Sustainable Greywater Management: Small-Scale Water Treatment Systems Using Artificial Wetlands for Enhanced Reuse"

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Abstract.

Small-scale water treatment systems belong in the area of study of environmental engineering. It uses the concepts of wastewater treatment using artificial wetlands. Greywater used in the kitchen contains less chemicals when compared to any other type of wastewater. After disposal, it gets combined with wastewater with higher concentrations of impurities. By the use of small-scale water treatment systems, this wastewater can be treated at least twice before disposal to STPs. The treated water can be used for gardening or flushing purposes.

Major parameters to be tested in this type of greywater are pH, Acidity, Alkalinity, Chlorides, TDS and Dissolved Oxygen. This experiment is significant in finding the usability of kitchen wastewater, also known as greywater. The results of this experiment will help reduce the load on STPs and reuse water twice before disposal.

Keywords: Wetlands, oxidation, wastewater parameters

1. Introduction

With the increasing urbanization, the demand for sustainable eco-technologies for wastewater treatment has been booming. With increased environmental awareness, safe treatment of pollution is one of the major concerns of most countries around the world. One such method of treating wastewater while keeping the environmental conditions in check is “constructed wetlands”. These constructed wetlands mimic naturally occurring wetlands and aid in the growth of vegetation in an area while treating greywater. This treated water can then be reused for irrigation, gardening, or even as kitchen water.

Constructed Wetlands were first developed in 1960 by Dr. K. Seidel in Germany [1]. She was German botanist in the 1900s. She showed that plants take up nutrients from the applied wastewater when a reed system is planted in an inert media [2]. Developed by Dr. Seidel, the vertical flow constructed wetland was one the first constructed wetlands in history [3].

There are mainly four types of constructed wetlands, namely: free-floating plants, floating leaved plants, emergent plants, and submerged plants. Under emergent plants, we have sub-surface flow-constructed wetlands and surface flow-constructed wetlands. Sub-surface flow constructed wetlands are divided into two categories, vertical flow constructed wetlands and horizontal flow constructed wetlands. A system of HF and VF together is known as a Hybrid system.

2. Design/Methods/Modelling

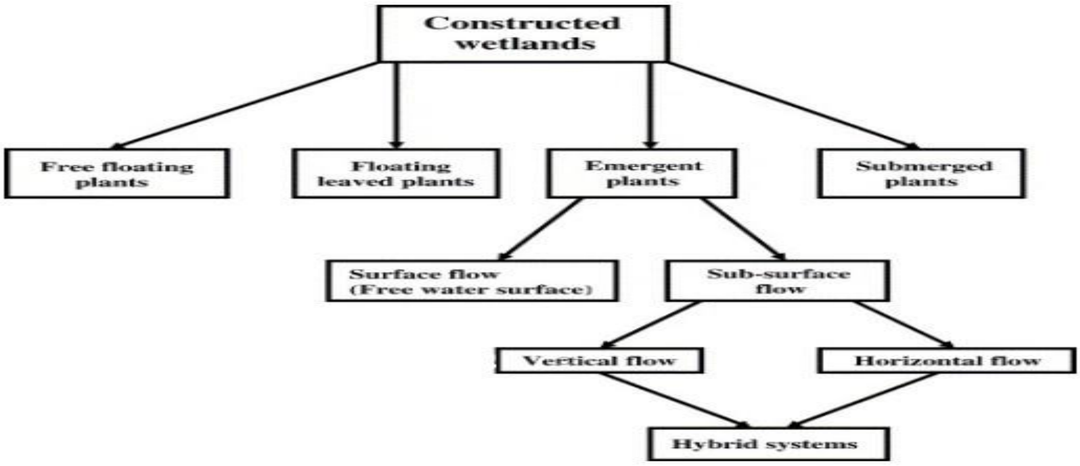


Figure 1- CW classification flowchart

There are three types of processes that take place in a constructed wetland [4]:

1. Physical processes: Filtration/ Settling
2. Chemical processes: Oxidation, Reduction, Volatilization, Adsorption and Precipitation
3. Biological processes: Accumulation in plant tissues, compost accumulation, biogas production.

Dr. K. Seidel explained about the origin of constructed wetlands and differentiated between Horizontal Flow Sub-Surface Constructed Wetlands (HFCW) and Vertical Flow Constructed Wetlands (VFCW) [1]. She stated that in a HFCW limited phosphorous removal took place. The major methods for removal of nitrogen are nitrification and denitrification but usually nitrification is incomplete or insufficient in HFCW. However, it is the most used methods that treats onsite domestic wastewater. It is also known for treating landfill leachate. The working of the VFCW was explained to be intermittent with wastewater gradually percolating down through the bed. It was observed to provide good oxygen and hence derived to help with better nitrification. It helps with good removal of organics, TSS and Ammonia. In this method, very little room is required for denitrification. It also requires less land. It can be used for small sources of pollution [5] . Studies observed that VFCW showed better mass removal efficiency when compared to HFCW. The whole treatment process is primarily influenced by the vegetation, sand strata and substrate interaction. The phosphates removal efficiency was promising and stable in the treatment process and hence can be adopted in small-scale purposes.

Wetlands systems were studied back in the 90's [6][7]. In the experiment conducted by (Johansen and Brix, 1996), they used two beds, the first one being HF and the second one being VF. The HF bed was sized at 8.8 m^2/pe and the VF bed was sized at 0.76m^2/pe. They found that the levels of BOD_5 and TSS removed was significant but the nitrification remained incomplete. However, TN was reduced presumably due to denitrification. He then explained that the experiment conducted by (Burka, U. and Lawrence, 1990) included 4 stages of CW beds. Firstly, there was a VF sized 0.74 m^2/pe followed by another VF of 0.23 m^2/pe then there was a HF of 0.12 m^2/pe size and finally another HF with 0.30 m^2/pe size. He observed that although the removal of BOD_5 and TSS was satisfactory, the VF stages were too small to achieve full nitrification. However, remarkable denitrification was taking place in both the HF stages despite the relatively low BOD_5.

A multistep treatment is more efficient of which constructed wetlands are a part [8]. The first step would be a primary treatment tank or a settling tank followed by a constructed wetland and finally consists a recirculating sand filter. They stated that the importance of multiple steps is that none of the steps must operate at the 98% level but the overall efficiency will be 98%. Based on the end use of the effluent, the domestic wastewater management strategy must be planned [9]. Factors like ground water recharge or discharge, agricultural reuse, etc must be taken into consideration.

It was noted that nutrient removal efficiencies in hybrid vertical flow constructed wetlands were dependent on the species of plants used in the wetlands [10]. The plant roots could be the key factor in nutrient removal. The highest nutrient removal efficiency was achieved in late summer and early autumn, i.e. July, August and September.

A study was conducted on the types of plants used in constructed wetlands [11]. The authors reviewed multiple papers and derived a table with details of the type of plantation and the filter media suitable for these plants. They concluded that it is essential to know the type of plant to be used in a constructed wetland according to our preferred location and soil type. These are the discussed guidelines for selection of plants [12]:

•As the rate of survival will be high of native species, plants that are selected for the CW are preferred to be native to the area of where the CW is being constructed.

•They must all be flood tolerant. This is an essential factor because the plants will be subjected to constant flow of wastewater for treatment.

•They should be from the plant species that grow all year long and must be long lasting. This way they will continue growing in the same area without any concern of being washed away or carried away by external factors like wind.

•They must be plants that grow relatively faster as the use of slower growing plants will require a greater number of plants that must be planted close to each other.

•They should be studied for the types of pollutants they treat and must be selected based on the pollutants that they're going to be exposed to.

•If the wetland is used as wildlife habitat, the plants selected must be able to provide food and shelter for the wildlife of the area.

Reeds can be planted as rhizomes, seedlings or planted clumps [9]. The clumps can be planted during all seasons. Rhizomes and seedlings will grow best when planted pre-monsoon.

Experiments with aquatic macrophytes to treat dairy wastewater noted that *Cyperus articulatus* was the aquatic macrophyte with the best global performance in organic load reduction, significantly superior to the others [13]. All studied macrophytes supported the gross organic loads of the diary effluent, allowing treatment without the need for dilution. Their findings demonstrated that the series combination of CWs is a tactic that can boost phytoremediation effectiveness, particularly when the goal is to recycle organic and inorganic waste. Different species of plants in the categories of polycultures (species mixtures) and monocultures were studied [14]. It was concluded that polycultures may perform better than monocultures. Although, *Typha Latifolia* was noted to be the stronger competitor, it has a few aesthetic drawbacks and possesses an aggressive nature due to which it is avoided in the use of these systems. However, experiments with two plants, *Phragmites Carca* and *Typha Latifolia* and found that *Phragmites Carca* was more efficient in N removal when compared to *Typha Latifolia* [15]. *Phragmites Carca* gets established quickly and grows profusely. They concluded that the performance of a wetland depends on rainfall, temperature, etc.

When studied the efficiency of *Typha Latifolia* integrated with Biochar, it was found that they treat BOD, COD, Nitrates, Sulphates, Phosphates and Coliform [16]. The *Typha* leaf seemed to have contributed to high respiration and photosynthesis activities, leading to efficient oxygen supply in its rhizome in wetlands. These plants have been noted to develop well in Biochar. The efficiency of *Typha* integrated with Biochar was relatively more. Due to *Typha*'s enhanced root system, the efficiency of the wetland seemed to have increased. An experiment on biochar said that the results of soil analysis showed that the crude oil degradation efficiency of biochar was 34% [17]. Later, another study revealed that biochar was characterized as a new carbonaceous material for the adsorption of toluene from water [18]. Cocopeat is a magnetic sorbent with potential use in oil spill clean-up [19]. Therefore, concluding that cocopeat can absorb oil. BOD elimination efficiency in percentage of *Typha Latifolia* was 88.3% and *Phragmites Australis* was 84.5%. Cattails (*Typha Latifolia*) was seen to be more efficient than Common Reed (*Phragmites Australis*) [20]. Cattails were seen to contribute to higher pollutant removal. They noted that it is essential to select substrate porous media for Nitrogen and Phosphorus removal. It was observed that finer porous media from river bed (igneous rock) contribute to higher Nitrogen and Phosphorus removal. An experiment was conducted with 4 constructed wetland pilot projects out of which two included *Cyperus Articulatus* plants and the other two were unplanted [21]. High organic matter removal efficiency can be achieved with *Cyperus Articulates*. The total biomass production by *Cyperus Articulatus* was 5.0 (±0.16) kg.m-2.

The plant *Cyperus Alternifolius* can eliminate parameters like COD properly [22]. This is a suitable system for primary treatment. However, it is not appropriate for advanced wastewater treatment like the tertiary purposes and nutrients removal such as phosphorus. Therefore, it is better to use this plant alongside other plants that are capable of phosphorus elimination. Overall, *Cyperus Alternifolius* is widely famous, fast growing, cost-effective and can also be used as feed for livestock and aquaculture. An experiment was conducted using the plant species of *Cana Indica* to treat greywater [23]. The water storage capacity of their tank was 50 litres. They built and used a HFCW and concluded that they were able to reduce BOD, Suspended Solids, Total Solids and Fixed Solids significantly.

1.1 Plants used in Wetlands

1.1.1 The commonly used plants for constructed wetlands are:

Figure 2- Water Hyacinth

Figure 3- Typha Latifolia

Figure 4- Scirpus Validus

Figure 5- Phalaris Arundinacea

Typha Latifolia:

The common name of Typha L. is cattails. When compared to common reed, cattails are more efficient [20]. It treats BOD, COD, Nitrates, Sulphates, Phosphates and Coliform. The Typha L. leaf contributes to high respiration and photosynthesis activities, this in turn leads to efficient supply in its rhizome in wetlands. Typha L. is seen to have developed well in Biochar and is more efficient when incorporated with it. The efficiency of the wetlands increases due to the enhanced root system of this plant [16].

Phragmites Australis:

The common name of Phragmites A. is common reed. These plants were found to be the most commonly planted variety in constructed wetlands. In Phragmites australis, root exudates are reported to possess antibacterial activity against pathogenic and faecal indicator bacteria [24].

Cyperus Articulatus:

High organic matter removal efficiency can be achieved with C. Articulatus [21]. In an experiment, the total biomass production was 5.0 (±0.16) $kg.m^{-2}$. It concluded that this species could be promising for treating domestic wastewater in the Columbia Caribbean region. C. Articulatus can transfer high amounts of oxygen to constructed wetland systems compared to other plants that are commonly used [13].

1.1.2 Role of plants

When compared to the degradation processes that are caused by micro-organisms, plants play a very minor role in treating common wastewater parameters. However, in the case of other pollutants like heavy metals and special organic compounds, the selection of the right kind of plant species plays a vital role to enhance the treatment efficiency. In India the *Phragmites* species have been reported to be successfully used. They are observed to grow to a height of 3-4 m at full growth [2]. The roots and rhizomes of the plants used in wetlands penetrate through the soil, loosen the soil and help with percolation. They supply oxygen to the micro-organisms present in the substrate which in turn helps stabilize the organic matter applied.

The latest trends in science and engineering show that Constructed Wetlands have potential use in the near future [25]. CW can be used in agricultural schemes and can aid in increasing the fertility of the soil. They host birds and are a potential source of timber and wood. They also stated that CWs yield biomass which is a source of renewable energy. Effluent from CWs can be used in the agricultural fields. While comparing the life cycle cost analysis of different wastewater technologies, Moving Bed Biofilm Reactor (MBBR) and Sequencing Batch Reactor (SBR) require high construction, operation and maintenance cost but also have higher removal efficiency with less land requirement [24]. In the case of CWs, they require larger area in ratio but have a higher removal efficiency of organic matter and nutrients. They also cost less for operation and maintenance. CWs only require 1%-2% of capital cost for operation and maintenance which is very low in comparison to conventional systems. The economic evaluation of proposed NTS (Natural Treatment Systems) models, such as the CW's, estimates that these are 2-10 times cheaper than the conventional STP providing 1.200 million m^3 / day of treated wastewater as irrigation source in Hyderabad and 38.254 million m^3 / day in the Indian context [26]. Dr. Shyam Asolekar, who also published a book [2], along with some of his students from IIT Bombay worked on a constructed wetlands project. They designed it on an institutional scale to treat wastewater generated in the IIT Bombay campus. This treated water is then discharged into the Powai Lake. The capacity of the system is 25 KLD.

Mr. Chris Shirley-Smith of Water Works UK collaborated with Imperial College London and Cranfield University to engineer the idea of GROW- Green Rooftop Water Recycling Systems. This construction pumps greywater from washbasins, baths and showers up to the GROW system, which is built on the roof a building. Specially chosen plants are planted in this inclined system. Wastewater passes through this setup and leaves green water which is not drinkable but can be used for gardening or toilet flushes. This system helps waster to be reused twice before being treated. They carefully choose semi-aquatic plants to use in this system. They found of the most successful plants to be water mint. They learned that the roots of this plant work as a disinfectant [27].

There are both aerobic and anaerobic microbial transformations in a CW. Microbes are known to be capable of degrading most of the organic pollutants but the rate of degradation of these pollutants varies considerably. It depends on chemical and structural properties of the organic compound and also the chemical and physical environment of the soil [28].

A study was conducted on the efficiency of a mini constructed wetland in treating small scale greywater [29]. Their study focused on the water used by 6 females of the average age of 20 to 30 years. The used water included wastewater from three bedrooms, two bathrooms, a living room and a kitchen. They used a pre-treatment tank to separate food waste and hair follicles. This tank consisted of four layers, namely: gravel, coal, fine sand and gravel again. This filtered water was then sent to two constructed wetlands out of which only one was planted with *Lepironia Articulata*. This system was observed to be a feasible alternative for small scale greywater treatment. The efficiency of grey-water reuse at household level was assessed [30]. The aim was to build a project that aim could implement grey water collection, treatment and productive reuse in home farming. A total of six constructed units were monitored and the treated water was used for the irrigation of trees. Experiments were run on the trees for 2 years while using treated water and observed a positive growth of the olive trees. An on-site wastewater treatment system for a two-family house in Greece was designed and constructed [31]. The facility was monitored for a time period of 40 months. Their setup comprised of three settling tanks, the third one had a pump. Then they had a vertical flow CW followed by a Zeolite tank and an effluent collection tank. It was concluded that in rural and ecologically remote areas, sewer collection is impractical and impossible. Small-size, on-site constructed wetlands provide an excellent alternative solution for this problem. The author stated that his experiment in 'Advira' operates satisfactorily, showing high removal efficiencies for BOD, TSS, COD, ammonia, phosphorous, etc.

1.2 Components of an artificially constructed wetland[32]

1) Impermeable layer of clay
2) Substrate level of gravel
3) Ground vegetation zone

1.2.1 Impermeable layer of clay

This layer filters and prevents waste particles from travelling further down into the lower aquifers.

1.2.2 Substrate level of gravel

This level supports the root zone by providing it with nutrients. The water flows in this root zone. The processes of denitrification and bioremediation are performed in this layer.

1.2.3 Ground vegetation zone

The above ground vegetative layer is the layer that contains plant material. The type of vegetation used depends on the local climate and pollutants to be treated [23].

2 THEORETICAL ANALYSIS

- In this experiment a pot of specific dimensions is used.
- Approximately 2 litres of greywater is supplied to it every 2 days from the top.
- The tub weighs about 10 kgs. It includes the combined weight of soil, sand, gravel of different sizes, biochar, and plants.
- Each layer is about 10 cm in height.
- Four, small, healthy Canna Indica plants are planted into the prepared bed.
- Holes are drilled from the bottom of the pot. This pot is placed on a plate. Hence, the effluent is collected in the plate.
- Treated water samples are collected and tested in the laboratory, every alternate day.

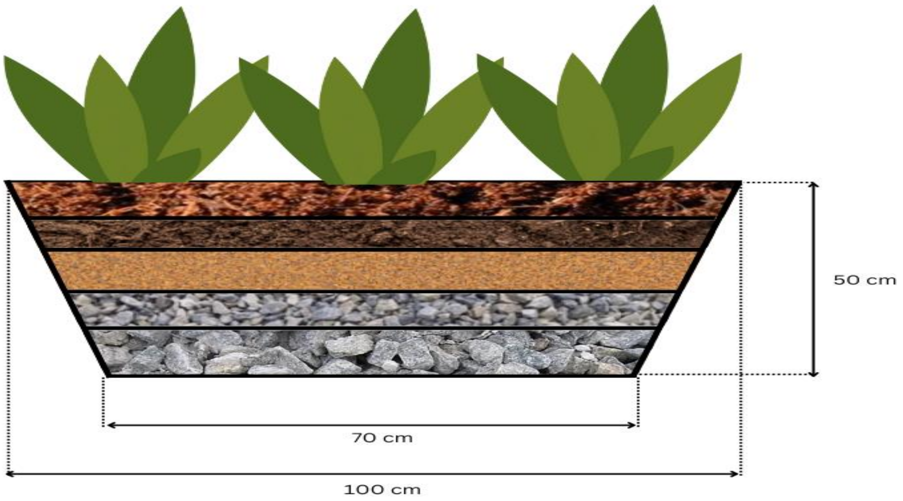


Figure 6– Depiction of the experimental setup

3 EXPERIMENTAL INVESTIGATIONS

3.1 Materials used

Figure 7- Pot of dimensions: 100cm x 70cm x 50cm

Figure 8- Layer 1:

Gravel ≥ 4.48mm

Figure 9- Layer 2:

Gravel 1.18mm

Figure 10- Layer 3:

Fine sand

Figure 11- Layer 4:

Garden soil

Figure 12- Layer 5:

Cocopeat

Parameters tested

Determination of pH

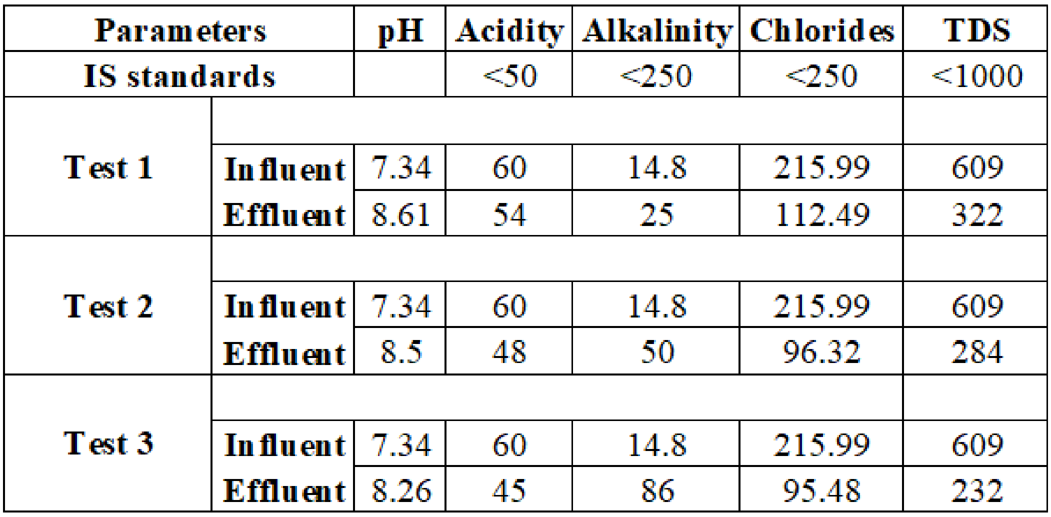
Determination of Acidity

Determination of Alkalinity

Determination of Chlorides

Determination of Dissolved Oxygen

4. EXPERIMENTAL RESULTS



Parameters		**pH**	**Acidity**	**Alkalinity**	**Chlorides**	**TDS**
IS standards			<50	<250	<250	<1000
Test 1						
	Influent	7.34	60	14.8	215.99	609
	Effluent	8.61	54	25	112.49	322
Test 2						
	Influent	7.34	60	14.8	215.99	609
	Effluent	8.5	48	50	96.32	284
Test 3						
	Influent	7.34	60	14.8	215.99	609
	Effluent	8.26	45	86	95.48	232

Table 1- Test results

A sample of greywater was used an influent for the experimental setup. The setup was watered every alternate day with the same sample. The above values determine the results obtained for three different effluent tests which were conducted on alternate days. The experiment was conducted in a span of 6 days.

Column one represents pH values. This test was conducted using pH paper and then pH meter for better accuracy.

Column two represents the acidity of the sample of water taken.

Column three represents the alkalinity of the sample of water taken.

Column four represents the chlorides of the sample of water taken.

Column five represents the total dissolved solids in the sample of water taken. this was determined using tds meter.

According to the tests conducted the pH of the influent was 7.34. In the first test of the effluent, the value increased to 8.61. In the second test the value was noted to be 8.5. Finally, in the third test, the value came down to 8.26. This shows that the effluent was relatively more basic than the influent.

According to Indian Standards, in usable water, chloride content must be below 250mg/l. In the influent the number of chlorides is 215mg/l. In the first test of the effluent, the

concentration of chlorides was seen to be reduced to 112.49mg/l. In the second test, it went down to 96.32mg/l and finally in the last test the results were found to be 95.48mg/l.

According to Indian Standards, water having TDS above 1000 ppm is unsafe for human consumption. The effluent had a concentration of 609 ppm TDS. After the first treatment, the test results showed significant reduction in TDS values at 322 ppm. In the second test the value reduced to 284 ppm. Finally, the third test showed values of TDS as 232 ppm.

4. Conclusions

This project involved the construction and evaluation of a mini-artificial wetland prototype, comprising layers of aggregates, sand, soil, and cocopeat. A continuous supply of wastewater served as the influent for this experimental setup. Initial testing of the influent for various wastewater parameters, followed by alternate-day testing of the effluent, revealed a significant reduction in impurities. The findings affirm the efficacy of the mini-artificial wetland in mitigating impurities in wastewater.

In light of the results, it is recommended that the reduction in impurities could be further enhanced by implementing proper pre-filtration before treatment and subsequent disinfection. The absence of disinfection may compromise the overall effectiveness of the system, emphasizing the importance of a comprehensive treatment approach.

In conclusion, this study successfully examined the parameters of greywater using a small-scale, eco-friendly wastewater treatment setup. The results, while satisfactory, suggest the potential for improvement with further refinements to the model. The project highlights the promising prospects of decentralized wastewater treatment, encouraging ongoing efforts in research and development for more appealing and efficient outcomes in sustainable greywater management.

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