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Use of Constructed Wetland Systems for Greywater Treatment: A Review

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ABSTRACT

Constructed wetland systems (CWs) can be considered the most promising and sustainable alternative for wastewater treatment in different parts of the world. There is an enormous potential for the application of CWs in developing countries. However, the use of CWs for greywater treatment is still underutilized in developed countries, and it is almost not popular in developing countries where greywater treatment and recycling can be advantageous. The removal mechanisms, including microbial degradation, phytoremediation, phytoextraction, sedimentation, adsorption, filtration etc., can be identified within the CWs. Subsurface CWs can be considered a viable alternative since tropical countries have a year-round conducive climate for rapid biological growth. Vertical flow CWs have been identified as the effective type of wetland for removing TSS, BOD and TN efficiently, while Horizontal flow CWs have been recognized as the better option for removing TP. The performance of CWs in terms of TN, TP and COD removal is significantly affected by several limiting factors prevailing in the temperate climate. Providing insulating materials, identifying most suitable macrophytes, introducing a zeolite tank for the further purification process of the effluent and incorporating the greenhouse structures can be used to improve the performance of CWs in the temperate regions.

KEYWORDS: *Constructed wetland systems, Greywater, Removal mechanisms*

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INTRODUCTION

The majority of freshwater bodies in developing countries have been degraded by various pollutants which caused a huge negative impact on human health and aquatic ecosystems. Poor infrastructure facilities and lack of proper wastewater management systems have led to this deterioration of freshwater bodies. Therefore efficient wastewater management systems are required to treat wastewater generated from different sources and remove the pollutant load before releasing the effluent to the environment.

Greywater treatment can be considered as a better alternative than treating black water due to the lesser pollutant load (i.e. pathogenic pollutants) and the process involving an effective water management technique while providing water for non-portable industrial, agricultural and residential requirements. Greywater is the wastewater generated from domestic activities including baths, washing machines, hand basins, dishwashers, laundry and kitchen and it does not include the wastewater generated from toilets. Approximately about 50 to 80 % of the wastewater originated in developing countries is comprised of the greywater generated from the bathroom, laundry and kitchen sources (Edwin et al., 2015). Table 01 shows different sources of greywater and the percentage generated from each source with the chemical composition. Accordingly, the percentage originated from bathroom, washing/laundry and kitchen are 50% to 60%, 25% to 35% and 10%, respectively (Poyyamoli et al., 2013). Table 02 summarises the characteristics of untreated greywater from each source, including chemical, physical, biological and microbiological characteristics (Imhof et al., 2005).

TABLE 01: Comparison of greywater generated from various sources (Poyyamoli et al., 2013)

Source	Percentage Generated	Composition
Bathroom	50 -60%	Soap, shampoo. dyes, toothpaste, cleaning products
Washing/Laundry	25 -35%	Detergents and associated chemical agents
Kitchen	10%	Detergents, cleaning agents, food particles, fats & oils, other waste materials

TABLE 02: Summary – Features of untreated greywater from each source (Imhof et al., 2005)

Water source	Characteristics
Laundry	Chemical –Sodium, Phosphate, Boron, Ammonia, Nitrogen, surfactants Physical – high content of suspended solids, lint and turbidity Biological – high in BOD Microbiological – variable thermotolerant Coliform loads
Bathroom	Chemical – shampoo, soap, dyes, toothpaste, cleaning agents Physical- high in suspended solids, hair and turbidity Biological- low in BOD Microbiological- low levels of thermotolerant Coliform loads
Kitchen	Chemical- detergents and cleaning agents Physical- food particles, fats & oils and turbidity Biological- high in BOD Microbiological- variable thermotolerant Coliform loads

Most of the developing countries, including Sri Lanka, suffer due to poor wastewater management techniques and the untreated wastewater released to the water bodies and the environment has caused a significant impact on human health and environmental pollution. Greywater management is not only an option for having healthy living conditions but also has a more significant potential for reuse (Imhof et al., 2005).

Constructed wetland systems (CWs) can be identified as artificially created ecosystems with partially to completely saturated soils planted with submergent, emergent or floating macrophytes or combining these three types (Kadlec and Wallace, 2009). According to the World Health Organization, several factors, including the water scarcity for irrigation, high cost for chemical fertilizers, minimize soil degradation, high cost for constructing the wastewater treatment plants and socio-cultural acceptance of practice, have influenced the increase in the reuse of wastewater for agricultural purposes especially in semi-arid areas. CWs can be recognized as a successful greywater treatment technique by filtration and bacterial decomposition of the pollutants using hydrological, biological and biogeochemical functions. CWs are becoming popular as a series of engineered and managed natural systems receiving worldwide attention for efficient and sustainable wastewater treatment and recycling processes (Edwin et al., 2015).

Many studies have been conducted to measure the performance level of CWs for wastewater treatment under different design configurations. Therefore, this research was carried out to study the effectiveness of using CWs for greywater treatment in tropical, sub-tropical and temperate regions in the world by a critical literature review.

Constructed wetland systems

Constructed wetlands have been used effectively since the 1950s to treat wastewater with different designs and structures throughout the world and are currently considered a common alternative for treating wastewater in both tropical and temperate regions. There is an enormous potential for the application of CWs in developing countries. However, the adaptation of this technology for wastewater treatment is considerably slow. There are various advantages, including lower cost, simpler construction, operation and maintenance, utilization of natural processes, cost-effectiveness over the other techniques. However, the treatment process is considered economical only when the land is available and affordable due to larger land requirements. Moreover, different design criteria have to be introduced for various types of wastewater and climatic conditions (UN-HABITAT, 2008). The basic design consists of five major components: basin, substrate, vegetation, liner, and inlet/outlet arrangement system. CWs are shallow basins filled with filter material known as 'substrate' (i.e. sand or gravel) and comprised of vegetation which is tolerant of saturated conditions (UN-HABITAT, 2008). Wastewater is introduced into the basin and flows over the surface or through the substrate medium. There are two primary categories of currently available CWs designs; surface flow (SF) or free water surface (FWS) CWs and subsurface flow (SSF) CWs.

Free water surface (FWS) CWs (Figure 1.1) have open water areas and consist of all three types of macrophytes, including submergence, emergent and floating (Kadlec and Wallace, 2009). There is a minimum interaction with the soil-water interface and the primary removal process is obtained by settling, adsorption and plant uptake mechanisms. FWS CWs allow efficient volatilization of the compounds into the atmosphere through an air-water interface.

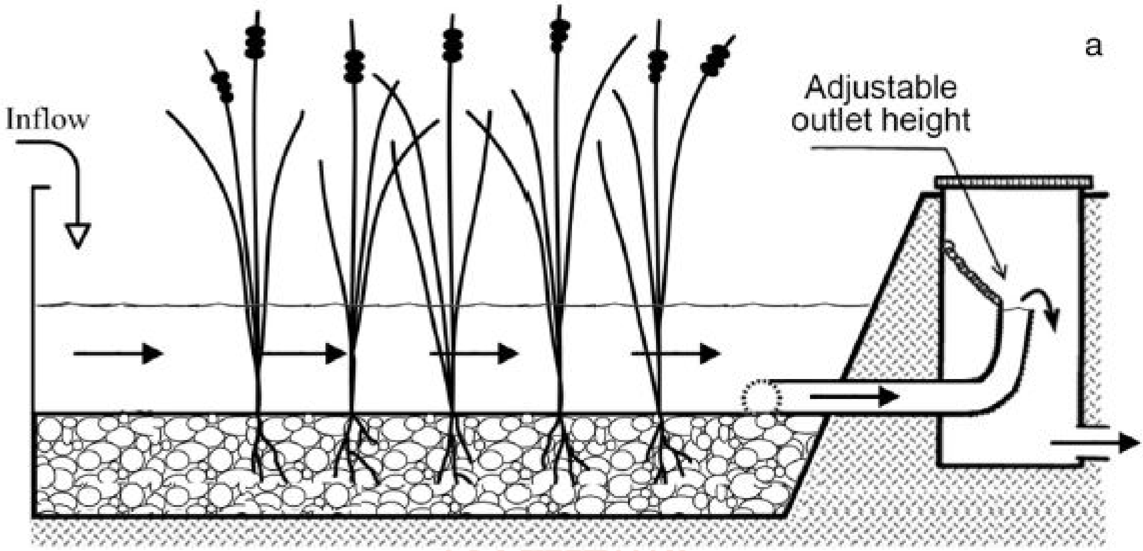

Figure 1.1: Functional schematic diagram of a free water surface constructed wetland system (Wang et al., 2017)

Subsurface flow CWs are constructed according to the three design principles; horizontal flow (HF) wetlands, vertical flow (VF) wetlands and hybrid wetlands. HF wetlands (Figure 1.2) are fed with wastewater at the inlet, and the flow occurred through the porous substrate under the bed surface in a more or less horizontal pathway until the treated wastewater reaches the outlet. It comes with contact with a complex of aerobic, anoxic and anaerobic zones. Roots and rhizomes present in the wetland vegetation will provide aerobic zones for the substrate. During this wastewater pathway through the rhizosphere, microbiological degradation, physical and chemical reactions help purify the wastewater. HF wetlands have been identified as an effective configuration of wetlands to remove the organic pollutants and Nitrates (UN-HABITAT, 2008).

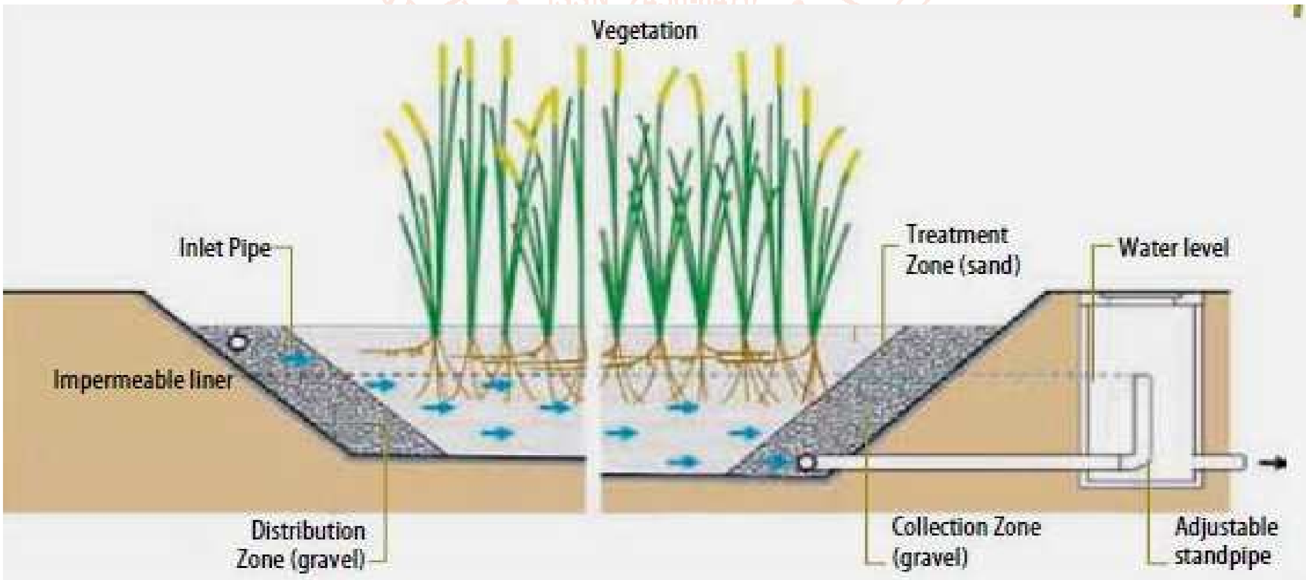

Figure 1.2: Schematic cross-section of a horizontal flow constructed wetland system (Morel and Diener, 2006)

VF wetlands (Figure 1.3) allow gradual, downward percolation of wastewater when the wastewater enters from the top part of the wetland and collected by a drainage network constructed at the bottom. VF wetlands are fed intermittently over the wetland surface and allow large batch flooding. Studies have shown that the latest model of CWs have been established according to the vertical flow system due to the greater Oxygen diffusion capacity with a good nitrification process, efficient removal of organic pollutants and pathogens. VF wetlands are considerably required a small land extent than the HF wetlands.

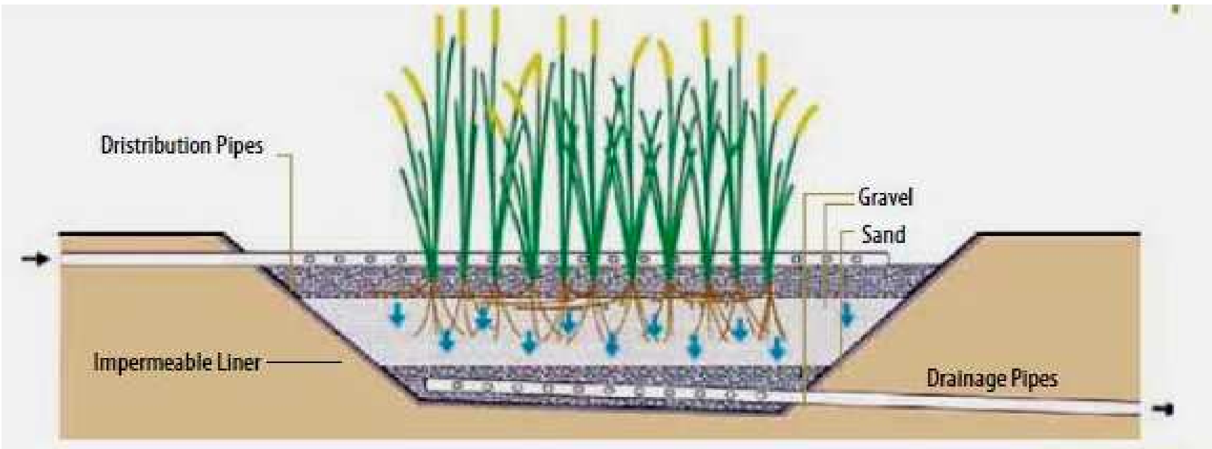

Figure 1.3: Schematic cross-section of a vertical flow constructed wetland system (Morel and Diener, 2006)

Horizontal flow wetlands are a proven technology in removing BOD_5 and Total Suspended solids (TSS) but not good for the nitrification process due to the limited Oxygen transfer capacity. Even though the VF wetlands have greater Oxygen transfer capacity and required a smaller land area, VF wetlands are less efficient in solid removal and can become clogged due to improper media selection (UN-HABITAT, 2008). Hybrid wetlands have increased performance levels with the combined effect of both HF CWs and VF CWs.

Role of wetland macrophytes

Aquatic macrophytes create the main structural elements in CWs and provide a root zone/rhizosphere where all the physiochemical and biological processes occur. These processes are performed by different types of macrophytes present in the CWs including, submergent macrophytes (i.e. *Hydrilla verticillate*), emergent macrphytes (i.e. *Typha angustifolia*), floating-leaves macrophytes (i.e. *Nelumbo lutea*) and floating macrophytes with leaves and flowers/fruits (i.e. *Eichhornia crassipes*) with the combined effect of microorganisms, soil and the pollutant reactions.

Macrophytes improve the water quality in the CWs by facilitating the oxygen transfer process to the soil through the plant tissues and leakage from the root system, trapping the suspended particulate matter, stabilizing the sediments. Furthermore, substrate, sediment and litter are subjected to the chemical transformation on the surface of the macrophytes. Macrophytes have both above ground and below ground plant structures which provide an increased surface area for the growth of the microorganisms and microbial biofilms. There is a decomposed layer of litter and other dead organic materials at the bottom of the CWs. This debris layer creates a favourable, conducive environment for microbial growth (Tanaka et al, 2011). Although the various species of macrophytes have been identified, only a few species are recognized to be more active in removing nutrients through the assimilation process into their tissues. The macrophytes that can assimilate nutrients and high growth rate are suitable for the CWs (Edwin et al., 2015).

Wetland functions can be affected by the difference between tropical and temperate environments. There is a distinct dry and wet season in the tropics, and the humidity is higher in the year around, and the ambient temperature does not change substantially at any time as it would occur in the temperate countries (Pearce and Smith, 2000). Studies have shown that the CWs constructed in the warm tropical climate provide optimum macrophytes and microbial activity during the whole year (Tanaka et al., 2011).

Many developing countries are located in the tropical zone, which experiences rapid population growth and economic change and suffers from poor wastewater management techniques. Considering all the factors regarding the cost-effectiveness and sustainable development, the CWs can be introduced as an effective wastewater treatment option, which can significantly reduce the suspended solids, BOD, pathogens, heavy metals, excessive nutrients from greywater. CWs are one of the most promising and best engineered, sustainable alternatives for wastewater treatment that are being successfully implemented in several countries worldwide, especially in tropical and sub-tropical regions. According to the distribution of the CWs in the world, there are two main types; a.) CWs in the tropical and sub-tropical regions and b.) CWs in the temperate regions.

Performance of CWs in Tropical and Sub-Tropical Regions

CWs show performance variability in terms of contaminant removal efficiency in different regions of the world. The tropical regions occupy more than 50% of the world wetland area, and it is about four hundred fifty million hectares of the land area (Zhang et al., 2015). Tropical regions experience a year-round warm climate averaging

25 ˚C to 28 ˚C with abundant rainfall and sunshine. Most of the biological activities are induced by increasing temperatures in the tropical CWs. A temperature range of 15 ˚C to 25 ˚ C is considered the most conducive temperature for microbial activity (Truu et al., 2009). CWs is vital for the developing countries with the tropical climate, where the highest greywater treatment efficiencies can be obtained than in the temperate climate. SSF CWs can be considered an appropriate alternative since tropical countries have an optimum climate for rapid biological growth, influencing the treatment process and removal efficiency (Seswoya and Zainal, 2010). HF wetlands are famous in many tropical countries due to the low maintenance cost and simple operation procedures, while the VF wetlands are more often used in sub-tropical countries (Dadan et al., 2016).

Performance of CWs in terms of Total Nitrogen (TN) and Total Phosphorous (TP) removal efficiency has significantly lower in the cold, temperate climate than the tropical and sub-tropical regions (Zhang et al., 2015). The temperature significantly affects the removal efficiencies of Total Kjeldahl Nitrogen (TKN) and Ammonium. Nitrogen removal rates at a warmer climate are significantly higher than those observed at lower temperature conditions (Caselles-Osorio and Garcia, 2007). Furthermore, according to the literature, Ammonia volatilization has increased by 1.3 to 3.5 times with each 10 ˚C increase in the temperature from 0 ˚C to 30 ˚C and doubled the denitrification rates with each 10 ˚C increase of the temperature (Ng and Gunarathne, 2011). However, CWs for greywater treatment is still underused in industrialized countries, and it is almost not popularized in developing countries where wastewater treatment and recycling can be used to acquire various advantages.

Studies have shown that the hybrid CWs appeared more efficient in removing TSS, COD, and TN than the other wetland design configurations for tropical and sub-tropical regions. VF CWs remove TSS, BOD and TN more effectively than HF CWs, while the HF CWs are recognized as the better alternative for removing TP than VF CWs (Zhang et al., 2015).

Examples from Tropical and Subtropical Countries

Sri Lanka: Treatment of wastewater at Hostel complex, Faculty of Agriculture, Rajarata University of Sri Lanka

Surface flow constructed wetland system with two different macrophytes; Typha angustifolia and Scirpus grossus were established for bathroom wastewater treatment at students' hostel and the pollutant removal efficiency was evaluated. The removal efficiencies of BOD_5, total phosphorous (TP), nitrate-nitrogen (NO_3^-N), ammonium-nitrogen (NH_4^+N) and TSS were recorded as 68%, 43%, 67%, 78%, 82% and 90%, 53%, 85%, 86%, 79% for *Typha angustifolia* and *Scirpus grossus* respectively. The researchers have found that the *Scirpus grossus* planted wetland system is more effective in removing NO_3^-, NH_4^+, TP and BOD_5 than the *Typha angustifolia* planted wetland system. Therefore, Free Water Surface constructed wetlands with *Scirpus grossus* have been recognized as an effective technique for treating greywater before releasing it into the natural environment (Jinarajadasa et al., 2018).

Sri Lanka: Constructed wetland system for slaughterhouse wastewater treatment, Batticaloa

Treatment efficiency of slaughterhouse wastewater was estimated using a constructed wetland planted with *Typha latifolia* and the effectiveness was measured concerning the COD, TSS, Total Dissolved Solids (TDS), BOD_5 , Nitrates and Phosphorus. The removal efficiencies were recorded as 77.5%, 88.7%, 71.3%, 93.3%, 68% and 85.8% respectively. This study recommended that the CWs can effectively treat slaughterhouse wastewater due to the significant reduction of the above-mentioned parameters with retention time. The beginning, the concentration of Nitrates, Phosphorous, BOD5, COD, TSS, and pH in the wastewater were higher than the permissible limits for safe discharge of industrial wastewater Central Environmental Authority. Furthermore, this study showed a significant reduction in the parameters with the treatment process of a constructed wetland system. The researchers have concluded that the CWs ensure a more stable, efficient removal of pollutants from the slaughterhouse wastewater (Keerthana and Thivyatharsan, 2018).

India: Constructed wetlands for the treatment of greywater in a campus premises

A SSF wetland system was constructed at Jawahar Navodaya Vidyalaya (JNV) campus, India, to treat laundry greywater and planted with *Arundo donax* and *Typha latifolia* . The ability to remove BOD, COD, TSS and Coliforms is much higher (67 – 80%) than for the nutrient (25 – 40%) removal. Furthermore, it was recorded that around 25 to 30% of the horticultural water requirement can be reduced by utilizing the treated greywater. Purified greywater has been stored in a hydroponic system before using for irrigation. Furthermore, frequent laboratory tests are required to ensure that the wetland systems are performing according to the guidelines given by the regulatory bodies. It was concluded that the greywater treatment done by using CWs and reuse of the treated greywater offers a cost-effective, nature-based, energy-efficient alternative compared to the other conventional treatment technologies, and CWs are found to be the most appropriate and economical technique for the developing countries. This research has shown that the use of CWs offers an opportunity for considerable savings in the cost of wastewater treatment for small communities, and SSF CWs are better options for on-site campus treatment because of the simple design configuration and less space to treat the same amount of grey water treated by other types of CWs (Edwin et al., 2015).

India: Treatment of wastewater from the kitchen in an institutional hostel mess using a constructed wetland

Integrated constructed wetland systems unit combined with a horizontal flow and vertical flow wetlands were built near the hostel mess in Chennai, India and planted with *Phragmites australis.* The total removal efficiency of TSS, TN, TP, BOD and COD were recorded as 41%, 76%, 77%, 75% and 36%, respectively. This study suggested that the integrated wetland systems can be considered a viable alternative for reducing the organic matter from kitchen wastewater released from the institutional hostel mess (Baskar et al., 2009).

India: Development of the "French system" vertical flow constructed wetland to treat raw domestic wastewater in India

A VF wetland system was established at BITS Pilani Goa campus, India, to treat single household raw sewage water planted with two different macrophytes; *Typha angustata* and *Canna indica.* The two macrophytes species were considered due to their nutrient removal efficiency and Biochemical Methane Potential (BMP) efficiency. *Typha angustata* was selected for planting in the single household wetland system as it is found in the natural wetlands of Goa and they have higher BMP than other species. The nutrient removal efficiency the wetland system was monitored at two hydraulic loadings at 0.150 m/day and at 0.225 m/day. The removal efficiencies of COD, BOD, TKN, Ammoniacal Nitrogen (NH3-N), TP, Total Dissolved Solid (TDS) and Total Volatile Solids (TVS) at the HLR of 0.150 m/day, for the 1st stage were 64%, 65%, 15%, 21%, 34% and 54% respectively. And for the 2nd stage reactor the values were 90%, 88%, 50%,52%, 58% and 71% respectively. Moreover, after changing HLR (Hydraulic Loading Rate) to 0.225 m/day the removal efficiencies of COD, BOD, TDS, TVS, TKN and NH_3-N at 1st stage was 61%, 62%, 33%, 40%, 35% and 58% and for the 2nd stage reactor it was 90%, 84%, 61%, 64%, 47% and 82% respectively.

Even though the wetland system was operated for short period of time of 40 weeks, the results showed that there is a strong indication that the two-stage VF CWs with a small area of 0.79 m^2 per person can be effectively used to remove the COD and BOD by 90% and 84% respectively (Yadav et al., 2018).

Nepal: Constructed wetland manual –United Nations Human Settlement Programme

This research was carried out from the year 1998 to 2000. The treatment system comprised a settling tank and a VF wetland planted with Phragmites karka and Canna latifolia to treat grey water generated in the private residential area. Regular inspection of the feeding tank, regular removal of unwanted vegetation in the bed, annual desludging of the settling tank and annual harvesting of the vegetation were done to ensure the proper functioning of the wetland. Average BOD, COD and TSS removal efficiencies were more than 80%. (Figure 1.4). Furthermore, this wetland system's operation and maintenance cost was recorded to be negligible, and it showed that the reuse of treated greywater resulted in saving the water expenses of the residence (UN-HABITAT, 2008).

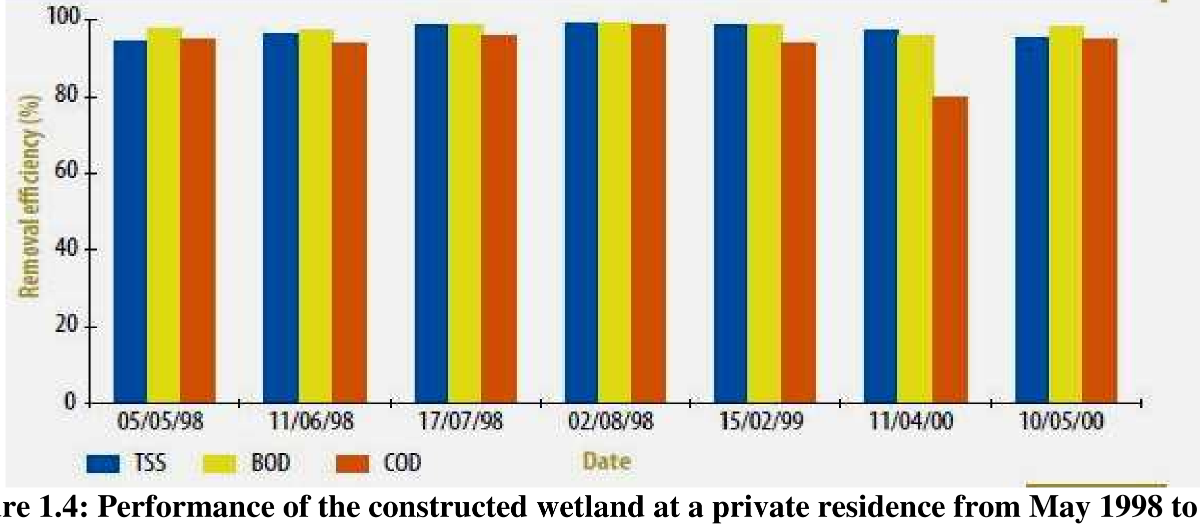

Figure 1.4: Performance of the constructed wetland at a private residence from May 1998 to May 2000 (UN-HABITAT, 2008)

Malaysia: Subsurface flow constructed wetland systems - proposed design area for high strength effluent domestic wastewater

A SSF wetland system was constructed by planting *Typha augustafolia* to estimate domestic waste water's contaminant removal efficiency. , The removal efficiency of BOD5, COD and Soluble Solids, was recorded as 74.9%, 65.8% and 92.1%, respectively. The study concluded that a larger surface area is required to achieve greater removal efficiency. In terms of the COD removal, the combination of *Typha augustafolia* and gravel might be not an excellent combination to treat high strength effluent septic tank. The study showed that the SSF CWs can be considered as the appropriate wetland system in tropical countries since they have year-round suitable climatic conditions for rapid biological growth (Seswoya and Zainal, 2010).

Israel: Recycled vertical flow constructed wetland system- A novel method of recycling grey water for irrigation in small communities

This study was conducted using VF wetland with water recycling and trickling filter; known as recycled vertical flow constructed wetland (RVFCW). This study emphasized that raw greywater for irrigation is becoming increasingly common and potentially cause environmental damage and public health risk. Regulations or the standard guidelines for the benefit of greywater are not available in most countries or not up to the sufficient standard since they have considered only the health risk while neglecting the environmental hazards. Efficient removal of all suspended solids and BOD, and about 80% of the COD after 8 hours was recorded. The researchers stated that there should be an appropriate technology with the proper standards and enforcement with education to reduce the potential risks of greywater reuse (Gross et al., 2006).

Tunisia: Performance of a constructed wetland treating domestic wastewater during a macrophytes life cycle

Hybrid wetland system was constructed combining VF and HF CWs to estimate domestic wastewater treatment efficiency. *Phragmites australis* and *Typha sp.* were planted as the wetland macrophytes. Both the macrophytes have started their life cycle at the beginning of the spring and continue the development process during summer. During the autumn season, the macrophytes have obtained the optimum growth rate, and then they entered a dormant stage. The main treatment performance results showed the average removal rates of BOD_5 (93 ± 2%), COD (89 ± 3%), TSS (98 ± 1.5%), TKN (38 ± 19%), TP (72 ± 16%) and the quality of the treated wastewater was evaluated according to the Tunisian standards. This study showed that the average effluent pH, BOD, TSS and faecal bacteria were aligned with the standards given, but COD, TN and TP loads were still above the standards mentioned by the quality criteria (Kouki et al., 2009).

China: Treatment performance and microorganism community structure of integrated vertical flow constructed wetland (IVCW) plots for domestic wastewater

Two parallel, pilot-scale IVCW systems were built in Central China to investigate the purification efficiencies, microbial community structure and enzyme activities. The mean removal efficiencies of 81.03 % for COD, 51.66 % for total nitrogen (TN), 42.50 % for NH_4^+-N, and 68.01 % for TP were achieved during the treatment process of domestic wastewater at a loading rate of 125 mm/day under sub-tropical climate. There was a significant positive correlation between the nitrate reductase activities and TN and NH_4^+-N removal efficiencies along with the significant correlation between the substrate enzyme activity and operational time. Moreover, the nitrate reductase activities could indicate the efficiency of the Nitrogen removal process in the IVCW systems (Wu et al., 2012).

Table 3 summerises pollutant removal efficiencies and the types of macrophytes used in CWs established in tropical and sub-tropical regions.

TABLE 03: The performance level of the CWs treating greywater in the tropical and sub-tropical regions

Country	Type of Wastewater	Type of CW	Removal Efficiency (%)								Types of Macrophytes	References
			TSS	TDS	BOD	COD	NH_4^+	NO_3^-	TN	TP		
Sri Lanka	Greywater	SF	82.0	-	68.0	-	78.0	67.0	-	43.0	*Typha angustifolia, Scirpus grossus*	(Jinarajadasa et al., 2018)
			79.0	-	90.0	-	86.0	85.0	-	53.0		
Sri Lanka	Slaughter -house wastewater	-	88.7	71.3	93.3	77.5	-	68	-	85.8	*Typha latifolia*	(Keerthana and Thivyatharsan, 2018)

India	Greywater	Integrated (VF + HF)	41.0	-	75.0	36.0	-	-	76.0	77.0	*Phragmites australis*	(Baskar et al., 2009)
India	Greywater	VF	66.0	89.0	85.0	82.0	-	-	-	-	*Colocasia esculenta*	(Gorky, 2015)
India	Domestic	VF	-	50.0	88.0	90.0	71.0	-	-	-	*Typha angustat, Canna indica*	(Yadav et al., 2018)
Malaysia	Domestic	SSF	92.1	-	74.9	65.8	-	-	-	-	*Typha angustifolia*	(Seswoya and Zainal, 2010)
Indonesia	Greywater	-	-	-	86.9	81.1	-	-	-	-	*Canna indica, Iris pseudocorus, Epipremnum aereum*	(Ibrahim, 2018)
Tunisia	Domestic	Hybrid (combined VF +HF)	98.0	-	93.0	89.0	-	-	38.0	72.0	*Phragmites australis,, Typha sp.*	(Kouki et al., 2009)
China	Domestic	Integrated VF	-	-	-	81.0	42.5	-	51.6	68.0	*Arundo donax, Canna indica*	(Wu et al., 2012)

CW: Constructed Wetland; SF: Surface Flow; SSF: Sub-Surface Flow; VF: Vertical Flow; HF: Horizontal Flow; TSS: Total Suspended Solids; TDS: Total Dissolved Solids; BOD: Biochemical Oxygen Demand; COD: Chemical Oxygen Demand; *NH4+*: Ammonium; *NO3-*: Nitrates; TN: Total Nitrogen; TP: Total Phosphorous.

Performance of CWs in Temperate Regions

Studies have shown that the cold climate and seasonal variations in a temperate climate can significantly impact the performance level of the pollutant removal process. It is reported that the SSF CWs are relatively appropriate for application in temperate regions (Kadlec and Wallace, 2009). Moreover, the literature shows that the TN removal efficiency of FWS CWs was lower in cold climates compared tolower in the cold climate than the tropical regions. TN removal was higher in VF CWs than the HF CWs irrespective of the climate, which can occur due to the available aerobic conditions present within the VF CWs.

Lower TP removal efficiency can be observed in the cold climate than tropical and sub-tropical regions due to tit the decreased pore space and thereby reducing the adsorption process of TP (Varma et al., 2020). The performance level of CWs is significantly affected due to the several limiting factors that prevailing in the temperate climate, including the premature drying of the macrophytes and reduction of microbial activities will enhance the inadequate contaminant/pollutant removal process. TSS removal efficiency in CWs is mainly performed by sedimentation, filtration and decantation mechanisms and those processes are not altered according to the seasonal variations or the temperature (Kadlec and Wallace, 2009). Studies have shown that the purification efficiency of BOD_5 decreases in periods of low temperature (Kadlec, 2003), while the COD removal mechanisms decrease during the winter season with the variation between 74% for unplanted and 81% for planted wetlands (Stein et al., 2003).

CWs can be subjected to clogging and freezing during the winter season, and there will be a significant reduction in treatment efficiency (Zhang et al., 2015; Wallace et al., 2001). Wetland vegetation is dormant during the winter season and reduces the Oxygen supply to the wetland, significantly affecting the Nitrogen and Phosphorous removal rates (Varma et al., 2020). It is found that the ideal temperature for Nitrification is located in the range of 25 ˚C to 40 ˚C (Vymazal, 2005).

There are relatively fewer published reports available for the temperate regions than CWs for the grey water treatment in tropical and sub-tropical regions. Although the CWs have enormous potential for treating grey water, the performance level in the cold climate is quite lower due to the declined natural mechanisms of the microorganisms and the wetland macrophytes. Therefore, the application of CWs for greywater treatment can be introduced as the best solution for the tropical and sub-tropical regions while introducing the new design concepts for the temperate climate to withstand the freezing atmospheric temperatures during the winter season (Wang et al., 2017).

Examples from Temperate Countries

Norway: High performance constructed wetland system for cold climate

HF wetland system was established with the combination of aerobic bio-filter to treat domestic wastewater. The removal efficiencies for the BOD, TN and TP were recorded as 81.1%, 57.9% and 81.3%, respectively. This study suggested that the increase of the wetland depth, keeping the water level at least 10 cm below the wetland surface, insulates the wetland with straw (new system and freezing and ice cap can be done to have successful frost mitigation. It showed that the CWs with pretreatment bio-filters remove more than 90% of Phosphorous and 40% to 50% of Nitrogen and bacteria to meet European standards for providing the swimming water quality and to produce an effluent quality that is not affected by the seasonal variations. Moreover, the pretreatment bio-filters which nitrify and reduce the BOD levels are necessary components within the CWs located in temperate regions (Jenssen et al., 2010).

China: Performance of integrated household constructed wetland for domestic wastewater treatment in rural areas

The experiment was carried out in the backyard of a rural family in Chang Ping, Beijing, China. It was an insulated VF model to avoid damage from low temperatures in winter. The Integrated Household Constructed Wetland (IHCW) system was planted with *Salix babylonica* to treat domestic wastewater in rural villages in northern China. It has achieved high overall removal efficiencies of 96.0%, 97.0%, 88.4% and 87.8% for BOD_5, TSS, NH_4-N, and TP, respectively. This study showed that a 0.4 m layer of biomass cover provided significant thermal insulation and maintained high treatment efficiency in freezing winter conditions. Moreover, it showed that this system is a cost-effective alternative for treating domestic wastewater, and it does not require any operational energy inputs while demonstrating the feasibility for single-family use in developing countries (Wu et al., 2011).

Estonia: Performance dynamics of a hybrid constructed wetland system

Hybrid constructed wetland systems were established with two subsurface flow filter beds and a two-chamber vertical subsurface flow filter followed by a horizontal subsurface flow filter with a total area of 432 m2 to measure the purification efficiency to estimate the mass removal process of organic matter, TSS, Nitrogen and Phosphorous. The purification effect for BOD_5, suspended solids, TP, TN and Ammonium were recorded as 86%, 84%, 89%, 53% and 73%, respectively. This research has shown that the hybrid CWs consisting of subsurface flow filters can work efficiently in Estonia's cold climate. Moreover, the treatment process parameters have met the standards given by the Water Act of Estonia for the wastewater treatment plants (Mander et al., 2007).

Greece: Converting treatment wetlands into treatment gardens: Use of ornamental plants for grey water treatment

VF wetlands were established to treat greywater and planted with *Pittosporum tobira, Hedera helix* and *Polygala myrtifolia.* The performance and economic feasibility of the proposed green technology concept were estimated during a 2-years study. The study has focused on using ornamental plants as the VF wetland system vegetation for grey water treatment to improve the aesthetic value and acceptability of the system.

The results have shown that the *Pittosporum tobira* and *Hedera helix* can be grown in the wetland system without any visual system. Those species tolerated both drought and flooding conditions, and partial defoliation of *Polygala myrtifolia* plants was observed during the winter. It showed that these species tolerated both drought and flooding conditions and were identified as suitable species for growing in residential buildings and in seasonal hotels. High average removal efficiencies of 99%, 96% and 94% were observed for BOD, COD and TSS, respectively, in all examined VFCWs, including unplanted beds. Furthermore, the 'treatment gardens' concept of the study has concluded that these systems provide an economically and technically viable alternative for greywater treatment with additional benefits to improve the aesthetic value of urban and peri-urban touristic areas (Kotsia et al., 2020).

Greece: A small-size vertical flow constructed wetland for on-site treatment of household wastewater

The study was carried out using a VF wetland system for on-site treatment of domestic wastewater, and the system comprised of a two-story building with three treatment stages, including two settling tanks with a VF wetland, a zeolite tank and planted using *Phragmites australis.* It showed the removal efficiencies of 96.4% for BOD, 94.4% for COD, 90.8% for TKN, 92.8% for Ammonia and 69.8% for TP with an effective purification process. Moreover, the zeolite was found to provide additional removal of Nitrogen, TP and organic matter and offered other effluent purification process (Gikas and Tsihrintzin, 2012).

Greece: On-site treatment of domestic wastewater using a small scale horizontal subsurface flow constructed wetland

Zeolite tank was used with a small scale HF wetland system and planted with the macrophyte variety; *Phragmites australis*. The zeolite tank was identified as an extra treatment unit to improve the effluent quality of the on-site wastewater treatment facility and it contributed more to remove Ammonia, TKN and less to BOD, COD and TP removal. The study concluded that the TKN, Ammonia and TP removal efficiencies dependence on the temperature and the use of CWs in wastewater treatment is an excellent solution for a single-family residence in rural areas. . The removal efficiencies were recorded as 86.5% for BOD, 84.6% for COD, 83.7% for TKN, 82.2% for Ammonia, 63.3% for TP, 79.3% for TSS and 99.9% for Total Coliforms (Gikas and Tsihrintzin, 2010).

Denmark: The use of vertical flow constructed wetland system for on-site treatment of domestic wastewater

A VF wetland system was constructed to estimate the purification effect of domestic wastewater. The wetland was planted by using the wetland macrophyte, *Phragmites australis*. This study has shown the guidelines for the VF CWs (planted filter beds), which fulfilled the requirement of 95% removal of BOD and 90% nitrification. Furthermore, this research has shown that this wetland system can be extended with the chemical precipitation of Phosphorous with Aluminium polychloride in the sedimentation tank to achieve a removal efficiency of 90% for the Phosphorous. Furthermore, the VF wetland systems are considered as an attractive alternative to the common practice of soil infiltration and provide efficient treatment of sewage before releasing it into the aquatic environment (Brix and Arias, 2005).

The performance level of the CWs for treating grey water in the temperate regions are summarized in table 4 according to the removal efficiencies of TSS, BOD, COD, NH_4^+, TN and TP with the type of macrophytes.

TABLE 04: The performance level of the CWs treating grey water in the temperate regions

Country	Type of Wastewater	Type of CW	Removal Efficiency (%)						Types of Macrophytes	References
			TSS	BOD	COD	NH_4^+	TN	TP		
Norway	Domestic	HF+ Aerobic biofilter	-	81.1	-	-	57.9	81.3	-	(Jenssen et al., 2010)
China	Domestic	VF	97.0	96.0	-	88.4	-	87.8	*Salix babylonica*	(Wu et al., 2011)
Estonia	-	Hybrid+ SSF filters	-	86.0	-	73.0	53.0	89.0	-	(Mander et al., 2007)
Greece	Greywater	VF	94.0	99.0	96.0	-	-	-	*Pittosporum tobira, Hedera helix, Polygala myrtifolia*	(Kotsia et al., 2020)
Greece	Domestic	HF	79.3	86.5	84.6	82.2	-	63.3	*Phragmites australis*	(Gikas and Tsihrintzin, 2010)
Greece	Domestic	VF	-	96.4	94.4	92.8	-	69.8	*Phragmites australis*	(Gikas and Tsihrintzin, 2012)
Denmark	Domestic	VF	-	95.0	-	90.0	-	-	*Phragmites australis*	(Brix and Arias, 2005)

CW: Constructed Wetland; SSF: Sub-Surface Flow; VF: Vertical Flow; HF: Horizontal Flow; TSS: Total Suspended Solids; TDS: Total Dissolved Solids; BOD: Biochemical Oxygen Demand; COD: Chemical Oxygen Demand; *NH4+*: Ammonium; *NO3-*: Nitrates; TN: Total Nitrogen; TP: Total Phosphorous.

CONCLUSION

Constructed wetland systems for greywater treatment can be recommended as the best alternative for the developing countries with the tropical climate where the highest treatment efficiencies can be obtained than the temperate countries. Subsurface flow constructed wetland systems are the best alternative for tropical regions due to the optimum climate for rapid biological growth with an enhanced removal process. The performance level of CWs in terms of TP removal has significantly lower in the cold climate. Hybrid wetlands can be recommended as the most appropriate wetland design for temperate countries with an increased purification process. Increased efficiency in the process of removing total Nitrogen and Phosphorus can be observed in tropical and sub-tropical regions (Total Nitrogen = 76.0% to 86.0% , Total Phosphorus = 71.0% to 85.8%) than in temperate regions (Total Nitrogen = 45.0% to 62.9% , Total Phosphorus = 36.5% to 89%). Greywater treatment processes in constructed wetland systems largely rely on biological processes, hence always affected by climatic conditions.

REFERENCES

[1] Albold, A., Wendland, C., Mihaylova, B., Ergunsel, A., and Galt, H. (2011). Case study-Constructed Wetlands, Sustainable wastewater treatment for rural and peri-urban communities in Bulgaria, WECF. (Available at *www.wecf.eu*)

[2] Anon. (2004). Constructed treatment wetlands. United States Environmental Protection Agency, 843-F-03-013, Office of water.

[3] Anon. (2008). Small-scale constructed wetlands for grey water and total domestic wastewater treatment, Ecosan Training Course 'Capacity Building for Ecological Sanitation', ESF, IESNI, Version 1. (Accessed 06. 12. 2020). Available at http://www.ecosanservices.org.

[4] Avery, L. M., Williams, R. A. D. F., Winward, G., Smith, C. S., Liu, S., Fayyaz, A., and Jefferson, B. (2007). Constructed wetlands for grey water treatment. Ecohydrology, Hydrobiology, 7(3-4), 91-200.

[5] Attwater, C. J. (1995). A literature review of constructed wetlands: A viable treatment system for acid mine drainage. Proceedings of 19th Annual British Columbia Mine Reclamation Symposium in Dawson Creek, BC, 1995. The technology and research committee on reclamation.

[6] Baskar, G., Deeptha. V. T., Rahman, A. A. (2009). Treatment of wastewater from kitchen in an institutional hostel mess using a constructed wetland. International journal of recent trends in engineering, 1, 6.

[7] Baumeister, R. F., Leary, M. R. (1997). WRITING Narrative Literature Reviews. DOI: *https://doi.org/10.1037/1089-2680.1.3.311*

[8] Bavor, H. J., Waters, M. (2007). Pollutant transformation performance in a peri-urban African wetland systems receiving point source effluent and different source pollutant inputs. Ecohydrology, Hydrobiology, 7(3-4), 201-206.

[9] Brix, H., and Arias, C. A. (2005). The use of vertical flow constructed wetland systems for on-site treatment of domestic wastewater: New Danish Guidelines. Journal of Ecological Engineering, 25(200), 491-500. DOI: https://doi.org/10.1016/j.ecoleng.2005.07.009

[10] Caselles-Osorio, A., Garcia, J. C. (2007). Impact of different feeding strategies and plant presence on the performance of shallow horizontal subsurface flow constructed wetlands. Sci. Total Environ. 378(3), 253-262.

[11] Chen, T. Y., Kao, C. M., Yeh, T. Y., Chien, H. Y., and Chao, A. C. (2006). Application of a constructed wetland for industrial wastewater treatment: A pilot-scale study. Chemosphere, 64(3), 497-502.

[12] Dadan, S. W., Taufiq, H., Dadan, S., TB, B. K., and Denny, K. (2016). A review on subsurface flow constructed wetlands in tropical and sub-tropical countries. Open Science Journal, 1(2).

[13] Di, Y., Liang, W., and Wu, Z. (2012). Treatment performance of integrated vertical-flow constructed wetlands for domestic wastewater. Journal of Ecological Engineering, 44, 152-159.

[14] Edwin, G. A., Poyyamoli, G., Nandhivarman, M., Prasath, R. A., and Boruah, D. (2015). Constructed wetlands for the treatment of grey water in campus premises. Implementing campus greening initiatives, world sustainability series, DOI: *10.1007/978-3-319-11961-8_25.*

[15] Gikas, G. D., and Tsihrintzin, V. A. (2012). A small-size vertical flow constructed wetland for on-site treatment of household wastewater. Ecological Engineering, 44(2012), 337-343.

[16] Gikas, G. D., and Tsihrintzin, V. A. (2010). On-site treatment of domestic wastewater using a small scale horizontal subsurface flow constructed wetland. Water Science and Technology-WST, 62. 3, 2010.

[17] Gorky, S. S. (2015). Treatment of wastewater using constructed wetland System. International research journal of latest trends in engineering and technology. 2, 3.

[18] Gross, A., Shmueli, O., Rosen, Z., Raven, E. (2006). Recycled vertical flow constructed wetland system- A novel method of recycling grey water for irrigation in small communities and households. Chemosphere, 66(2007), 916-923.

[19] Haydar, S., Haider, H., Nadeem, O., Hussain, G., and Zahrah, S. (2015). Proposed model for wastewater treatment in Lahore using constructed wetlands. Journal of faculty of engineering and technology, 22(1) (2016)07-

17. Available at https://www.researchgte.net/publication/274076630.

[20] Hoffmann, H., Platzer, C., Winker, M., and Muench, E. V. (2011). Technology review of constructed wetlands, subsurface flow constructed wetlands for grey water and domestic wastewater treatment. Sustainable sanitation – ecosan program, Eschborn.

[21] Ibrahim, R. (2018). Grey water treatment development model using construed wetland system through mutualism symbiosis hydrophyta and mycorrizha. International journal of civil engineering and technology. 9 (10), 611-617.

[22] Imhof, B., Muhlemann, J., and Morel, A. (2005). Greywater treatment on household level in developing countries – A state of the art review, ETH DUWIS.

[23] Jenssen, D. O., Machlum, T., Krogstad, T., and Vrale, L. (2010). High performance constructed wetland systems for cold climates. Journal of Environmental Sciences and Health, Part A, Toxic/Hazardous Substances and Environmental Engineering, 40 (6-7), 1343-1353.

[24] Jinarajadasa, M. H. C. W., Jayalath, J. M. D. M., Dissanayaka, D. M. S. H. and Duminda, D. M. S. (2018). Constructed wetland system for treatment of wastewater at hostel complex, faculty of Agriculture, Rajarata university of Sri Lanka.

[25] Kadlec, R. H. (2003). Pond and wetland treatment. Water Sci. Technol. 48(5), 1-8.

[26] Kadlec, R. H., Wallace, S. D. (2009). Treatment Wetlands. Second Edi. ed. Boca Raton, FL.

[27] Kayombo, S., Mbwett, T. S. A., Katima, J. H. Y., Ladegaard, N., and Jorgensen, S. E. Waste stabilization ponds and constructed wetlands design manual. Joint publication by UNEP-IETC with the Danish International Development Agency (Danida).

[28] Keerthana, K., Thivyatharsan, R. (2018). Constructed wetland system for slaughterhouse wastewater treatment. DOI:http://doi.org/10.4038/agrieast.v12i1.47.

[29] Kouki, S., M'hiri, F., Saidi, N., Belaid, S., and Hassen, A. (2009). Performance of a constructed wetland treating domestic wastewater during a macrophytes life cycle. Desalination, 246(1-3), 30 Sep. 2009, 452-467.

[30] Kotsia, D., Deligianni, A., Fyllas, N. M., Stasinakis, A. S., and Fountoulakis, M. S. (2020). Converting treatment wetlands into treatment gardens: Use of ornamental plants for grey water treatment. Journal: Science of the Total Environment, 744(2020)140889. DOI:https://doi.org/10.1016/j.scitotenv.2020.140889.

[31] Mander, U., Tooming, A., Mauring, T., and Oovel, M. (2007). Performance dynamics of a hybrid constructed wetland system. Ecohydrology, Hydrobiology, 7(3-4), 297-302.

[32] Morel, A. and Diener, S. (2006). Greywater Management in Low and Middle-Income Countries, Review of different treatment systems for households or neighborhoods. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dubendorf, Switzerland.

[33] Ng, W. J., Gunarathne, G. (2011). Design of tropical constructed wetlands. In: Tanaka, N., Ng, W. J., Jinadasa, K. B. S. N. (Eds.), Wetlands for tropical application. Imperial College Press, 69-94.

[34] Pearce, E. A., Smith, C, J. (2000). The Hutchinson World Weather Guide, 5th Edition, Helicon, 2000.

[35] Poyyamoli, G., Edwin, G. A., Muthu, N. (2013). Constructed wetlands for the treatment of domestic grey water: An instrument of the green economy to realize the millennium development goals. In: The economy of green cities, Springer, Netherlands, pp 313-321.

[36] Presentation on Sustainable sanitation and water management and constructed wetlands by Beat Stauffer, SSWM, International seecon gmbh. (Accessed 06. 12. 2020). Available at https://sswm.info/media/3.

[37] Roberts, B. M. (2011). Thesis on Development of portable recycled vertical flow constructed wetlands for the sustainable treatment of domestic grey water and dairy wastewater. Degree of Master of Science, Department of animal science, Colorado State University, Fort Collins, Colorado.

[38] Romanowski, N. (2009). Planting wetlands and dams. Second edition, A practical guide to wetland design, construction and propagation, published by Landlinks press, 150 Oxford Street, Collingwood WC 3066, Australia.

[39] Seswoya, R., and Zainal, M. Y. (2010). Subsurface flow construed wetland systems-Proposed design area for high strength effluent

domestic wastewater. Faculty of Civil and Environmental Engineering, Kolej University Technology Tun Hussein Onn, Batu Pahat, Johor. Available at *https://core.ac.uk/download/pdf/12007719.pdf*

[40] Stein, O. R., Hook, P. B., Biederman, J. A., Allen, W. C. and Borden, D. J. (2003). Does batch operation enhance oxidation in subsurface constructed wetlands?. Water Science and Technology, 48(5), 149-156. DOI:*10.2166/wst.2003.0306.*

[41] Tanaka, N., NG, W. J., Jinadasa, K. B. S. N. (2011). Wetlands for tropical application, wastewater treatment by constructed wetlands. Imperial College Press, 57 Shelton Street, Convent Garden, London WC2H9HF.

[42] Transfield, D., Denyer, D., Smart, P. (2003). Towards a methodology for developing evidence- Informed management knowledge by means of systematic review. British Journal of Management, Vol. 14, 207-222.

[43] Truu, M., Juhanson, J., Truu, J. (2009). Microbial biomass, activity and community composition in constructed wetlands. Sci. Total Environ. 407, 3958-3971. DOI:*https://doi.org/10.1016/J.SCITOTENV.2008.11.036.*

[44] Tsihrintzis, V. A., Akratos, C. S., Gikas, G. D., Karamouzis, D., and Angelakis, A. N. (2010). Performance and cost comparison of a free water surface and a vertical subsurface flow constructed wetlands. Journal of Env. Tech, 28, 2007 (6), 621-628.

[45] Tuszynska, A., Worst, M., Pempkowiak, H. O. (2007). Pollutants removal effectiveness in hydrophyte filters with sequential vertical and horizontal flow. Ecohydrology, Hydrobiology, 7(3-4), 321-327.

[46] UN-HABITAT. (2008). Constructed wetlands manual. NU-HABITAT Water for Asian Cities Programme Nepal, Kathmandu, Volume 978-92-1-131963-7

[47] Yadav, A., Chazarenc, F., Mutnur, S. (2018). Development of the 'French System' vertical flow constructed wetland to treatrawdomestic wastewater in India. Ecological Engineering 113(2018), 88-93. DOI: *https://doi.org/10.1016/j.ecoleng.2018.01.001*

[48] Varma, M., Gupta, A. K., Ghosal, S., Majumder, A. (2020). A review on performance of constructed wetlands in tropical and cold climate: Insights of mechanism, role of influencing factors and system modification in low temperature. Science of the Total Environment, 755(2).

[49] Vymazal, J. (2005). Horizontal Subsurface flow and Hybrid constructed wetland systems for wastewater treatment. Eco. Eng. 25(5), 478-490.

[50] Wang, M., Ahang, D. Q., Dong, J. W., and Tan, S. K. (2017). Constructed wetlands for wastewater treatment in cold climate – A review. Journal of Environmental Sciences. (Wang, M., et al., Title- A review, j. Environ. Sci. (2017). DOI: *http://dx.doi.org/10.1016/j.jes.2016.12.019*

[51] Wallace, S. D. (2005). Constructed wetlands: Design Approaches – PowerPoint presentation in (M. A. Gross and N. E. Deal, eds.) University Curriculum Development for Decentralized Wastewater Mgt. National Decentralized Water Resources Capacity Development Project. University of Arkansas, Fayetteville, AR.

[52] Wallace, S., Parkin, G., Cross, C. (2001). Cold climate wetlands: Design and performance. Water Sci. Technol. 44, 259-265. DOI:*https://doi.org/10.2166/wst.2001.0838.*

[53] Wu, S., Austin, D., Liu, L., Dong, R. (2011). Performance of integrated household constructed wetland for domestic wastewater treatment in rural areas. Ecological Eng., 37(6), 948-954. DOI: https://doi.org/10.1016/j.ecoleng.2011.02.002.

[54] Wu, S., Chang, J., Dai, Y., Wn, Z., Liang, W. (2012). Treatment performance and microorganism community structure of integrated vertical flow constructed wetland pots for domestic wastewater. Environmental Science and Pollution. Research 2013, 20:3789-3798.

[55] Zhang, D., Jinadasa, K. B. S. N., Gersberg, R. M., and Liu, Y. (2015). Application of constructed wetlands for wastewater treatment in tropical and subtropical regions (2000-2013). Journal of Environmental Sciences 30, DOI:*10.1016/j.jes.2014.10.013.*