Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 4, Issue 2; April-June, 2017, pp. 112-117

http://www.krishisanskriti.org/Publication.html

A Sustainable Approach to Manage Household Wastewater

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Abstract—*Water is a vital resource for the survival of all living beings. Today world is facing the challenge on account of an increased fresh water demand with development, population rise and shrinking supplies due to over-exploitation. In India, the per capita water availability is reducing progressively due to increase in population. The objective of this paper is to highlight the present scenario of fresh water availability in India and to present the suitability of constructed wetlands (CW) for the treatment and management of household wastewater to reduce fresh water consumption. By integrating this technique with the houses not only treats the domestic wastewater but it further reduces pressure on local water resources.*

Keywords: *Constructed wetland, Green technology, Household wastewater management, Recycle, Zero discharge.*

1. INTRODUCTION

Water is a vital resource for the survival of all living organisms. Although water is abundant in nature and renewable natural resource covering about 71% of the planet, a very small fraction of this is effectively available for human consumption. Out of all the water present on earth, saline water in oceans, seas and saline groundwater make up about 97% of the total. Only 2.5–2.75% is fresh water, including 1.75–2% frozen in glaciers, ice and snow, 0.5–0.75% as fresh groundwater and soil moisture, and less than 0.01% of it as surface water in rivers, lakes, wetlands, ponds and a very little amount of water (0.04%) is present in atmosphere [1]. Most of the world's fresh water is frozen in glaciers. Today world is facing the challenge on account of an increased water demand with population rise, development, and shrinking supplies due to over-exploitation. In India, as a result of rapid industrialization and development, the demand for fresh water is increasing both in urban and rural areas. Additionally, climate change is a global matter of concern which would have very serious impact on water resources including increased evaporation rates, a higher proportion of precipitation expected as rain, rather than snow, increased water temperatures, and decreased water quality in both inland and coastal areas. Increased evaporation rates are expected to reduce fresh water supplies in many regions of the country. More frequent and severe droughts resulting from climate change will have serious management implications on water resources. Currently, 1.6 billion people of world, live in absolute water scarcity regions and the number is expected to rise to 2.8 billion by 2025 [2].

In India, the per capita water availability is reducing progressively due to increase in population. Various parts of the country are facing a serious water crisis. Data reveals that the crisis is getting worse day by day. The per capita water availability has come down by 70% in 60 years from 1951 to 2011. The per capita availability of water as per 1951 census was 5177 cubic meters. As per the 2001 census, it was 1816 cubic meters. This is down to 1545 cubic meters as per 2011 census. It has continuously decreased owing to the increase in population [3]. According to a case study done in India and three other countries (France, United States, China), there will be no drinking water by 2040 if consumption of water continues at the current rate. In most of the countries, electricity production is the biggest source of water consumption as the power plants need it for cooling. By 2040, there will not be enough potable fresh water in the world to satisfy the thirst of the world population if we continue doing what we are doing today to meet our energy demands [4].

The objective of this paper is to highlight the present scenario of fresh water availability and to present the suitability of constructed wetlands (CW) for the treatment and management of household wastewater to reduce fresh water consumption. CW treatment is a sustainable approach to remove nutrients and other contaminants from wastewater. In the last several decades, these systems have been constructed to treat the wastewaters originated from different sources for quality improvement [5-10].

2. CONSTRUCTED WETLAND (CW)

In recent years, CW have emerged as an alternative low cost and sustainable wastewater treatment systems in developing countries [11]. These are engineered wastewater treatment systems that use natural processes to improve the quality of wastewater by utilizing shallow (usually less than 1 m deep) beds/channels, water loving plants, substrate (soil, coarse sand and gravels) and a diversity of microorganisms [8]. CWs are capable of reducing contaminants including inorganic & organic matter, toxic compounds, metals and pathogens from wastewaters of different origin.

On the basis of wastewater flow, the CW systems are classified into two categories: surface flow (SF) or free water surface flow wetlands and sub-surface flow (SSF). A surface flow (SF) wetland consists of a sealed shallow bed/channel (<1m), substrate to support the roots of plants and the water control inlet-outlet structures. In this system wastewater surface is above the substrate and the near surface layer is aerobic while the deeper substrate conditions are usually anaerobic. The advantages of SF CWs are that their capital and operating costs is low but these systems generally require large surface area and have a lower contaminant removal efficiency compare to SSF [6, 7].

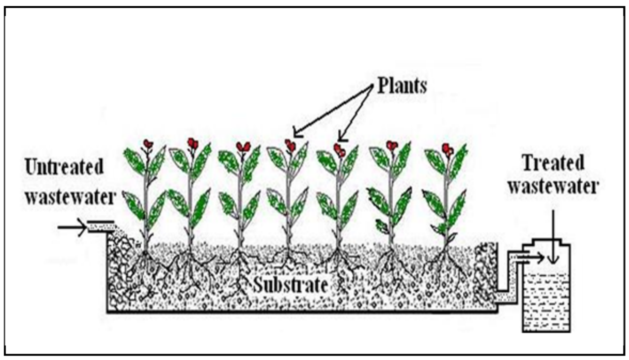

Fig. 1: Horizontal sub-surface flow constructed wetland (HSSF-CW)

A subsurface flow (SSF) CW consists of a sealed basin with a porous substrate. The water level is designed to remain below the upper layer of the substrate (Fig. 1). The wastewater is forced vertically or horizontally into the substrate by gravity depending on the type of the system. SSF CWs are further subdivided into two types: horizontal flow (HF) and vertical flow (VF), according to the flow direction of wastewater. Since last few years, the combination of horizontal flow and vertical flow CWs have been used, named as hybrid systems, for the wastewater treatment. These hybrid systems act more efficiently to improve the quality of domestic and industrial wastewaters [7]. SSF CWs are more efficient on area basis as compared to SF systems [11].

3. APPROACH FOR HOUSEHOLD WASTEWATER MANAGEMENT

A number of factors like climate, culture, food habits, life style, population size, working conditions, and type of development determine the requirement of water. Domestic water consumption makes up 8% of total global water use [2]. Mainly in developed countries, domestic water use is often many times larger than the World Health Organization (WHO) minimum recommended per capita consumption. Thus, household water consumption has a large potential to be reduced. Advantages of reducing household water consumption include lower water bills, reduce pressure on local water resources, and increase the availability of potable water for basic needs such as drinking, cooking, and bathing. According to Bureau of Indian Standards (BIS), IS:1172-1993, a minimum water supply of 200 litres per capita per day (lpcd) should be provided for domestic consumption in developed cities [12]. It also mentions that the amount of water supply may be reduced to 135 lpcd for the economically weaker sections (EWS) of the society and in small towns [13]. But in reality, some high income households have a tendency to consume 250-600 lpcd [14]. The average size of Indian household's members per family is 4.45, according to the census data 2011. It means that about 600-2470 L of water is required for a family on daily basis. This large quantity of fresh water gets converted into wastewater after use and becomes the part of sewage. Therefore it should be mandatory in a water-scarce country like India to manage household wastewater.

In addition to installing water saving appliances, source separation and recycle of wastewater is a way to optimize water use at home. CW treatment is a green technology and sustainable approach to treat the household wastewater. The treated wastewater can be efficiently reused for secondary purposes like floor washing, car washing, gardening, and flushing the toilets. Now a days the concept of terrace gardening is very popular in cities. Depending on the space available on the terrace, one can plan the terrace garden to grow medicinal plants, fruits, and vegetables. For this purpose treated wastewater can be utilize efficiently. In addition, it enhances the quality of surrounding microclimate, increases oxygen level, and reduces the temperature. In a home with older toilets, an average flush uses about 13.5 L, and the daily use is 71 lpcd. In a home with ultra-low-flow (ULF) toilets, with an average flush volume of 6 L, the daily use is about 35 lpcd. Per capita, this much of fresh water could be saved by recycling of treated wastewater.

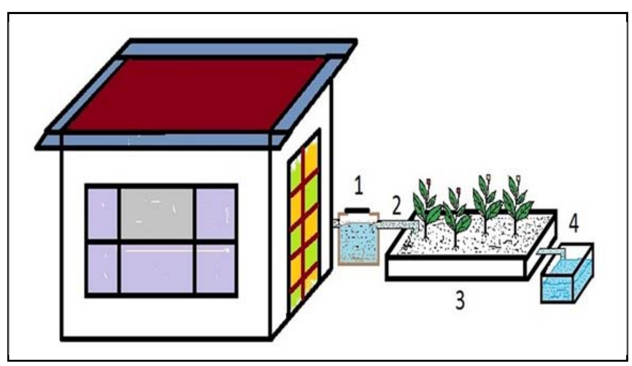

Fig. 2: Wastewater treatment setup - sedimentation tank (1), inlet for CW (2), HSSF-CW (3), treated wastewater (4)

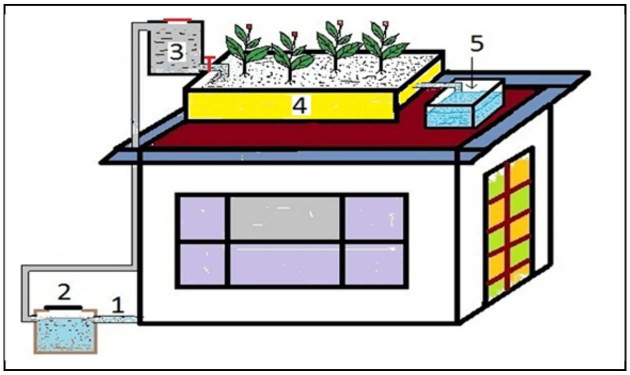

Fig. 3: Wastewater treatment setup – inlet for untreated wastewater (1), sedimentation tank (2), wastewater storage tank (3), HSSF-CW (4), treated wastewater (5)

Author suggests two approaches to carry out the operation of household wastewater treatment by utilizing horizontal sub-surface flow constructed wetland (HSSF-CW) (Fig. 2 and 3). HSSF-CW is an efficient treatment configuration and easy to maintain. Fig. 2 shows the installation of CW facility on the ground surface. This approach could be adopted for the houses in which sufficient ground surface is available. If there is a lack of ground surface in the premises of house, the top roof could be utilized for the installation of treatment facility as shown in Fig. 3. In second case, additionally a water pump is required for uplifting the wastewater onto the roof. In both the cases, a sedimentation tank is must for the removal of suspended solids (SS) from the wastewater. If the treatment system is not equipped with sedimentation tank, the SS clog the void space present in the substrate and system fails to work.

4. DESIGN ASPECTS AND TREATMENT EFFICIENCY OF CW

A large quantum of research and information is available for wetland designs. The CW should be simple, design the rectangular beds/channels with little slope to facilitate the free flow of wastewater under the influence of gravity. Avoid over-engineering the design with rectangular channels and regular morphology. After installation, give the system time of about one month to acclimatize. In general, CW consists of a properly designed basin that contains wastewater, a substrate, plants, and inlet-outlet structures. These components can be manipulated in constructing a wetland. Other important components of the wetland, such as the communities of microbes, algae, and fungi develop naturally. The CW bed usually 30-60 cm deep dug into the soil, lined with plastic or rubber sheet (liner) to prevent wastewater infiltration and is partially filled with 20-30 cm of soil in SF CW and 20-50 cm with sand and gravel in SSF CW [6]. The bed length should be 3 times larger than the width to ensure that the wastewater is not flowing too quickly through the system. The USDA-NRCS (1991) guidelines suggest an overall length to width ratio of 4 to 1 [15]. The bottoms should be relatively level from side to side and bed should slope about 1-3% upstream. It must be sealed to avoid possible contamination of ground water. A variety of synthetic liners are available which include asphalt, synthetic butyl rubber, high density polyethylene, and polyvinyl chloride (PVC) sheets. The liner should be covered with 3-4 inches of soil to prevent the penetration of plants roots. CW substrates support the vegetation, provide sites for biochemical and chemical transformations, and provide sites for storage of removed pollutants. It includes soil, coarse sand, gravel, and organic materials. The soil pH should be between 6.5 and 8.5 for efficient removal of contaminants [6]. The electrical conductivity (EC) of a soil affects the ability of plants and microorganisms to process the wastewater flowing into a CW. Soils with an EC of less than 4 mmho/cm are best as a growth medium [16, 17]. The redox potential of the soil is an important factor for the removal of nutrients such as nitrogen and phosphorus. The substrate's capacity to remove and retain contaminants is a function of substrate-water contact. Coarse sand and gravels have high porosity values which facilitate the flow of wastewater moves quickly. Porosity is equal to ratio of void volume to the total volume, and is expressed as percent. In case of sand, it is about 30-32% and 35-40% for gravel [18]. Soil texture affects plants root growth and the retention of contaminants. Sandy, coarse-textured soils have a low potential for contaminants retention but little or no restriction on root growth. However medium textured or loamy soils are a good choice, as these soils have high retention of contaminants and little restriction on root growth. Loamy soils are especially good because they are soft which favors root penetration [6, 16, 17]. Sand and gravels can also be used as alternative to soil but a combination of soil, coarse sand and gravels is better option for wetland substrate. The coarse media for substrate provide more surface area for treatment and the flow conditions should be closer to laminar. Small rocks (8 to 15 cm) should be used at inlet zone of CW to ensure rapid infiltration which further prevents ponding and algal growth [18].

In CWs, wastewater flow is regulated by flow control structures which should be simple, easy to adjust to ensure an even distribution of flow, and sized to handle maximum design flows. If the CW is designed with parallel cells, a flow splitter will be required. At SF CWs, the wastewater level is controlled by the outlet structure, which can be an adjustable riser pipe weir, or spillway. A variable-height weir, such as a box with removable stop logs, allows the wastewater levels to be adjusted easily. Spillways are easy to construct but are not adjustable; incorrect water levels can lead to wetland failure and correcting spillway height can be difficult. A PVC elbow attached to a swivel offers easy control of the water level. At SSF wetlands, outlets include subsurface manifold, and weir boxes or similar gated structures. The manifold should be located just above the bottom of the bed to provide for complete wastewater level control, including draining [6].

The treatment efficiency of any CW system is mainly depends upon wastewater characteristics and system hydrology.

Precipitation, infiltration, evapotranspiration (ET), hydraulic loading rate (HLR), and water depth can all affect the removal of contaminants not only by altering the hydraulic retention time (HRT) but also by either concentrating or diluting the wastewater. ET plays a very important role in regulation of water budget for CW [10]. It directly affects the HRT of wastewater in the system. In CW, HRT is the average time that wastewater remains in the wetland cell, expressed as mean volume divided by mean flow rate. If short-circuiting develops, effective residence time may change significantly from the calculated residence time. According to USEPA handbook on constructed wetlands, HRT can be calculated by using the equation 1 as shown below [6, 18].

$$HRT = nLWd/Q \qquad \text{eq.} \qquad (1)$$

where n is effective porosity of media (% as a decimal), L is length of bed (m), W is width of bed (m), d is average depth of wastewater in bed (m) and Q is average flow through the bed (m^3/d). A HRT of 5-6 days is sufficient for the significant removal of contaminants from wastewaters [10]. For SSF-CWs, Kickuth (1977) [19] proposed the following equation (2) which is widely used for sizing the systems for domestic sewage treatment:

$$A_h = Q_d\,(\ln C_{in} - \ln C_{out})/K_{BOD} \qquad \text{eq.} \qquad (2)$$

where A_h is the surface flow of the bed (m^2), Q_d is the average flow rate (m^3/d), C_{in} is the influent BOD_5 (mg/l), C_{out} is the effluent BOD_5 (mg/l) and K_{BOD} is the rate constant (d^{-1}). A typical SSF-CW has a maximum depth of filtration bed usually 0.6-0.8 m in order to allow the roots of wetland plants to penetrate the whole bed to ensure the aerobic conditions throughout the bed.

5. WASTEWATER TREATMENT MECHANISM IN CW

In CWs, a combination of physical, chemical, and biological processes takes place for the reduction or removal of contaminants which includes sedimentation, filtration, chemical precipitation, adsorption, microbial interactions and uptake or transformation by plants [20]. The detailed treatment mechanism for the removal of suspended solids (SS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen, phosphorous, metals and pathogens from wastewater, has been reviewed by the author in earlier publication [9]. The two main mechanisms operative in most of the CWs are liquid/solid separations and constituent transformations. Separations typically include gravity separation, filtration, absorption, adsorption, ion exchange, and stripping. Transformations may be chemical, including oxidation/reduction reactions, flocculation, acid/base reactions, precipitation and biochemical reactions occurring under aerobic and anaerobic conditions facilitated by root zone environment. The predominant physical mechanisms for suspended solids removal are flocculation/sedimentation and filtration [7]. The surface forces are also responsible for the reduction of suspended solids include vander Waal's force of attractions and electric forces, which may be attractive or repulsive depending on the surface charges [21]. The removal of contaminants from the wastewater mainly depends on the root zone interactions between contaminants, plant roots, substrate (soil) and a variety of microorganisms. The substrate is the main supporting material for plant and microbial growth.

6. PLANT SPECIES

Both vascular plants (higher plants) and non-vascular plants (algae) are important in CWs. Plants uptake play a direct role in the removal of contaminants from wastewater but indirectly they provide aerobic conditions to the microorganisms in the root zone for the degradation of pollutants [10]. Plant uptake does not contribute much to nutrient removal (<10%) [22]. The function of plants in CWs is basically to grow and die: plant growth provides root zone aerobic conditions for the oxidation of contaminants and attachment sites for microbial development; death creates litter and releases organic carbon for microbial growth. They stabilize substrates while enhancing its permeability [6]. In addition, ornamental plants increase the aesthetic value of the treatment site.

Seeds, seedlings, entire plants, or parts of plants (cuttings, rootstocks, rhizomes, or tubers) can be used to establish wetland vegetation. Plantation should be done in spring season at the new site by hand [6]. Planting early in the spring growing season is generally successful. For tall plants such as cattails, the stem should be broken over or cut back to 1 ft to prevent wind throw. Vegetative propagules are usually spaced at 1-3 ft intervals. Plants should be allowed to become well established before the wastewater is introduced into the system. It takes about one month for satisfactory growth. Wastewater should not be added until the plants have shown new growth, indicating the roots have recovered from transplanting. A wide variety of submerged and floating plants have been used in SF CWs e.g. *Typha*, *Scirpus*, *Digitaria*, *Cyperus spps.* etc. The plant species generally used in SSF CWs includes *Phragmitis australis* (common reed), *Typha spps*. (cattail), S*choenoplectus* (bulrush), *Canna indica* (lily), *Colocasia esculenta* (elephant ear), *Cyperus papyrus*, *Pistia stratiotes Pseudacorus spps.* etc.

7. TREATMENT OF HOUSEHOLD WASTEWATER

CWs have been effectively utilized for the treatment of domestic wastewaters with promising results. Municipal wastewater treatment by SF and SSF CWs has been studied by several researchers and 50-80% of nitrogen and phosphate, up to 90% reduction in BOD, COD, SS, bacteriological pollution have been reported [23, 24].

Camacho et al. (2007) [25] reported the domestic wastewater treatment by using HSSF-CW. Five HSSF-CWs were fed for 10 months with synthetic domestic wastewater, using HRT of 7.6 days. The plant species used were *Phragmites australis*, *Lythrum salicaria*, *Cladium mariscus* and *Iris pseudacorus*. The performance in terms of COD, total N, total P and SO_4^{2-} removal obtained by the different CWs were ranged between 80-90%, 35-55%, 15-40% and 45-60%, respectively. Sirianuntapiboon and Jitvimolnimit (2007) reported the treatment of sewage by SSF-CW with mono and mixed-cultures of *Typha latifolia* and *Canna siamensis* [23]. The removal efficiencies of the system with both mono and mixed-cultures were highest at the HRT of 6 days. The highest SS, BOD_5, ammonia-N_2 and total phosphorus removal efficiencies of about 91, 91, 86 and 87%, respectively, were obtained. Valipoura et al. (2009) studied the HSSF-CW system for treatment of domestic wastewater by using *Phragmites spps*. At optimum HRT of 10 h, 75.15% COD, 86.59% BOD_5, 27.54% TDS, 73.13% TSS, 8.86% chlorides, 70.22% NH_3-N, 31.71% PO_4-P and 92.11% MPN reduction was achieved [26]. Tilak et al. (2016) investigated the treatment performance of CW for residential urban colony wastewater [5]. Results showed that the COD, TSS, total nitrogen and total phosphate removals in the first and second CW over a three-month period averaged 42%, 74%, 39% and 41% and 34%, 82%, 14% and 35% respectively. Both the CWs showed similar rates of TSS removal irrespective of the type of wetland plant species. These results confirm the efficacy of field scale SSF-CWs to improve the quality of domestic wastewater.

8. CONCLUSION

Worldwide high water consuming developmental activities and population growth are responsible for declining per capita water availability. The household activities, like washing clothes, bathing, toilet flushing, and washing dishes and utensils are the most intensive water consuming activities in the cities. To reduce household water consumption, sustainable water management practices should be adopted which further reduce the costs and energy spent for water supply, volume of wastewater, money and energy required for wastewater treatment.

CWs have recently emerged as a sustainable technology for the treatment of wastewater because of its high efficiency, low cost, easy operation and maintenance. It is a green technology as it utilizes natural energy sources (such as solar and gravitational), soil, plants and microorganisms, which are the active agents in the treatment process. Additionally the ornamental plants grown in CWs enhance the appearance of the treatment site. The treated wastewater could be successfully utilize for secondary purposes i.e. toilet flushing, car washing, floor washing, gardening, to recharge underground water table etc.

By integrating this technique with the houses not only treats the domestic wastewater on one hand but on the other hand it reduces the pressure on local water resources by minimizing the daily domestic water consumption. In water scarce cities of India like Delhi, Chennai, Jamshedpur, Dhanbad, Meerut, Faridabad, Visakhapatnam, Madurai and Hyderabad etc., it should be implemented by the government to integrate CW treatment systems at domestic and institutional levels to reduce fresh water requirement. By doing so several hundred litres of fresh water could be saved on per household basis and the concept of zero discharge can also be achieved.

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