlands is used and studied as an additional step. It was concluded that these wetlands are capable of reducing the effect of particle load in treated waste waters [5]. In [6] a novel decentralized sewage treatment reactor [DSTR] was designed. The main focus of this reactor was the wastewater produced domestically in rural areas. It showed better performance compared to the activated sludge reactor. The aim of **[7]** was to provide effluents for water reuse applications. This was done by means of an integrated pilot-scale treatment system. The system was continuously checked for a period of almost two years. It proved worthy for sewage treatment. In [8] constructed wetlands and stabilization pond methods are compared. Both methods were found to remove pollutants in a very efficient rate. Constructed wetlands needed less land compared to the stabilization pond method. However it was concluded that cost and volume determine the technology to be chosen. [9] proposed the usage of microalgae for water treatment process. Algae produce biomass which in turn is helpful for various activities. It was found that microalgae uses nitrogen and phosphorous for their growth which in turn reduces those contents in wastewater. Another advantage is that they do not lead to secondary pollution. Hence the role of microalgae is much pronounced. In [10] less expensive and eco-friendly methods for water purification are discussed. Macrophytes were the centre of this study. They are applicable in purifying water as well as waste water. Testing of macrophytes for metal tolerance by nutrition enhancement was carried out. In [11] an attempt was made to study a constructed wetland which uses hyacinth for wastewater treatment. Hydraulic structures and their effects on such a system were also investigated. The capability of wetlands was strongly emphasized once again in this paper. In [12] a bio-rock approach for treating polluted river water in wetland systems of low concentration was investigated. Nitrification and denitrification processes were also taken into account. [13] discussed about heavy metals and their removal. Phytoremediation is studied and proposed as a new method for removing these heavy metals and contaminants from water. It was found to be cheap and eco-friendly. Sources and effects of heavy metals are also studied. The plants which are commonly used for phytoremediation process was also reported. [14] provided an overview of the different wetlands that are suitable for all climatic conditions and geographical areas. It also presented an idea of alternative species. [15] explained the plants used in constructed wetlands and their functions. The abilities of plants and their role in different phenomena of wetlands were discussed in detail. [16] proposed a post treatment method for removal of algae and other effluents such that the overall advantage of the process is not hindered. Water reuse is at the core of this project and is more focused on polishing effluent more economically such that the main aim of water reuse can be distinctively maintained. [17] China has been regarded as a largely industrialized country and hence waste water treatment is of much importance. The pollutant removal efficiency of all the constructed wetland systems was studied with special reference to China. The existing limitations and challenges in implementing such systems in China along with the future course work were studied. In [18] an apparatus for treating waste water is discussed. The apparatus was controlled in such a way that aerobic and anaerobic zones with in the waste water basin are controlled, adjusted and varied. In [19] the effect of temperature and hydraulic loading rate on removal of pollutants in a wetland system was assessed. The removal performances were high when compared to conventional techniques. The hydraulic retention was found to be high for a large foot print of the system.

In this paper the focus is on constructed wetland systems

3. TYPES OF CONSTRUCTED WETLANDS AND THEIR CHARACTERISTICS

Constructed wetlands are man-made systems. It is engineered from an ecosystem which is not a natural wetland. As mentioned in the introductory part wetlands form a part of the secondary or tertiary treatment systems. Topsoil is used in constructed wetlands as they support vegetation and provides nutrients and nourishments for microbes to grow abundantly. Gravel is the ingredient in topsoil which facilitates this feature [20].

In this section we review the different types of wetlands available and their characteristics. The design of each and every wetland is different. The process by which they remove pollutants is also different. Figure B1 shows the characteristics of various wetland systems.

Constructed wetlands can be classified in to the following types

3.1. Free water surface constructed wetlands

[21**]** The free water surface constructed wetlands is a volume based method. It consists of a sealed basin or a group of basins. The main components of wetlands include rooting soil and water. The standard water depth is 20-40 cm. Vegetation forms a major part of wetlands. Many of the wetlands are concerned with macrophytes. In addition to it, species which occur naturally in a wetland system also forms a part of the vegetation. It should be noted that macrophytes are planted in a wetland system. Microbes degrade the organic matters present in the wastewater and the colloidal particles are made to settle down. Vegetation helps in removing the solid particles through filtration. Nitrogen is removed to a great extent whereas phosphorous retention is low. The reason is that phosphorous has to be removed by the soil but the contact of water with soil is limited in these type of constructed wetlands. Since it is a volume based method the amount of pollutant removed is measured by means of the hydraulic retention time. Figure B2 shows the image of a FWS CW used for the tertiary treatment of municipal wastewater

Municipal waste water is the primary target of these type of wetlands. It can also be used for treating animal, industrial and agricultural wastage. America and Australia are more involved in the construction of these types of wetlands whereas Europeans has come to this arena recently.

3.2. Constructed wetlands with horizontal subsurface flow

These types of wetlands consist of gravel or rock bed. It is sealed by an impermeable cover. Vegetation is planted on these covers. Waste water makes its way through the inlet and then through the medium sealed under the permeable cover finally reaching the outlet. From the outlet the treated water is collected. The name horizontal comes from the fact that water makes the flow in a horizontal direction throughout the process. Microbial degradation along with aerobic and anaerobic processes together contributes to the treatment of wastewater in these types of constructed wetlands. In this method ammonia removal is limited since there is lack of oxygen in the medium. As stated above in constructed wetlands, the removal of phosphorous is not satisfactory and hence various other additional methods need to be used. One of the main advantages of these types of wetlands is that it provides an atmosphere for the growth of bacteria [22, 23]. Figure B3 shows the schematic layout of a constructed wetland with horizontal subsurface flow.

3.3. Constructed wetlands with vertical subsurface flow

As the name indicates the flow of water is in vertical direction in these types of wetlands. The medium used is sand and unlike horizontal subsurface flow wetlands the input is batches of water. The system completes one cycle when all the water of the previous batch is removed completely. They are more aerobic and conditions for nitrification are much improved. Removal of phosphorous is very limited in this case also [24]. The advantage is that constructed wetlands with vertical subflow require less space. Figure B4 shows a CW with vertical subsurface flow.

3.4. Hybrid constructed wetlands

As the name indicates it is a combination of different types of wetlands especially horizontal subflow and vertical subflow types. The advantage of each of the systems is combined for maximum outcome. They are of not much prominence but are slowly gaining importance in the relevant fields. These wetlands are used particularly for the removal of ammonia and nitrogen [25]. Table A1 shows the comparison of horizontal and vertical subsurface flow wetland systems.

3.5. Expenses

The main criteria to be met for implementation of these wetlands are the practical procedures which are to be implemented. Choosing the land, testing the land for suitability, design of the system and other techniques add to the cost and require attention [26]. Wetlands are comparatively cheaper when compared to other forms of wastewater treatment. Since they are all involved in biological activity, they can turn the waste products into eco-friendly substances which can even be reused.

3.6. Types of macrophytes

Wetland macrophytes can be classified based on their physiology, morphology, submerged and emergent type [27, 28].

3.6.1. Free floating type

[29] They float on the surface of water and are not rooted to the substrate. Water hyacinth and duckweed are the two most commonly used macrophytes.

3.6.2. Submerged type

Submerged type are either floating in the photic region of water or rooted in the substrate or are a combination of both. Examples are waterweed, coontail and naiads. They are not extensively used in construction wetlands [30].

3.6.3. Emergent type

This type of macrophytes is rooted in the sediments. [31] Examples include giant reed, bulrush, common cattail and common reed. They require periodical maintenance.

4. BIO-HEDGE WATER HYACINTH WETLAND SYSTEM

Land requirement is a main problem of wetland systems. Hence a bio-hedge water hyacinth wetland system can be considered as a choice. Water hyacinth [32] is chosen because they have the capacity to reduce nitrogen, phosphorous content and BOD (Biological Oxygen Demand) to a great extent. The scientific name of water hyacinth is Eicchornia crassipes. In this system the advantages of bio-hedge is made use of. Energy savings and improved bio film formations are the results of the usage of these wetland systems.

4.1. Experimental setup

The plant consisted of three sections viz storage tanks, head tanks and a wetland system.

A rectangular tank of known dimensions was used to form a shallow pond system. Water hyacinth plants are collected from available water bodies. Bio hedges are hanged in a direction parallel to water flow. They are plastic mesh shaped structures which enables microbial growth. Water hyacinth plants are placed in between these biohedges. Due to the presence of bio-hedge the amount of microbes increased gradually.

Raw sewage was considered as the input to the system. The parameters to be assessed for the proper treatment of wastewater are pH, Chemical Oxygen Demand (COD), Bio Chemical Oxygen Demand (BOD), dissolved oxygen, nitrogen, phosphorous, ammonia, phosphate, suspended solids and amount of coliform bacteria. Table A2 shows the concentration ranges of BOD and COD in domestic water.

Both the inlet water and the outlet water was collected and the performance was measured using the following formula

$$\text{Removal Efficiency}(\%)=((C_i-C_{e)}/C_i)\text{x}100$$

where C_i=influent concentration

C_e=effluent concentration

Pour plate technique was used to determine the amount of microbes at the input, biohedge surface and outlet. The plant used has a key role to play in the above mentioned process as they provide the substrate for the growth of microorganisms [33]. Figure B5 shows the plan view of a phytoremediation system.

It has been found that the usage of the system required 66% less land space than traditional systems and 32% less land space than shallow pond systems. Thus phytoremediation process is much sustainable in this system. Figure B6 shows the nutrient content of water hyacinth before and after the process.

5. SAND FILTRATION

The widely used technique for domestic waste water treatment is sand filtration [34]. There are two types of modes in this technique viz single pass, recirculation mode. Ammonification, nitrification and carbon removal takes place in a single pass and hence one of the modes is called single pass mode. Coliform bacteria can be removed completely. When the nitrified effluent is passed through an anoxic zone in order to remove the total nitrogen content it is called recirculation mode. The recirculation ratio can be expressed follows

$$\propto = Q_r/Q$$

where $\propto$=recirculation ratio

Q_r =return flow from the filter

Q =influent wastewater

6. FACTORS AND THEIR REMOVAL MECHANISMS

Different factors available in wastewater have to be taken care of separately for the removal process. They are removed by different processes and steps.

6.1. Total Suspended Solids (TSS)

Sedimentation and filtration are the two removal mechanisms in this case **[**34**].** Size and shape of the particles affect removal mechanisms to a great extent. Larger particles settle down more swiftly than tiny particles.

6.2. Pathogens

Bacteria, viruses, fungi and protozoans are the pathogens which are present in wastewater. The removal mechanism is sedimentation followed by exposure to ultraviolet radiation **[**35**].** However a heavy rainfall can cause the sedimentation process to be ineffective.

6.3. Nutrients

Nitrogen and phosphorous are the two main nutrients present in wastewater. Nitrogen can be removed by volatilization, ammonification, nitrification and de-nitrification. The removal of phosphorous is of much concern because wetland systems are not effective for their removal. Temporarily they can be removed through animal and plant intake but once the plant or animal die it re-enters the system [36].

7. CONCLUSION

This article reviewed the different types of constructed wetlands used in wastewater treatment. Constructed wetlands are one of the reliable techniques for wastewater treatment. They can be considered as an effective method than natural wetlands because here the process takes place in restricted conditions. Solid suspended particles and organic matters can be efficiently removed whereas nitrogen can be removed by a combination of wetlands. However removal of phosphorous, pesticides and pharmaceuticals must be concentrated and researched further. Biohedge based wetland system was found to be more suitable for phytoremediation. Water hyacinth was recognised to be a suitable macrophyte for phytoremediation process and was regarded as an effective step in pollution degradation. An optimal wetland construction can be carried out only after finding all the contaminants in wastewater and devising suitable methods for removal of these pollutants.

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APPENDIX A

Table A1.Comparison of wetland systems

Horizontal Subsurface flow	Vertical Subsurface flow
High removal rate of TSS	High removal rate of organic matter
Potential for denitrification is high	Potential for nitrification is high
Less smell and mosquitos	Requires less land
Operating cost is low	Less prone to clogging
Phosphorous removal is not effective	Phosphorous removal is not effective

Table A2.Concentration ranges of BOD and COD in domestic wastewater

Concentrations of Organics in Untreated Wastewater (Domestic)			
Contaminant	Concentrations (mg/L)		
	Weak	Medium	Strong
BOD	<100	~ 200-250	>300
COD	<250	~ 430	>800

APPENDIX B

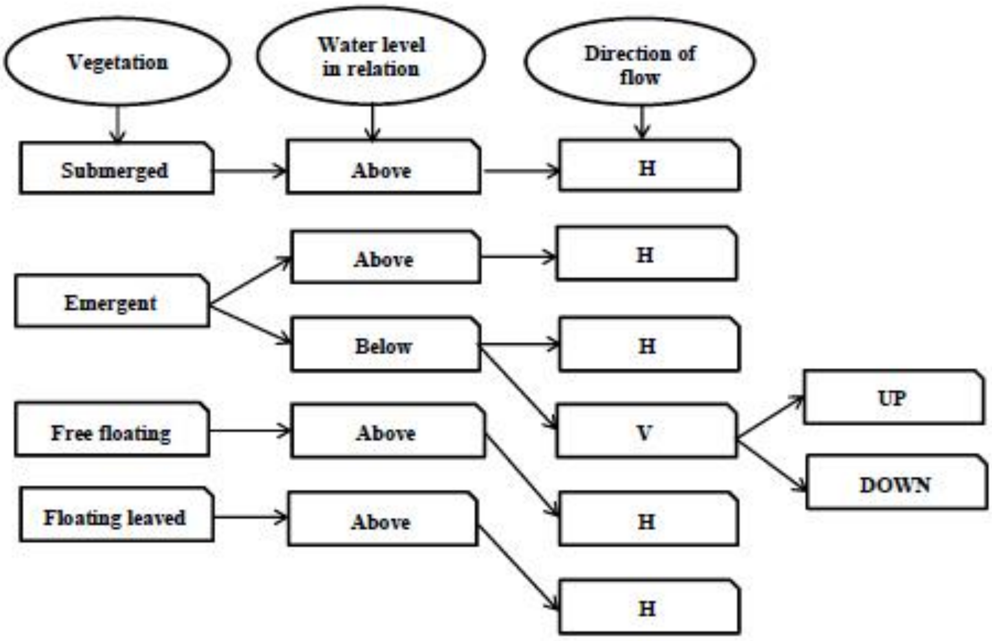
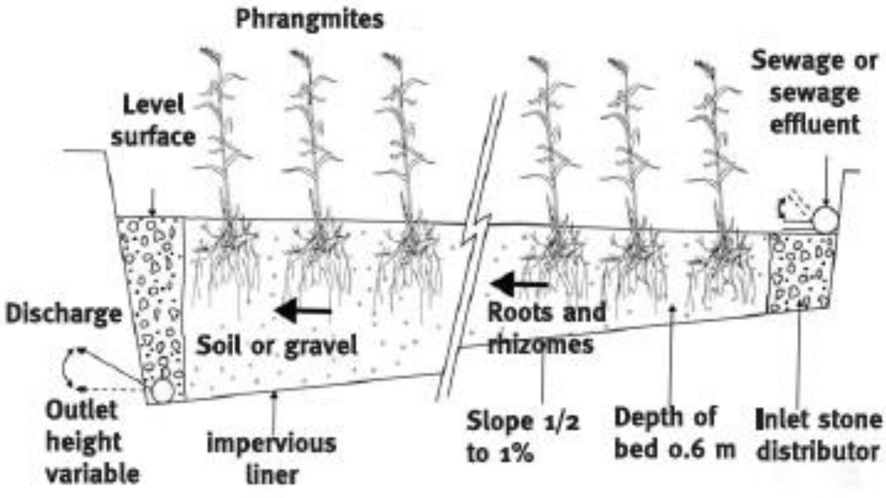


Figure B1.The major characteristics of various types of constructed wetlands

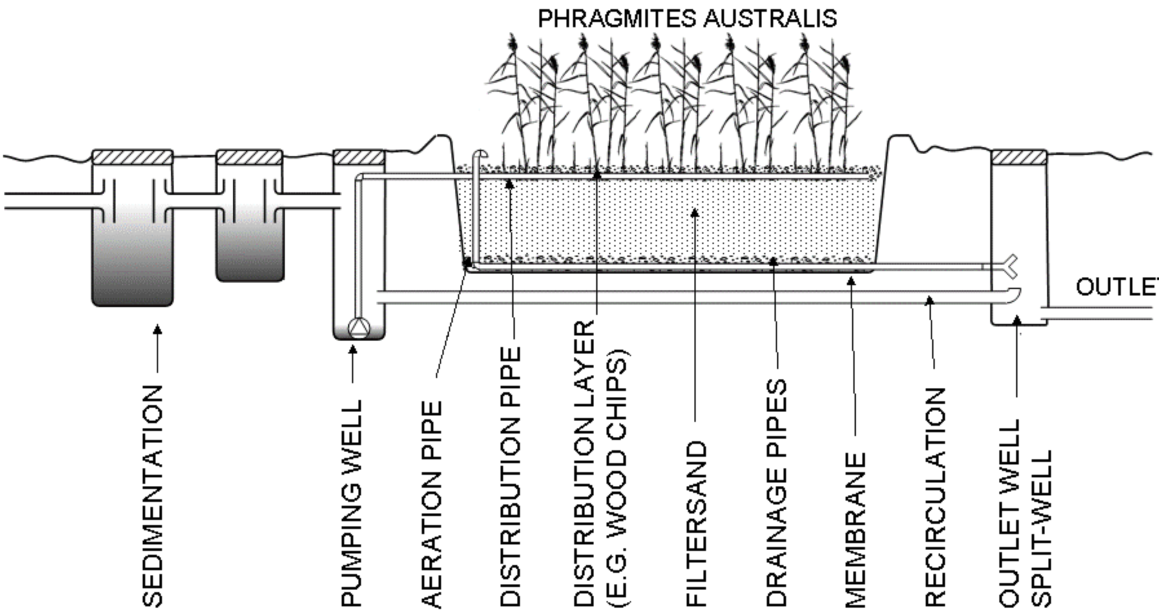
Adapted from [20]

Figure B2.A FWS CW for tertiary treatment of municipal wastewater



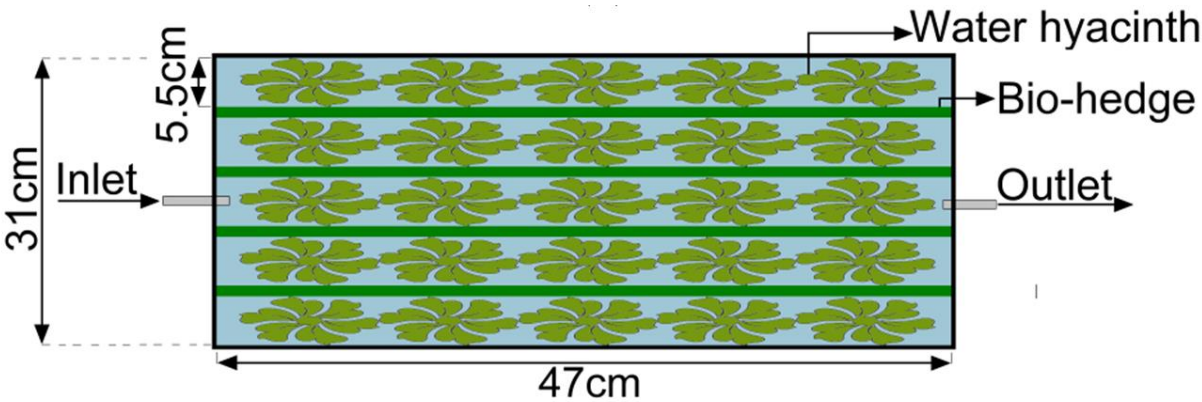
Adapted from [2]

Figure B3.Schematic layout of a constructed wetland with horizontal subsurface flow



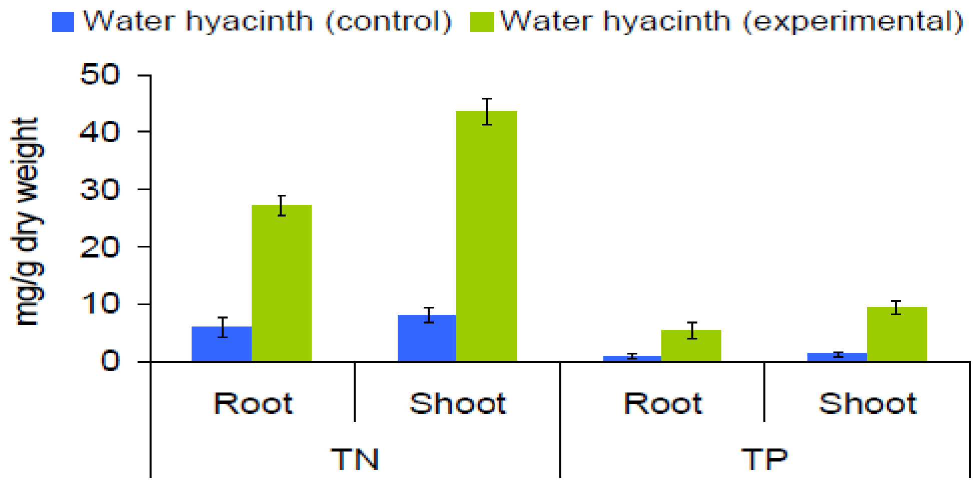
Adapted from [20]

Figure B4. Schematic Layout of a constructed wetland with vertical subsurface flow



Adapted from [32]

Figure B5. Plan view of the bio hedge phytoremediation system



Adapted from [32]

Figure B6. Amount of nutrients in water hyacinth before and after the process