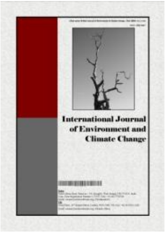

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Development and Design of Laboratory Scale Subsurface Flow Constructed Wetland System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Wetlands have traditionally functioned as a natural filtration system. Constructed wetlands (CWs) are a cost-effective and efficient green technology for treating many different types of wastewaters. The efficiency of constructed wetland depends upon the type of media, vegetation, effluent concentration, and applied hydraulic load. The objective of the present paper is to Development and Design a laboratory scale constructed wetland system. The important considerations in the design are the size of the wetland, aspect ratio, depth of each layer, and slope. The length, width, and height of the CWs are 1.2 m; 0.3 m; and 0.65 m; respectively. The total volume of CWs is 0.234 m^3 and the treatment section in the system consists volume of 0.135 m^3. Twelve sampling points are provided to collect the water from the different layers (media) of the wetland. An aeration pipe is provided at the bottom of CWs. With the laboratory scale constructed wetland system, we can analyze the different types of wastewater.

Keywords: Constructed wetland; design; substrates; sampling points; subsurface flow.

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1. INTRODUCTION

Among the primary elements of agriculture, which provides the food needs of the population, soil and water sources are the basic natural resources of the country but due to the release of untreated agricultural runoff, domestic wastewater and industrial wastewater result in the deterioration of surface water quality, loss of biodiversity and can cause a serious risk to the environment and public health [1]. With the development of the economy, the emission of heavy metals, phosphorus, and nitrogen-rich wastewater into flowing water bodies such as lakes, small rivers, reservoirs, and estuaries has increased. It caused several environmental problems including eutrophication, on health and the marine ecosystem [2].

Increasingly, wetlands are being considered an important part of an ecosystem with multiple functions, such as flood detention, water storage, purification, nutrient transformation, and support for biodiversity. Recently researchers have been particularly interested in water purification and contaminant removal. Constructed wetlands are treatment units, similar to natural flood areas, which remove pollutants with the mechanism of the plant- medium -microorganisms system [3]. These are extensive, efficient low-energy systems for wastewater treatment that do not require specialized manpower for their management [4].

CWs, have been popularly used to treat many different types of wastewater, including agricultural wastewater, domestic sewage, mine drainage, industrial effluent, landfill leachate, polluted river water, urban runoff, and stormwater [5]. To imitate the processes of natural wetlands, these systems are designed as horizontal - subsurface flow (HSSF), vertical - subsurface flow (VSSF), and free-water surface (FWS) inside a controlled environment [6]. The capability of the constructed wetland (CW) has been rediscovered in recent years, favoring its development, particularly through the use of subsurface flow (SSF) wetlands [7]. Numerous research has been conducted on the design and development of CWs, and it has been suggested that CWs may be effective in eliminating a variety of pollutants (nutrients, organic debris, trace elements, pathogens, pharmaceutical contaminants, and so on) [8].

Water flows horizontally or vertically through the substrate in subsurface flow wetlands, which are comprised of rock, sand, soil, and artificial media. Purification occurs when the surface of the medium and plant rhizospheres come into touch with wastewater. At high treatment rates, the subsurface flow method is more efficacious than the surface flow method at removing contaminants [9]. The effectiveness of the system is mainly influenced by their (CWs) area, Aspect ratio, depth of water, and the time taken to pass through the wetland.

The current study aims to Development and Design of laboratory scale subsurface flow constructed wetland (SSF CW) system for treating wastewater.

2. MATERIALS AND METHODS

2.1 Hydrologic Design of Constructed Wetlands

Wetland designs, in practice, tend to imitate natural wetlands in terms of the overall design, while supporting the wetland activities that are considered to contribute much more to water quality management. For effective Constructed wetlands, Mitsch [10] gives the following recommendations:

- Maintain a straight forward design, Complex technical solutions are prone to failure.
- Designed to be low-maintenance.
- Design the system to take use of natural energy like gravity flow.

2.2 Hydraulic Design of Constructed Wetland

2.2.1 Volume

The volume (V_w) of a constructed wetland (CW) refers to the amount of water that would be stored inside the basins. Wetland's water volume can be calculated by multiplying the average water depth (h) by area (A_w) [11,12].

$$V_w = A_w h$$

2.2.2 System width, length and depth

2.2.2.1 Aspect ratio

Aspect ratio (l: w) is an important consideration in the design of wetland systems [12]. The aspect ratio (l: w) of the wetland bed is a highly essential factor in the hydraulic design of wetland systems. The hydraulic gradient specifies how much total head is present in the system to surpass horizontal flow resistance in the porous medium. The full potential of the hydraulic gradient is correlated to the available depth of the bed divided by the length of the flow route. In earlier studies, many systems were designed with aspect ratios of 4:1 or higher.

2.2.2.2 Length

The length of a particular wetland is determined by the capacity of the outlet and inlet structures to effectively distribute and collect the water without causing short-circuiting [12].

2.2.2.3 Depth

The depth of media in the SSF CW system is limited to the rooting depth of macrophytes planted in the wetland, flowing water comes in contact with the plants and gives an effective treatment in the removal of pollutants [13]. In the removal of pollutants, the effect of water depth is not clear. The main problem in the sub-surface flow system is that the depth of the media may be known, but the actual operational water level is difficult to determine.

2.2.3 Slope

For simpler planting and frequent care, the upper portion of the medium should be uniform or nearly equal. To keep a consistent water depth throughout the Subsurface flow system, the bottom slope would theoretically equal the slope of the water level. A slope of 0.5 to 1% is recommended for easy operation and efficient drainage [14].

2.2.4 Substrates

The substrate is an important design element in CWs and SSF CWs. The choice of appropriate substrates for use in CWs for treating wastewater is a crucial issue because it can offer an ideal growth medium for plants while simultaneously allowing efficient wastewater transportation [15]. Furthermore, substrate sorption could be the most essential factor in absorbing contaminants like phosphorus [16].

2.2.5 Substrates size and type

Wetland media provide support for a variety of wetland plants, as well as locations for biochemical reactions and accumulation of pollutants. It is advised that the diameter of the planting medium should not exceed 20 mm [12]. To prevent clogging, the media in the inlet and outflow regions should be around 40 to 80 mm in diameter and extended from top to bottom of the total system

Table 1. Substrates commonly used in CW for wastewater management

Kinds of Substrates	Source
Natural Material	
Sand	[17]
Gravel	[18]
Clay	[18]
Vermiculite	[19]
Peat	[8]
Limestone	[20]
Industrial by-product	
Alum sludge	[21]
Oil palm shell	[22]
Artificial products	
Activated carbon	[23]
Compost	[8]
Others	
Alum sludge	[24]
Biochar	[25]
Rice straw	[26]
Construction wastes	[27]
Bauxite	[28]

2.2.6 Inlet and outlet piping

Another crucial design component has been identified as an influent feeding mode [29]. The inlet of CW is designed to reduce the risk of clogging and short-circulating in the substrate and to maximize equal flow distribution through the wetland [11]. Similarly, outlet pipes should be designed effectively to reduce the risk of short circuiting, maximize uniform flow collection, & allow the operator to regulate the operational level of water and drain the bed [30].

2.2.7 Wetland porosity

The plants and settled sediments occupy a section of the water column in a constructed wetland, reducing the area available for water. The void fraction (ε) or porosity of a wetland is the percentage of the total volume through which water can flow. In constructed wetland design calculations, the recommended porosity value for a completely vegetated zone is 0.65 to 0.75 [31,32]. Porosity of substrate were given in Table 2.

Table 2. Porosity of substrate

S. No.	Substrata	Porosity (%)	Source
1.	Soil	31.84	(Experimental Result)
2.	Biochar	33.68	
3.	Sand	32.00	[33]
4.	Fine Gravel	36.50	[34]
5.	Pebbles	38.00	[34]

3. RESULTS AND DISCUSSION

To construct the lab-scale wetland polyacrylic material was used. About 8 mm thickness material was selected. The aspect ratio, length, and width of the SSF-CW were maintained at 4:1 [35,36], 1.2 meters [35], and 0.3 meters [12,37], respectively as shown in Figs. 1 and 2. Design parameters for SSF CWs were given in Table 3.

Table 3. Design parameters for subsurface flow constructed wetlands

S. No.	Particulars	Unit	Magnitude
1	Aspect ratio		4:1
2	Length of the bed	m	1.2
3	Width of the bed	m	0.3
4	Bed slope	%	1
5	Side slope		1:1
6	Media depth	m	0.5
7	Thickness of each layer	m	0.1
8	No.of bed layers		5
9	Bed materials		Pebbles, gravel, sand, Biochar and soil
10	Free board	m	0.15
11	Total volume	m^3	0.234
12	Volume of treatment zone (without freeboard)	m^3	0.135
13	Total volume of treatment zone (including freeboard)	m^3	0.175

3.1 Width of the Basin

$$W = L/ALR$$

$$= 1.2/4$$

$$= 0.3 \text{ m}$$

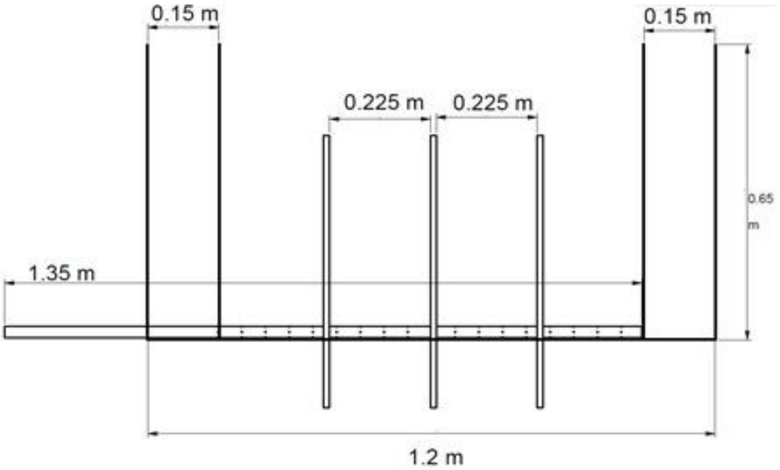

Fig. 1. Front view of the laboratory scale constructed wetland system

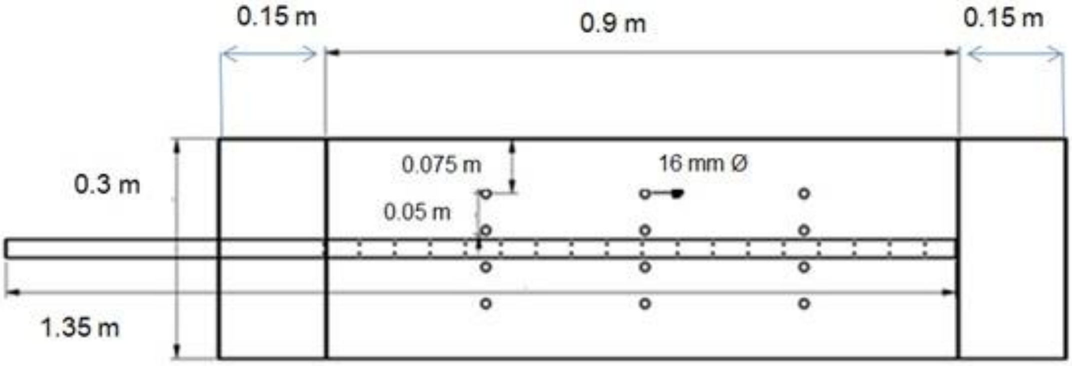

Fig. 2. Top view of the laboratory scale constructed wetland system

3.2 Inlet Water Pumping

To supply water into the wetland a small tank in the inlet section is provided with a volume of 0.029 m^3. The water holding capacity of the tank up to the soil layer is 18.90 liters. To prevent the overflow, holes are made parallel to the soil layer as shown in Fig. 3, the diameter of the holes are 4 mm through this water is discharged into the soil layer.

3.3 Treatment Section of Wetland

In this section the wastewater is exposed to different layers such as pebbles, gravels, sand, biochar, and soil, the top soil layer is provided which works as a platform to grow the macrophytes as shown in Fig. 4. Instead of biochar different types of substrates can be used [5] as mentioned in Table 1. The thickness of each layer is 0.1 m and 0.15 m of freeboard (Fig. 5) is provided for plant growth. The volume of the treatment section is 0.175 m3. Treatment efficiency is generally limited in HSSF CWs due to poor oxygen transmission rate [38] to overcome this an aeration pipe is provided at the bottom of the wetland [39] as shown in Fig. 4, it increases the removal rate of pollutants from SSF CWs when treated with various wastewaters [40]. After arranging all media in the system, the laboratory scale constructed wetland system can be seen as shown in Figs. 6 and 7.

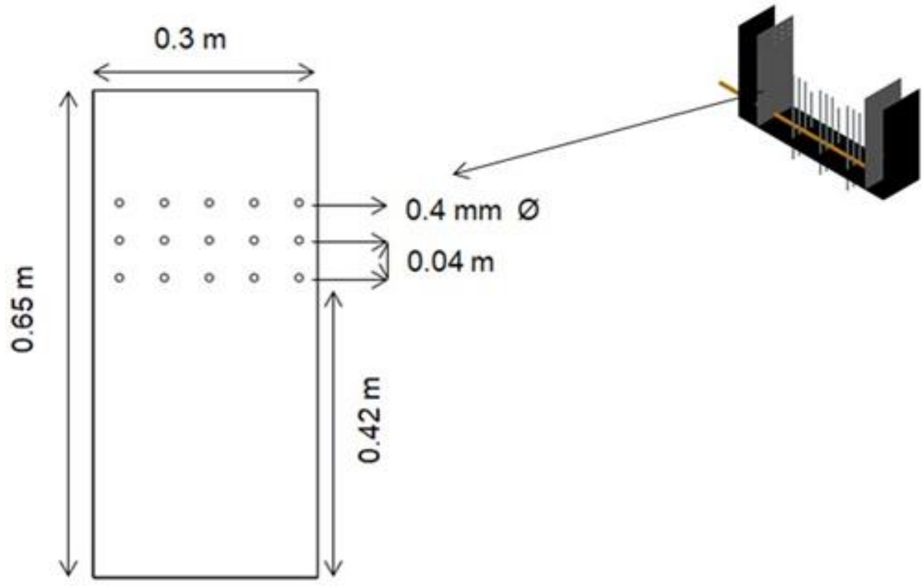

Fig. 3. Dimensions of inner plate in the Inlet collection tank

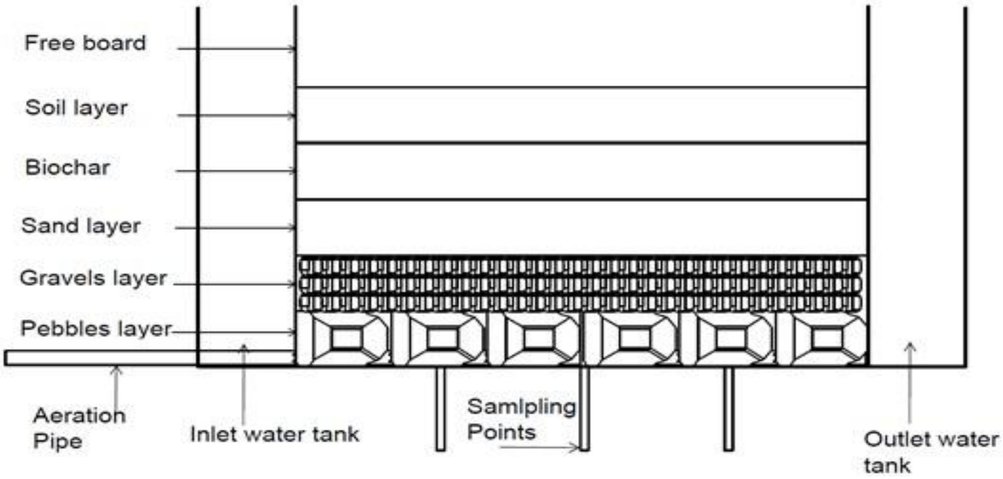

Fig. 4. Schematic diagram of laboratory scale constructed wetland system

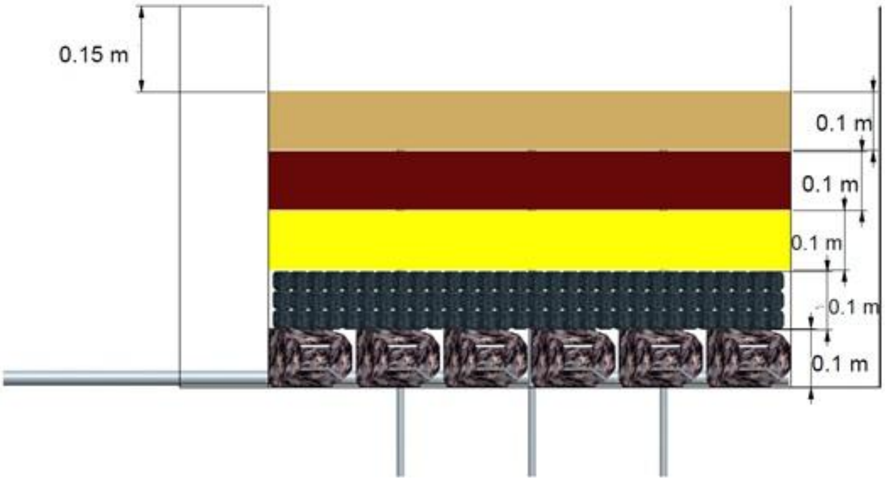

Fig. 5. Thickness of the each layer in laboratory scale constructed wetland system

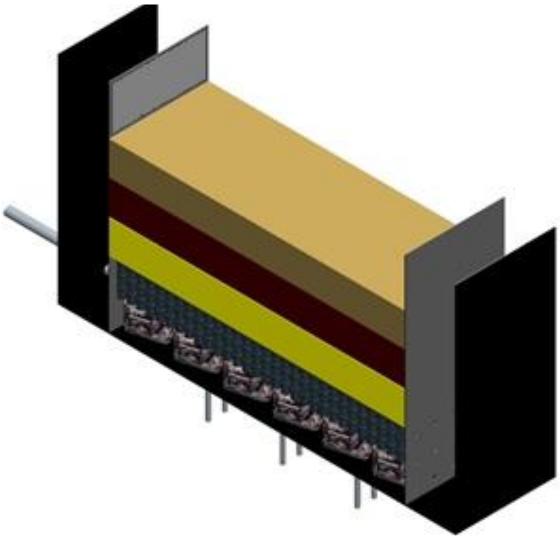

Fig. 6. Isometric view of the each layer in laboratory scale constructed wetland system

Fig. 7. Constructed wetland in laboratory scale after arranging the media

3.4 Outlet Collection Tank

To collect the treated water from the wetland an outlet collection tank is provided [41]. To collect the water from the treatment section at the bottom of the inner plate holes are provided. The diameter of the holes is 4 mm through this water is discharged into the outlet collection tank as shown in Fig. 8. The volume of the tank is 0.029 m3 (Fig. 9) and the water holding capacity is 29.25 Liters.

3.5 Sampling Points

Wastewater samples are collected during the research, to collect the sample from different layers of wetland sampling pipes are provided [8] as shown in Fig. 10.

To collect the water from different media, sampling pipes are placed at different heights as shown in Fig. 11. The sample is collected from the bottom of the laboratory scale constructed wetland system as shown in Figs. 12(a) and 12(b). The length of the pipe from the above and below base layer is given in Table 4.

The treatment section in the laboratory scale constructed wetland system is divided into the different zones as shown in Fig. 13. At the end of each zone, sampling pipes collect the water from different media as given in Table 5. The arrangement of sampling pipes in a laboratory scale constructed wetland system can be seen in Fig. 14.

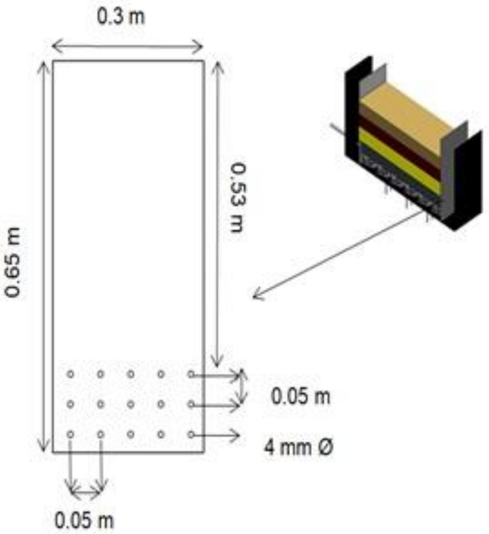

Fig. 8. Dimensions of inner plate in the outlet collection tank

Fig. 9. Collection tank

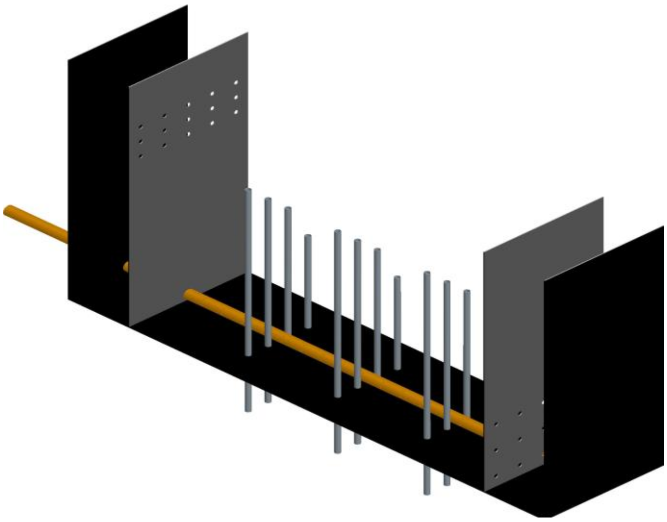

Fig. 10. Digital isometric view of the different sampling points to collect samples from different layers in laboratory scale constructed wetland system

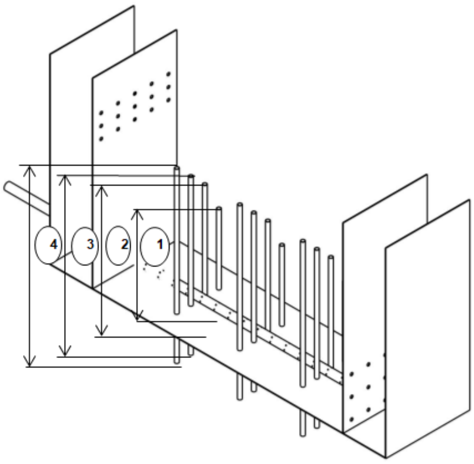

Table 4. Sampling pipe length

S. No	Total length	Length above base layer	Length below base layer
1	0.4 m	0.25 m	0.15 m
2	0.5 m	0.35 m	0.15 m
3	0.55 m	0.4 m	0.15 m
4	0.6 m	0.45 m	0.15 m

Fig. 11. Isometric view of the different sampling points to collect samples from different layers in laboratory scale constructed wetland system

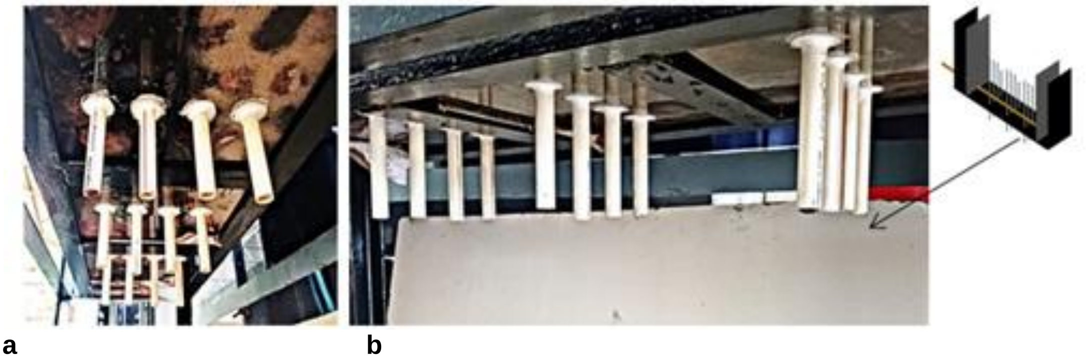

Fig. 12(a), 12(b). Sampling pipes at the bottom of laboratory scale constructed wetland system

Table 5. Sampling collection pipes

Sampling zone	Sampling pipes	Sampling Collection layer
Zone A	1A	Middle of Sand layer
	2A	Middle of Biochar layer
	3A	Below the Soil layer
	4A	Middle of Soil layer
Zone B	1B	Middle of Sand layer
	2B	Middle of Biochar layer
	3B	Below the Soil layer
	4B	Middle of Soil layer
Zone C	1C	Middle of Sand layer
	2C	Middle of Biochar layer
	3C	Below the Soil layer
	4C	Middle of Soil layer

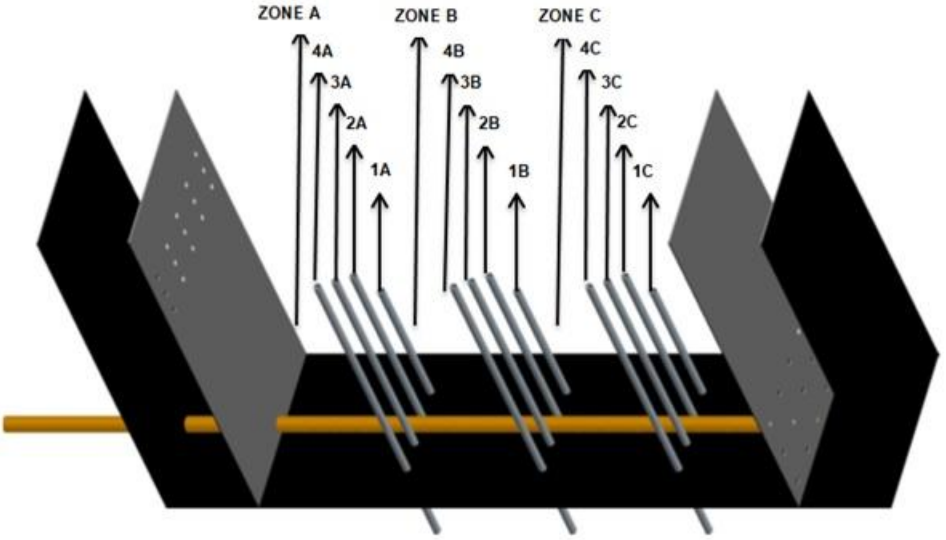

Fig. 13. Sampling collection pipe zone

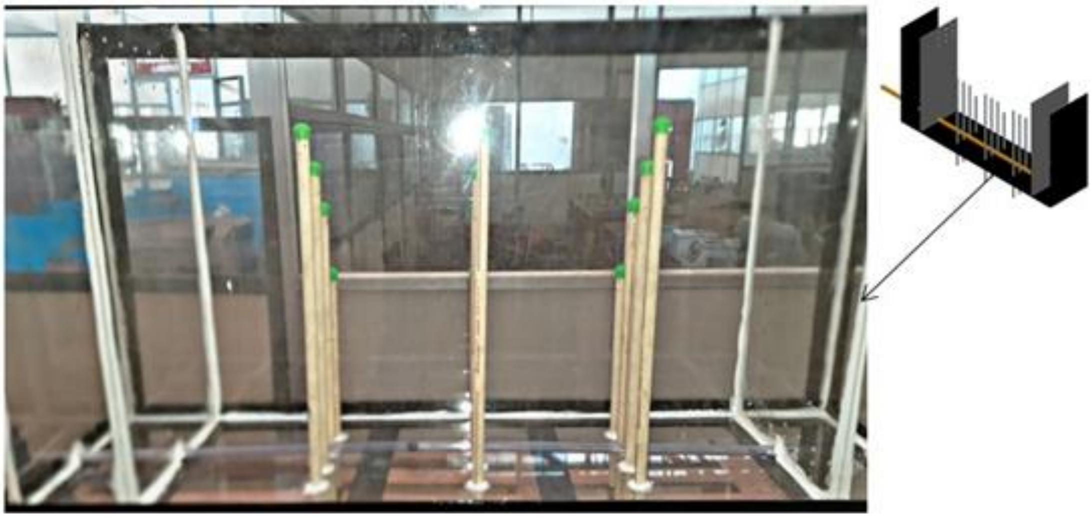

Fig. 14. Laboratory scale constructed wetland system

4. CONCLUSION

Constructed wetland (CWs) is a potential technique to remove pollutants from water. These treatment systems are the cheapest available choice, which is ecologically friendly, efficient, and simple to operate and maintain and have a great potential in developing nations, especially in small-scale industries. In the present study, a sub-surface flow constructed wetland (SSF CWs) treatment system was developed by integrating adsorbent media. This laboratory scale constructed wetland system is useful to know the removal rates of pollutants from the different types of media. An effort was taken to design the complex internal structural components to ensure the hydraulic and hydrologic safety of the treatment system. Every component of the system was properly constructed based on the design recommendations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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