**Treatment of GW through lab-scale constructed wetland**

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Abstract

Wastewater generated from houses is classified into two types-greywater and blackwater. Greywater is wastewater that suffers from little to no faecal contamination. Due to the lesser amount of faecal matter, it has been found that treating greywater separately from blackwater may be more economical since it reduces loads on treatment technologies. Segregated greywater may also be used for irrigation, flushing, etc.

Regarding greywater treatment, constructed wetlands are a technology that proves to be very promising. They require low operational costs, can be maintained easily and without much skill, and have shown the ability to improve water quality considerably.

In the present study, the characteristics of greywater generated from the hostels of IIT Indore were studied. The greywater was then treated using a lab-scale constructed wetland. Samples of the treated greywater were tested for several parameters. This study shows that greywater segregation and treatment through technologies like constructed wetland is a strategy that can be adopted to conserve water in our institute.

Abbreviations

BlackWater-BW GreyWater-GW

Light GreyWater-LGW Dark GW-DGW

Constructed wetland-CW Surface flow constructed wetland-SFCW

Subsurface flow constructed wetland-SSFCW Vertical subsurface flow constructed wetland-VSSFCW

Horizontal subsurface constructed wetland-HSSFCW Membrane BioReactor-MBR

Rotatory Biological Contractor-RBC Total dissolved solids-TDS

Total suspended solids-TSS Hydraulic retention time-HRT

Introduction

Domestic wastewater is the major contributor to the total wastewater generated (up to 75%) (Delhiraja & Philip, 2020). Typically, GW flow is around 65 % of the total wastewater flow from a household. Further, light GW is around 50 % of the total GW (Ghaitidak & Yadav, 2013). Due to a large amount of GW being generated, and the ease with which it can be reused for purposes like gardening, flushing, etc., due to less contamination, it’s reuse is seen as a viable way to reduce freshwater consumption.

GW is wastewater collected from household sources without input from toilets or commode streams. (Vuppaladadiyam et al., 2019). The quality of GW mainly depends on the water supply source, the type of water distribution system (e.g. leaks or biofilm formation on the walls of pipes), and household activities (Eriksson et al., 2002). According to household activity due to which GW is generated, GW can be classified into two types.

Light GW is generated from bathing, brushing, face, and hand washing in sinks. Bathroom GW contains soaps, shampoos, toothpaste, body care products, shaving waste, skin, hair, body fats, lint, and traces of urine and faeces (Noah , 2002). The pH of light GW is similar to that of tap water. The turbidity in light GW is moderate and mainly caused by surfactants such as soap and shampoo. TDS and TSS are much lower in the case of light GW, leading to fewer chances of clogging in the treatment system.

Dark GW is generated from dishwashing and laundry activities and is generally more contaminated than light GW. Water generated in the kitchen is generally more contaminated than in the laundry. Various detergents increase the alkalinity and pH of laundry water considerably. The main reason for high turbidity in kitchen wastewater was floating food and soil particles. In contrast, in laundry and bathroom water, it was attributed to the presence of detergents, hair, fibers, etc. (Edwin et al., 2014). Similar to turbidity, TSS is higher in kitchen wastewater than in laundry wastewater. However, TDS is higher in laundry wastewater as compared to kitchen wastewater.

Various treatment techniques exist for the treatment of GW. These include filtration, coagulation, chlorination, MBR, RBC, and constructed wetlands. In the present study, we utilized a vertical flow constructed wetland for the treatment of GW.

Constructed wetlands (CW) are also one such system considered sustainable, cost-effective, and a viable treatment option for treating GW in small communities (Ramprasad et al., 2017). Over the past few years, CW has gained popularity due to its effectiveness, low capital investment, and low cost of operation with less maintenance over the conventional systems for treating various types of wastewater such as municipal wastewater, textile effluent, and landfill leachate (Masi et al., 2010). Constructed wetlands have also been used to treat GW in many circumstances.

Constructed wetlands can be classified into two types based on the type of flow: surface flow and subsurface flow wetlands. The free water surface flow (FWSF) constructed wetlands resemble natural wetlands’ appearance and function. These comprise open water areas, emergent vegetation, and varying water depths (Naz et al., 2009). Subsurface wetlands are once again divided into vertically constructed wetlands and horizontally constructed wetlands.

HSSF CW is continuously fed from a side of the wetland. The depurated wastewater is collected on the opposite side, keeping all the soil saturated with water. Because of this, the opportunities for contact between air and water are limited and, in turn, the oxygen transference (Kadlec et al., 1996). On the other hand, VSSF CW is sequentially fed throughout the entire surface of the wetland, collecting the depurated wastewater at the bottom of it. In this case, there are parts of the soil saturated and unsaturated water (Mena et al., 2008). So, there is greater availability of oxygen to water. VSSF also requires less space to operate, as compared to HSSF. The design of HSSF also involves providing a slope to the surface, which may become complex. Therefore, in the present study, VSSF was used to treat GW.

In the present study, a lab-scale VSSF was designed, and the plant used was Pandanus Veitchii. Pandanus is a species of tropical plant that occupy less space and also serves various ornamental purposes. It is also easily available and easy to maintain, and thus can easily be planted in a larger area for larger scale wetlands.

GW has an increasing international recognition as an alternative water source for reuse such as irrigation, toilet flushing, etc. Therefore, GW should be regarded as a valuable resource and not a waste (Ghaitidak & Yadav, 2013). The present study aims to characterize the GW being generated from hostels in IIT Indore, specifically the bathwater and laundry water. The study also aims at studying the purification capability of a constructed VSSF with Pandanus Veitchii as the plant. The characteristics of the treated water are also studied.

The scope of this study is limited to the study of two GW samples collected from C.V. Raman hostel in IIT Indore to give an idea of values of parameters like TSS, TDS, etc. Also, batch loading was performed in the CSSF with 1.5 liters of water loaded every day, and the sample collected for five days were tested to get an idea of the variation of various parameters like TSS, TDS, etc. with time, and the removal efficiency of lab constructed wetland in removing such parameters.

Literature review

Reuse of GW

A study conducted by (Vuppaladadiyam et al., 2019) considered the risks and benefits associated with GW reuse and the hindrances in treating GW and reusing it for various purposes such as irrigation flushing, etc.

When it comes to irrigation, there are two factors to consider. Firstly, GW contains many Legionella species, which in aerosol form can be inhaled during irrigation or flushing, leading to disease. Higher boron concentration and salinity may also have a detrimental effect on soil. Also, long-term exposure to untreated GW may reduce water permeability and capillarity.

If GW is not treated properly before reuse for flushing, it may lead to odor. Also, stagnant water may lead to the problem of mosquitoes. Thus, we see that many factors must be considered before reusing GW. Therefore, adequate treatment of GW is required before reuse.

The hindrances to GW treatment are mostly technological or due to public perception. Technologically speaking, it has been found that the segregation of GW and BW and treatment separately reduces the load on treatment technologies. Besides, it is easier to reuse GW with less treatment than BW, conserving fresh water for the aforementioned activities.

Also, the public has to be made aware of the benefits of GW reuse. Perceptions that regard treated GW as unsuitable for use must be corrected because this is an effective method to combat the scarcity of freshwater resources.

Therefore, in the present study, we attempted to characterize the GW and offer treatment techniques as constructed wetlands for future development in our institute.

Characterization of GW

A study conducted on the campus of IIT Madras (Delhiraja & Philip, 2020), compared the GW generated from various sources, such as the bathroom, wash basin, kitchen sink, and laundry, and tried to compare the values of various parameters such as pH, electrical conductivity (EC), turbidity, solids (total solids (TS), total suspended solids (TSS), volatile suspended solids (VSS), and total dissolved solids (TDS)), chemical parameters such as alkalinity, hardness, chlorides and sulfates, organics such as total biochemical oxygen demand (BOD5), total chemical oxygen demand (CODtot) and total organic carbon (TOC), nutrients such as total nitrogen (TN), ammonia (NH4+), nitrate (NO3−), nitrite (NO2−) and total phosphate (TP), pathogens (total and faecal coliforms), heavy metals, oil and grease, and surfactants such as SDS.

Comparing these parameters revealed the higher alkalinity and pH in laundry water due to the presence of detergents. However, the TSS and turbidity level in bathroom water was higher than that in laundry water. TDS level was larger in laundry water.

Similar studies have been conducted in other institutions, and these studies are necessary to understand whether the GW being generated follows similar trends to those observed universally. They are also necessary because a wide variation of these parameters is found in GW generated in different locations, such as hostels, offices, public dwellings, etc., due to different usage patterns. A detailed understanding of the variation of these parameters in laundry and bath water generated in IIT Indore hostels is necessary since many new hostels are being constructed. Treatment of GW generated from these hostels can be made efficient by understanding the contamination in the GW.

Treatment techniques for GW

A study by (Ghaitidak & Yadav, 2013) compared the efficiency of various treatment systems in treating GW. The various systems were compared regarding their removal efficiency for various parameters. They were also compared regarding whether pre-treatment was required, the ease of construction, and maintenance.

Coagulation/flocculation systems often require pH adjustment to achieve good action, mechanical removal of flocs, and post-treatment with NaOCl and HRT comparable to 8 hours which is not feasible. Even now, their removal efficiency is low compared to other technologies.

Different types of filtration show different removal efficiency in different parameters. The maintenance of the filtration unit is difficult, and the removal of primarily particulate matter only takes place, achieved in many other technologies in addition to chemical and biological purification.

RBC is a technology that uses the aerobic activity of bacteria to remove contaminants. Though it is efficient for removing organic matter, preliminary treatment is required for removing particulate matter. Additionally, the construction and maintenance of RBCs are difficult.

The MBR is one of the more promising technologies since it combines the biological purification of activated sludge process with membrane filtration to remove particulate matter. However, the periodic membrane removal and complex design inhibit its use in reuse scenarios.

Constructed wetlands are a class of easy biological treatments to construct and maintain. They provide great removal efficiency when it comes to physical parameters like TSS and turbidity, and provided adequate HRT, also provide good chemical purification and biological purification. This can be attributed to biofilm development at the roots of plants in wetlands, that through combined aerobic and anaerobic activity, indulge in nitrification and denitrification to remove nitrogen content, and also removal of phosphorous takes place. Plants also absorb other harmful chemicals.

Hence, in present study, a lab scale VSSF was constructed to treat the generated GW, and understand its efficiency at removing various parameters.

Different types of wetlands

A study by (Sundaravadivel & Vigneswaran, 2001) considered the various types of wetlands and the design aspects that must be considered when constructing a specific type of wetland.

SF wetlands are densely vegetated and resemble natural wetlands in many aspects, especially because the water level maintained is above the surface level. However, the collection of water may cause the problem of mosquitoes and odour.

HSSF wetlands have a gentle slope, and a continuous flow of water is maintained, leading to substrate saturation. The water table level is below the level of the surface. However, the design of this wetland is complex. There is reduced oxygen content, and a larger area is occupied.

VSSF occupies a small area and can be continuously loaded or batch loaded i.e., loaded at regular intervals; thus, frequent contact with oxygen is allowed. Thus, in our current study, a lab-scale VSSF was used to treat the generated GW with a batch loading of 1.5 litres every day for five days, and the five samples were tested for various parameters.

It has been observed that no study has been done highlighting the GW characteristics in our institute. Also, the viability of treatment techniques like VSSF for treating GW has not been explored for our institute.

This study aims to help guide the development of a large-scale constructed wetland to reuse GW in our institute, which would help us perform our part in freshwater conservation.

Materials and Methodology

Tests conducted

Tests were conducted for the following parameters: TSS, TDS, pH, EC, Alkalinity, and Hardness.

TSS test was conducted using a conical flask, funnel, and pre-weighted filter paper. A 100 ml sample was taken. The dry filter paper was fixed in the funnel, and the 100 ml sample was poured through the filter paper until it was deposited in the conical flask. Then, the paper was placed in a hot air oven for 2 hours to dry off excess fluid, thus depositing suspended solids on the paper. The final and initial weights were subtracted, and the difference was noted in mg. This value was then multiplied by 10, yielding the TSS value for the sample in mg/l.

The TDS, pH, and EC tests were conducted using the Hanna instrument for measuring the same. The pH was measured using a probe (HI1131) encased in a bulb of permeable glass, which consists of a sensor electrode with pH 7 buffer and a reference electrode with saturated KCl solution. Silver wires coated with silver are dipped in both electrodes. H+ replaces metal ions on the bulb, and the electromotive force generated is converted to pH.

The EC and TDS tests were conducted using another probe (HI76312) of four ring variety. In this probe, alternating current is sent through two outer drive electrodes, which induces a current in the solution. The voltage generated is converted to EC, and the probe is so adjusted that the TDS (mg/L) is half of EC (µS/cm).

The Alkalinity test was performed by titration of 2 ml sample diluted to 100 ml with distilled water (filter water for a sample of treated waters), to which 2 drops of methyl orange were added until orange coloration was observed. This solution was then titrated with 0.02 N H2SO4 solution until color changed to pink. The samples failed to react with the phenolphthalein indicator, which was also used. The Alkalinity was calculated as mg of CaCO3 per litre, given by the formula:

Where A=ml of 0.02 N H2SO4 used

N=Normality of acid=0.02

The Hardness of the sample was measured by titrating 50 ml of the sample diluted up to 100 ml with distilled water (filter water in case of treated waters), to which 2 ml ammonia buffer was added. Then 3-4 drops of EBT solution (0.5 g of dye in 100 g ethanol) was added until violet coloration was observed. This solution was titrated with EDTA solution (3.723 g of EDTA powder in 1000 ml of distilled water) until color changed to cobalt blue. The Hardness was calculated as mg of CaCO3 per litre by using the formula:

Where A=ml titration for sample

B=mg CaCO3 equivalent to 1 ml EDTA titrant

Design of VSSF

A lab-scale VSSF was designed in a circular plastic tub of 27 cm diameter and 45 cm depth. Two holes of cm in diameter were made, one at the bottom of the tub and one 15 cm above the first hole. PVC pipes were fixed in both holes, the first hole being for aeration and the second for the collection of treated water. M-seal was used to cover the area around the pipes to ensure no water leakage. Gravel was filled up to a depth of 15 cm, and soil was filled to a depth of 15 cm. The Pandanus Veitchii plant with a rooting depth of 12 cm was planted. The setup was loaded batch-wise with 1.5 litre of GW (bathwater) loaded daily for five days. An HRT of 1 hour was observed.

Results and Discussion

Characterization of LGW and DGW

Using the above procedure, characterization of LGW (bathwater) and DGW (laundry water) was done. The results obtained were similar to previous studies in most respects. However, there were also a few differences that are worth noting.

The TSS values for LGW and DGW were 50 and 240 mg/L, respectively. This is different from the results obtained in studies by (Delhiraja & Philip, 2020)where they found that TSS values were higher in LGW than in DGW. This may be attributed to different laundry habits involving a smaller amount of water and more water in bathing, leading to large amounts of particulate matter in DGW compared to LGW. (Henze et al. [2001](https://link.springer.com/article/10.1007/s10661-020-08369-0#ref-CR28)) found that TSS values for GW generally lie between 120-450 mg/L, and though this pattern was observed for DGW, values for LGW were lower than this predicted value.

The TDS values again showed dissimilar trends to (Delhiraja & Philip, 2020). TDS values for LGW and DGW were 96.1 and 73.75 mg/L, respectively. The values were far lower than those they presented, and the value for TDS in DGW was lower than that in LGW. This would indicate that the concentration of various ions, in this case, is smaller in LGW than in DGW.

The alkalinity values for LGW and DGW were 10.3 and 12.7 mg/L, respectively. These values were much lower than those reported by (Delhiraja & Philip, 2020). However, a similar trend was observed in that DGW, which contains cationic and anionic detergents, has a higher alkalinity than LGW.

The hardness values obtained for LGW and DGW were 50.7 and 87.3 mg/L, respectively. Similar to alkalinity, the values were lower than the values of (Delhiraja & Philip, 2020), but a similar trend was observed in that DGW had higher values than LGW.

The pH trend again deviated from that observed by (Delhiraja & Philip, 2020), such that the pH value of LGW was higher than that of DGW. However, the values lie generally between the range of 7.5-8.5, as concluded by previous studies and our study. The pH values for LGW and DGW were 8.17 and 7.54, respectively.

Finally, the EC values for LGW and DGW were 192.2 and 147.5 μS/cm, respectively. The values were much lower than those found by (Delhiraja & Philip, 2020), and the trend was also different in that DGW values were smaller than those of LGW. For the instrument we used, there was a relationship between TDS and EC such that

So, the absence of ions in DGW can explain its low conductivity.

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| --- | --- | --- | --- | --- | --- | --- |
| Paramters | TSS (mg/L) | TDS(mg/L) | pH | EC (mS/cm) | Alkalinity (mg/L) | Hardness (mg/L) |
| Light GW (bathwater) | 50 | 96.1 | 8.17 | 192.2 | 10.3 | 50.7 |
| Dark GW (laundry) | 240 | 73.75 | 7.54 | 147.5 | 12.7 | 87.3 |

Variation of parameters in the sample

The lab scale VSSF was loaded daily with 1.5 l LGW, and the HRT observed was 1 hour. TSS, TDS, pH, EC, Alkalinity, and Hardness variation was observed for the treated water over five days.

The TSS removal was almost complete, with TSS<1 mg/L observed. Due to the media's low velocity and large surface area in VSB wetlands, they have proven effective in removing suspended solids. VSB wetlands offer gravity settling, straining, and adsorption onto gravel and plant media (Norton, 2014).

There was also a reduction in the pH from 8.17 to an average value of 7.8, and the pH value was found to decrease with time. This can be attributed to sorption due to soil and uptake due to plants.

The other parameters showed an increase in their values, though their values showed a decreasing trend over time, and all values remained within permissible limits for reuse. This increase in values of parameters like TDS, Alkalinity, Hardness, and EC can be attributed to the presence of ions in the fertilized soil and the low HRT, which did not allow the absorption of the metal ions by the plant, which is the main mechanism of removal in large scale wetlands.

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| --- | --- | --- | --- | --- | --- |
| Parameter | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
| TSS | 0 | 0 | 0 | 0 | 0 |
| TDS | 142.8 | 65.75 | 122.5 | 101.5 | 101 |
| pH | 7.86 | 7.85 | 7.82 | 7.74 | 7.73 |
| EC | 285.6 | 131.5 | 245 | 203 | 202 |
| Alkalinity | 72.7 | 85.3 | 82 | 78 | 77 |
| Hardness | 200 | 190 | 156 | 137.3 | 135 |
|  |  |  |  |  |  |
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Conclusion

In the present study, GW from different sources (bathwater and laundry water) was taken from C.V. Raman hostel of IIT Indore, and its characterization was done to understand the variation of TSS, TDS, EC, pH, Alkalinity and Hardness in this water. Then, a VSSF was used to treat bathwater, and the treated sample was again tested for aforementioned parameters. Although the TSS and pH values fell into the acceptable range for reuse, the other parameters actually showed an increase from initial values and thus water could not be reused for purposes like irrigation. However, all parameters showed a steady decrease in value over the course of 5 days, mainly because the plants absorb the metallic ions causing increase in values of TDS, EC etc. over time. So, with continuous loading over a period of time it may be possible to reduce the value of the parameters to reusable standards. Also, greater removal efficiency will of course be achieved in large scale constructed VSSF, due to increase in area and retention time.

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