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Review article

# DESIGN OPTIMIZATION OF HZ FLOW CONSTRUCTED WETLAND FOR SUSTAINABLE ENVIRONMENTAL MANAGEMENT (PROPOSED MODEL)

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## ABSTRACT

In developing countries water pollution is one of the main threats to public health. Thus, it is essential to reuse wastewater to struggle for water scarcity and to look after the available water sources by treating wastewater resulting from human activities. In Pakistan annual per capita water accessibility has been reduced from 5,260 to 1,038 cubic meters from 1951 to 2010 respectively. If this condition continues then the water availability in Pakistan will reduce to 877 cubic meters per annum by 2020 and will further go down to a distressing point of 575 $m^3$ in 2050. In view of lack of resources and skilled manpower, required for sophisticated wastewater treatment technologies, there is need to examine the low cost wastewater treatment technologies like constructed wetlands. This study shows that Horizontal sub surface flow constructed wetland has been designed to check the efficiency in removing pollutants from Hudiara drain. The findings reveal that as compared to other conventional treatment systems, constructed wetlands are low cost, easily operated, and require minimum energy demand. For developing countries like Pakistan with limited technology and facing energy problems, constructed wetlands can be used for wastewater treatment.

**KEYWORDS:**

Constructed Wetland, Economical, Sustainability, Wastewater Management, Removal of Pollutants, Hudiara Drain, Environmental Management.

## INTRODUCTION

The population of world is increasing at alarming rate, mostly in urban center of Asia. The United Nations center for human settlements estimates that the urban population in Pacific region and in Asia is estimated to rise from 991 million to 2.44 billion among 1991 and 2020. It reflects that urban center of Asian cities will have to accommodate 1.4 billion more people. Hence, basic services, like water and sanitation to the public will be destabilized due to this quantum rise in population. Relocation from rural to urban areas is the main reason of increase in urban population (Islam-ul-Haque, 2015).Water is an inadequate supply and, most significantly, it is poorly dispersed geologically. Moreover, ever growing population existing on Earth is anticipated to be the root of numerous convicts in the future (Dordio 2013).

Figure 1 facilitates the idea of presenting how water is an inadequate resource; the major sphere represents all of Earth's water (estimated diameter 1384.0 km), the intermediary corresponds to Earth's liquid fresh water (i.e. groundwater, lakes, swamp water and rivers) and the smallest one is the water in lakes and rivers.

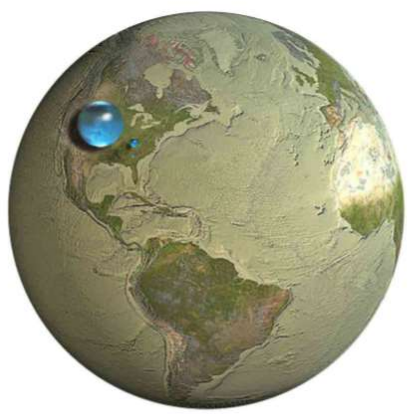

**Figure 1 Earth's Water Shown in Spheres (Samsó, 2014)**

The per capita water accessibility has been decreased more than 46% from 5,260 $m^3$ to 1,038$m^3$ from 1951 to 2010, in Pakistan. If the condition continues, then, the water availability in Pakistan will further reduce to 877 $m^3$ per annum by 2020 and will further go down to a distressing point of 575 $m^3$ in 2050 (Mustafa, 2013). Per capita water accessibility decreasing in Pakistan is shown in figure, below;

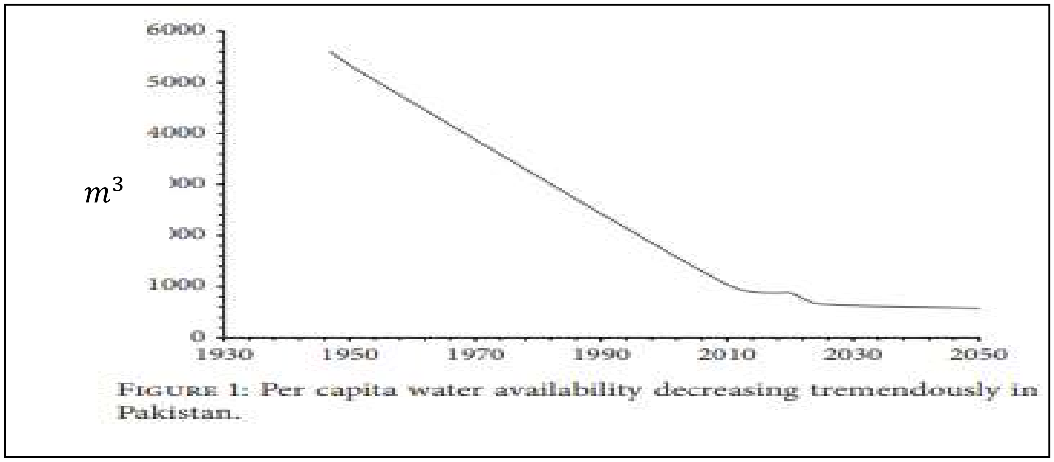


**Figure 2 Per capita Water Accessibility Decreasing in Pakistan (Mustafa, 2013).**

Water is a source for a large variety of anthropogenic activities, ranging from agriculture to industry. Generally, after achieving its primary purposes, the water is discharged in sewers/surface water bodies as wastewater due to the occurrence of contaminants in it (Zahra. S et al., 2012). Water bodies have been considered as spots for dumping of domestic and industrial wastewater which involve suitable treatment, with the passage of time (Kalbar P.P, et al., 2012).

Domestic and industrial enterprises discharge wastewater that is the mixture of water and redundant products. Treatment of wastewater before its disposal to the fresh water bodies is very essential as it adds nutrients, heavy metals and other noxious waste in receiving water bodies (Su et al., 2014). The use of wastewater is one of the alternating ways for irrigation for farming production (Khurana et al., 2012).
Concerns associated to water scarcity and wastewater disposal can concurrently solved by reuse of wastewater, as bio-fertigation. Chemical precipitation, lime coagulation, ion exchange, aeration, chemical oxidation, electrolysis, ultra-filtration, and chlorination techniques are being used for wastewater treatment across the world but all the techniques are costly (Mishra and Tripathi, 2016). Wastewater can be treated in a controlled, environmental protective and cost-effective manner, by various natural methods like natural ponds and wetlands (Mustafa, 2013). . For wastewater treatment constructed wetland (CW) is a well-known environmental protective technique. Surface flow and subsurface flow are the two basic varieties of constructed wetlands system. These systems utilize soil and aquatic plants. To eliminate the containments from wastewater physical, chemical, biological and biochemical processes play role in a constructed wetland system (CWS) (Vymazal, 2010).

This study is planned to design a horizontal subsurface flow (HSSF) constructed wetland system for treatment of wastewater carried by huduiara drain. To eradicate the contaminants from wastewater horizontal subsurface flow constructed wetland is an engineered structure which utilizes the aquatic plants and natural processes (Oladipupo et al., 2015). The HSSF wetland system works on the principle of phyto-remediation in which aquatic plants extort the contaminants through their roots from wastewater. This structure works like natural method that can eliminate the multi-pollutants from wastewater with merely a single plant (David, A. F. 2006). Many plants can be used in the wetland for elimination of contaminants. However, environment, nature of wastewater and nutrients to be removed affect the plant selection criteria (Pawan et al., 2015).

## LITERATURE REVIEW

A constructed wetland is an artificial shallow basin filled with substrate, usually soil or gravel, and planted with vegetation that has tolerance to saturated conditions. Water is then directed into the system from one end and flows over the surface (surface flow) or through the substrate (subsurface flow) and gets discharged from the other end at the lower point through a weir or other structure, which controls the depth of the water in the wetland (Donde Oscar Omondi et al, 2020).

Pollutants such as heavy metals, surfactants, pharmaceuticals and personal care products are also removed but that are not commonly targeted when designing municipal wastewater treatment systems (Vera et al., 2011). Constructed wetland systems contain a simulated substrate bed for the plant, a bio-film and emerging macrophytes above the water surface. The substrate frequently consists of a combination of sand and gravels. The bio-film contains algae, fungi and bacteria over substrate and plant stem surface.(Hoffmann et al, 2011).

### Subsurface Flow Constructed wetlands (SSFCW)

It’s one of the layer is filled with gravels or other aggregates whose level is above water level to avoid contact of wastewater to the layer exposed to air. It is provided with polyethylene line or reinforced concrete to make it. Free water surface, Vertical Flow and Horizontal Flow are major types of designs within SSFCW (Mthembu et al., 2013) (Khanijo, 2002) . CW systems contain a simulated substrate bed for the plant, a bio-film and emerging macrophytes above the water surface. The substrate frequently consists of a combination of sand and gravels. The bio-film contains algae, fungi and bacteria over substrate and plant stem surface (Hoffmann, Platzer, Winker, & von Münch, 2011) (Mahmood et al., 2013). In soil sand and gravel-based humid zones, CW with subsurface flow may be graded horizontally and vertically according to the direction of flow (Richard O. B. Makopondo et.al, 2020)

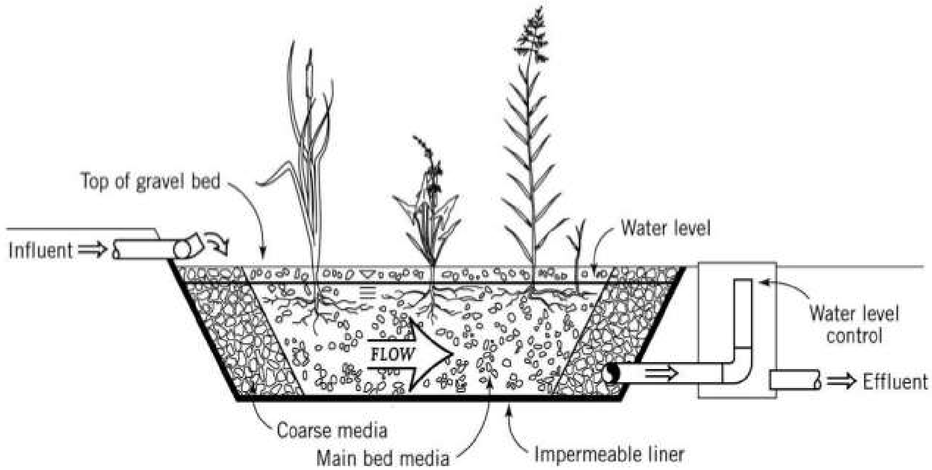


**Figure 3 Subsurface Flow Constructed Wetlands (Mthembu et al., 2013)**

**Horizontal Sub Surface Flow Beds (HSSFBs)**

Horizontal sub-surface flow CW (HSSFCW) is one of the most preferred types of wetland and has been successfully used during the past few decades for the treatment of various types of pollutants from the wastewater (Reetika Shukla et, al, 2021). Particular locations without energy supply and low hydraulic gradient, HSSFBs are a remarkable choice. Below the surface of the bed in a horizontal path, In HSSFBs, the wastewater flows slowly through the porous medium until it reaches the outlet zone (Dhote S, Dixit S 2009) (see Figure 4).

The water level at the outlet in HSSFBs is controlled with a regulating standpipe (Samsó, 2014). To avoid anaerobic conditions the submerged height of the bed should be less than one third of the total height of the filter bed (Hoffmann et al., 2011).

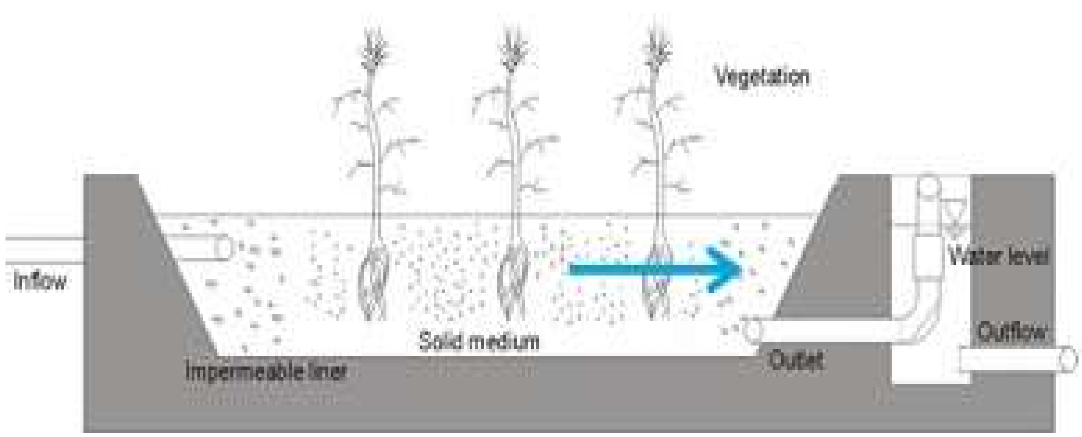


**Figure 4 Schematic Representation of a HSSFCW, Flow Circulates from Left to Right (Samsó, 2014)**

**Wetland Plants**

The essential elements of wetlands are wetland plants. Macrophytes are the large aquatic plants growing in wetlands. Most repeatedly used plants around the world are:

- Phragmitesaustralis (Common reed)
- Typha (latifolia, angustifolia, cattails, orientalis) (Surrency, 2010).
- Scirpus (e.g. lacustris, validus, californicus and acutus) are other commonly used species (Rodriguez & Brisson, 2016).

**Reed (Phragmites):**

It is a tall and aquatic perennial plant, commonly known as Reed Grass. It matures vertical up to 4 m tall. The plant grows richly in damp and waterlogged areas, both freshwater and brackish, along rivers, ditches, lake shores and ponds. Phragmites can spread laterally throughout the year by producing new shoots from spreading rhizomes. This plant grows plentifully in damped and waterlogged areas, both freshwater and brackish, along rivers, ditches, lake shores and ponds. In temperate countries, Phragmites australis is extensively used for reed bed treatment systems. Phragmites distributes 50% of plant biomass to root and rhizome systems. Enlarged root biomass permit for better oxygen transport into the substrate, generate a more aerobic environment favoring nitrification reactions (Sikora, 2011).

**Wastewater treatment in wetlands:**

In wetlands, pollutants like organic matter, suspended solids, pathogens, toxic waste, N and P are removed in wastewater treatment. In wetlands removal of pollutants and nutrients can be done by processed such as physical, chemical and biological (Zahra. S et al., 2012).

**Table 1** Removal Mechanism and Effects of W.W Constituents (Boutilier L et al., 2011) (Khanijo, 2002), (Zahra. S et al., 2012), (Zhang, 2012) (Liu et al., 2015) (Zhang, 2012) (Redmond, 2012), (Amacha et al., 2017), (Dordio and Carvalho, 2013) (Macci et al., 2015) (Bani , 2011) .

| **Wastewater constituent** | **Effect on Environment / Human Health** | **Removal mechanism** |
|---|---|---|
| Phosphorus | Excessive algae growth.<br>Diarrhea<br>Hardening of organs | Matrix sorption<br>Adsorption<br>Uptake by plant |
| Nitrogen | Depletion of dissolved oxygen | Ammonification,<br>De-nitrification<br>Uptake by plant |

| | | |
|---|---|---|
| | Free ammonia toxicity mainly to fishes. | Adsorption and absorption (sorption) |
| Soluble organics | Dissolved oxygen consumption by microorganisms for degrading organic matter. | Degradation in the presence of oxygen<br>Degradation in the absence of oxygen |
| Metals | Carcinogenic<br>Nervous breakdown<br>Cardio vascular tissue damage | Adsorption<br>Uptake by plant<br>Precipitation |
| Pathogens | Disease transmission | Sedimentation<br>Filtration<br>Die-off naturally<br>Emission of antibiotics from macrophytes |
| Total solids (TS) | Turbidity that interferes with the penetration of light through the water column | Sedimentation<br>Filtration<br>Chemical processes |

**OBJECTIVES:**

The specific objectives of the study are as follows:

- To construct a wetland based on horizontal subsurface flow beds (HSSFBs) for removal of pollutants in wastewater carried by Hudiara drain.
- To check efficiency of horizontal subsurface flow constructed wetland using reed plant across Hudiara drain.

**SURVEY FOR SITE SELECTION:**

Various sites along with Hudiara drain were visited to select suitable site to physically accommodate the size of wetland. Availability of wastewater raw materials and plants to be used were also considered in selection of site.

**Site Description:**

Hudiara Drain is located at Bhobtiyan Chowk Raiwind Road Lahore, Pakistan. This site was selected because it was the best site for wetland construction. It is located at a distance of 11.3km from The University of Lahore (Old Campus). Figure 5 shows the map of selected site.

**Hudiara drain:**

About 30 years ago, the Hudiara was a storm water drain used for irrigation purposes and to drain water into the Ravi. Hudiara Drain originates from Batala of Gurdaspur District Punjab, Indian and run along with the border; enters Pakistan near Laloo village, pass along the eastern superb of Lahore (Raiwind) and ends up in Ravi. The total length of Hudiara drain is 98.6 km, 44.2 km in Indian territory and 54.4 in Pakistan territory. Annual discharge of Hudiara drain is about 178 cusecs. This drain alone is center of attention for many environmental protection agencies in Pakistan & India due to proven high level of pollution into river Ravi. Figure 6 (a) & 6 (b) shows the upstream of Hudiara drain.


**Figure 5 Site Location**

**Figure 6 Hudiara Drain View (a)**

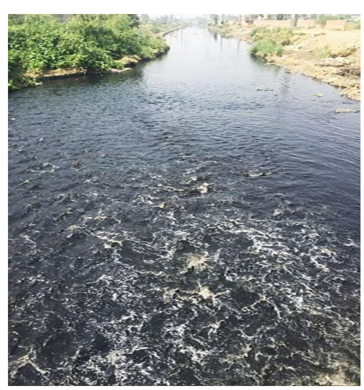

**Figure 6 Hudiara Drain View (b)**

**SELECTION OF TYPE OF CW:**

Different research papers were studied about the basic principle, uses, types, design and operation of constructed wetlands. Many of these researches used different materials and plants and alternate configurations to check the effect on the removal efficiency of the wetlands. The abiotic factors such as oxygen pH and temperature plays a vital role in removing pollutants from wetland (Kirby, 2002). Removal rates are much higher during warm weather as compared the winter season (Arshad, A., Ali, S, (2017), (Rozema et al., 2016).Horizontal sub surface flow wetland was selected because of the following reasons:

- **i.** High reduction of BOD, Nitrates, Phosphates, pathogens and heavy metals.
- **ii.** Does not have the mosquito problems.
- **iii.** No electricity is required if gravity flow is used.
- **iv.** Low operating costs.
- **v.** Fewer odors (Donde, 2020).

Among various species of plants available near site, Phragmites australis (Reed) was selected because efficiency of this plant has been reported better than other plants and it was easily available at site area. To determine treatment efficiency, visual inspections and odor checks are generally sufficient at the operator's level (Anurita, 2008), (Davor, 2017).

**DESIGN CRITERIA**

Reed method was used to calculate the area of sub surface flow wetland, inflow concentration, influent/effluent BOD concentration, temperature constant, porosity and water depth were selected as design parameters.

$$A = \frac{Q \ln\left(\frac{Ci}{Ce}\right)}{Kt \times d \times nv} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$K_t = K_{20} \times \theta_{20}^{(Tw-20)} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

**Table 4 Design Parameters**

| Parameters | Values | Units |
|---|---|---|
| Average daily flow, Q | 0.25 | $m/^3d$ |
| Average BOD of influent | 230 | mg/l |
| Required BOD | 70 | mg/l |

**Design of tanks:**

Length to width ratio for this study was assumed 2:1.

Hence the dimensions of the tanks are as follows:

**Primary Tank:**

Length =1.2 m , Width =1.22 m, Depth = 1.54 m

**Constructed wetland:**

Length =2.44 m, Width =1.22 m , Depth = 0.9 m

**Outlet Tank:**

Length =0.7 m, Width =1.22 m , Depth = 0.9 m

Schematic diagram of CW is shown in figure 7

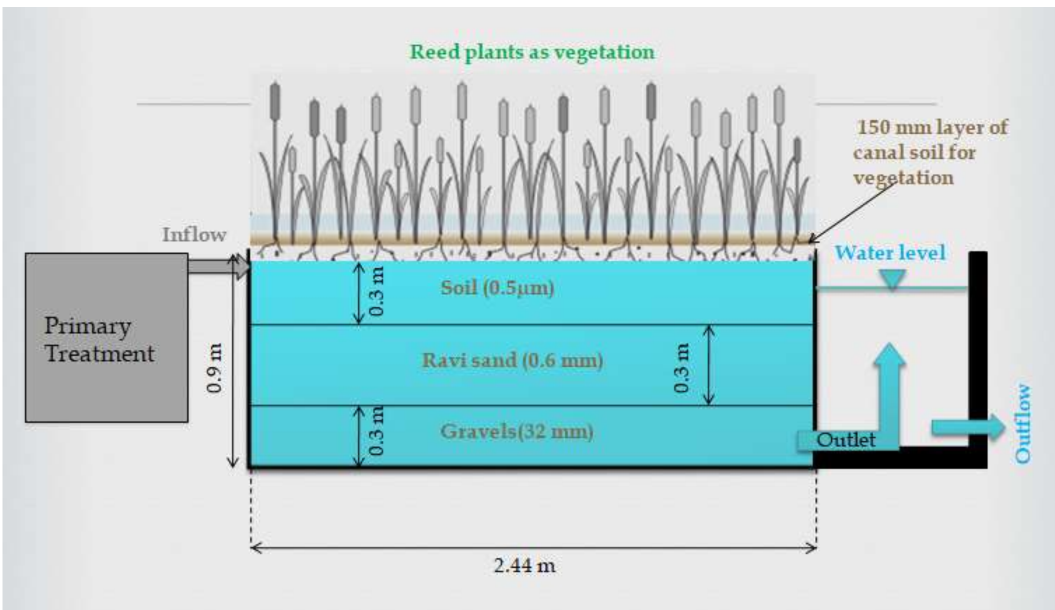


**Figure 7 Schematic Diagram of CW**

## COST ESTIMATION:

Overall cost estimation of the project starting from construction of wetland and ending at testing is shown in the table 3.

**Table 3 Cost estimation of the Project**

| **S. No.** | **Items** | **Quantity** | **Total cost (PKR)** |
|---|---|---|---|
| **1** | Excavation (Primary, Secondary & Outlet) | 45+81+9 cft | 1,350[a] |
| **2** | Brickwork (Primary, Secondary & Outlet) | 47+143+16 no. of bricks | 2,472 |
| **3** | Bed preparation for seepage control (Primary, Secondary & Outlet) (1:2:4) | 9+27+3 sqft | Included in mason charges per day |
| **4** | Cement (bed preparation + plastering) | 3 bags | 2,700[b] |
| **5** | **Layers** (Secondary tank)<br>Gravels<br>Sand<br>Soil<br>Vegetation | 20.25 cft<br>20.25 cft<br>20.25 cft<br>20.25 cft | 1,825[c]<br>506[d]<br>Locally available[e] |
| **6** | Plumbing Work | Valves, pipes, taps connections, etc | 3,600[f] |
| **7** | Mason / Labor charge | - | 4,500[g] |

| | | | |
|---|---|---|---|
| **9** | Transportations charge | Overall | 3,600 |
| Overall cost of the project = 20,553 PKR | | | |

*a* 1cft= 5 PKR **b** 1bag of cement= 900 PKR **c** 1cft= PKR **d** 1cft= PKR

**e** Sand and Vegetation **f** 1500rs material cost+ ,200 plumber fitting charges **g** 1500 per day (3days)

## CONCLUSIONS:

- To check the removal efficiency of constructed wetland the physical and chemical parameters (Biochemical Oxygen Demand, Turbidity, Nitrates and Phosphates, pH) must be taken into the consideration.
- A horizontal sub-surface flow constructed wetland gave a scheme about the common presentation of the system and its effective removal of pollutants.
- Phragmitesaustralis (Common reed), Typha (latifolia, angustifolia, cattails, orientalis), Scirpus (e.g. lacustris, validus, californicus and acutus are suitable for removing pollutants.
- Locally available plant Reed (Phragmites) is suitable and economical according to the climatic conditions of Pakistan.
- Primary tank plays a vital role in improving efficiency by removing suspended solids in constructed wetland.
- Efficiency of constructed wetland in removing pollutants varies in different seasons, flow rate of wastewater and detention time

## RECOMMENDATIONS:

- Line Departments Namely Water and Sanitation Agency Lahore, Environmental Protection Agency, Punjab and Irrigation and Power Department should explore possibilities of construction of wetlands along with the various stretches of Hudiara nullah for minimizing the pollution load being added into River Ravi.
- Since Hudiara drain is a source of pollution it is therefore recommended that a constructed wetland may be provided on a large scale for the treatment of wastewater of this drain to avoid Ravi's pollution.
- As compared to winter, removal efficiency of various pollutants in constructed wetland should be checked in different seasons, at different flow rates (monsoon season and dry weather) and different detention time (minutes, hours and days).

- Removal efficiency of different plant in constructed wetlands should be monitored.
- The removal efficiency of various pollutants in constructed wetland should be analyzed by varying the alignment flow.

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