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Design and Performance Evaluation of a Low-Cost Domestic Level Filter to Treat Kitchen Wastewater

P.G.K. Paranagama[1] , G.T. Chaminda[2] and C.P Rupasinghe[1]

[1]Department of Agricultural Engineering, Faculty of Agriculture, University of Ruhuna, Matara, Sri Lanka.

[2]Department of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Galle, Sri Lanka.

Correspondence:
[*]*gayaraparanagama1128@gmail.com*

https://orcid.org/0000-0003- 4852-1123

Abstract

The aspects of water security mainly govern by the availability and the quality of the water. As foreseen, use of portable fresh water for landscape irrigation can be a problem in the future. This research study was carried out with objectives of characterizing the raw kitchen wastewater (KWW), designing a domestic level filter for treating KWW and evaluating the removal efficiency of newly designed filter for reuse purpose. Four combinations of treatment systems were used namely in an order, sand and gravel layer, sand and bricks, sand and bricks with a coco peat layer and sand, bricks, coco peat and activated charcoal units for filtering. Raw kitchen wastewater samples were collected three times per day and made a composite sample by mixing equal proportion of each. Water quality parameters were measured before and after treatment of the KWW and compared with the Central Environmental Authority, Sri Lanka (CEA) standards. The average pH, Chemical Oxygen Demand (COD) and oil content in raw KWW was significantly higher than CEA standards. Based on results, raw KWW cannot be reuse for irrigation and it requires adequate treatment prior irrigation. The quality of filtrate from treatment system four resulted with the mean values of pH, electrical conductivity, temperature, total dissolved solids, COD and oil content and respectively quantitative figures were 7.2 ,0.65 mS cm^{-1}, 29.5 ^{0}C, 230.1 mg L^{-1}, 365 mg L^{-1} and 2.8 g L^{-1} .The combination of sand, bricks, coco peat and activated charcoal filter filtrated effluent was within the CEA standards, which can be reuse for irrigation.

Key words: *Irrigation, Quality parameters, Reuse, Treatment system*

1. Introduction

Water is essential for health and living. Water is one of the most important substances on the earth. All plants and animals must have water to survive (Oki and Kanae, 2006). Water availability and water quality are dominating in water security. In many countries especially developing countries, most people suffer from lack of water (Ukamaka et al., 2015). Water shortage is experienced due to the population growth, which causes higher demand for drinking water. Use of potable fresh water for landscape irrigation may lead to water scarcity in future.

Grey water management is more useful in reducing water scarcity (Kulabako et al., 2011). Grey water (GW) refers to wastewater from baths, sinks and other kitchen appliances. Wastewater (WW) from bathroom showers and washing machines is called as light GW whereas, wastewater from the kitchen sink is called dark GW (Allen et al., 2010).

In water scarce countries treated GW including treated kitchen wastewater (KWW) is very important for sustainability as a source of irrigation. Domestic KWW has a lot of substances such as organic food scraps from food processing, oil and grease, soap and detergents and other suspended compounds. These oil and grease, food particles can be removed, and then treated water can be used for gardening, and landscaping like agricultural purposes (Dalahmeh et al., 2012). Without any treatment, the direct release of domestic KWW to the environment may result in many negative effects. It may badly affect the health of the living beings in soil, and crops (Halalsheh et al., 2008). Many developing countries let the raw KWW flow into the rivers and large water bodies without treatment. More disposal of KWW can cause many negative environmental impacts by contaminating fresh water bodies and dispersion of pathogens such as eutrophication (Li et al., 2009). Also, rotten KWW can create unpleasant odour because KWW releases many nutrients like ammonia. Then insect pests are attracted to the KWW and which acts as a breeding environment (Mohamed et al., 2013).

KWW composition can be changed by many factors such as meal size and type prepared and the amount of water used to clean cooking pots and other items in the kitchen. Many parameters determine the qualitative and quantitative characteristics of KWW. Including pH, Temperature, Biological oxygen demand(BOD_5 , Chemical oxygen demand(COD), Electrical conductivity(EC), Total Dissolved Solids(TDS), Oil content (Li et al., 2009).

In Sri Lanka, untreated KWW reaches large water bodies and these water sources are contaminated with nitrogen in food waste,

chemicals in soaps and detergents and can be very harmful to aquatic organisms.

Filters are used to remove impurities by lowering the contamination of water (Tech, 2019) and many studies were carried out to develop filters to treat KWW. However, most of them are not easy to develop at domestic level. Therefore, studies are required to characterize raw KWW and to design a treatment set up for treating KWW, which enables its reuse. Hence the objectives of the study were to characterize the raw KWW, to design a domestic level filter for treating KWW and to evaluate the removal efficiency by the newly designed domestic filter for reuse.

2. Materials and Methods

Kitchen Waste Water samples were collected from the new hostel kitchen at Faculty of Agriculture, University of Ruhuna. The samples were collected three times per day (morning, noon and evening), and a composite sample was made with mixing the equal proportion of each sample. Composite samples were collected over 24 hours. Collected samples were analyzed for pH, EC, temperature, TDS, COD and oil content in the department of Agricultural Engineering laboratory. To calculate the flow rate of the treatment setup, three water samples were collected. The time taken to collect 10000 mL sample was recorded.

$$\text{Average flow rate (mL s}^{-1}) = [(10000 \text{ mL}/ t_1(s)) + (10000 \text{ mL}/ t_2(s)) + (10000 \text{ mL}/ t_3(s))]/3$$

$t_1 =$ Time spent for collecting sample 1

$t_2 =$ Time spent for collecting sample 2

$t_3 =$ Time spent for collecting sample 3

Five filter materials were used as sand, gravel, bricks, coco peat and activated charcoal for the treatment setup. Respective sizes of filter materials and different combinations used in the treatment set up are given in (Table. 1).

Table 1: Filter materials and their respective sizes

Combination No	Filter Material	Size (mm)
1	Sand	0.5 – 2
	Gravel	8 - 10
2	Sand	0.5 – 2
	Bricks particles	8 - 10
3	Sand	0.5 – 2
	Bricks particles	8 – 10
	Coco peat	Whole
4	Sand	0.5 – 2
	Bricks particles	8 – 10
	Coco peat	Whole
	Activated charcoal	8 - 10

Gravel, brick particles, and activated charcoal were separated into the relevant sizes using sieves. All the filter materials were cleaned and washed using tap water until dust, colours, and other impurities were removed. The coconut nut shells were used to produce activated charcoal, and chemical activation was done by soaking in 25% $ZnCl_2$ solution for 24 hours.
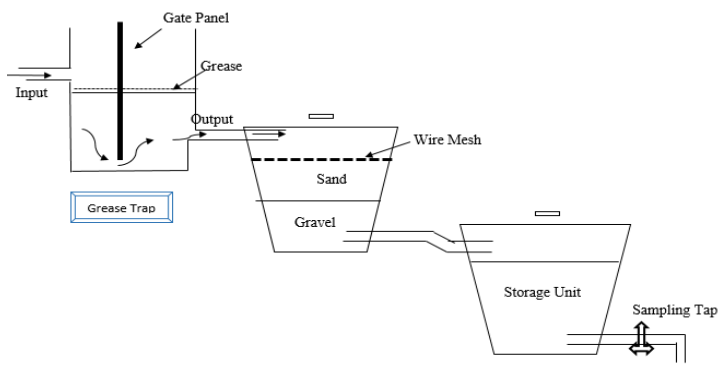
KWW Treatment Setup

A domestic level simple KWW treatment setup was developed in Faculty of Agriculture, University of Ruhuna. The domestic kitchen wastewater treatment setup was tested to treat the wastewater coming from the new hostel, Faculty of Agriculture, University of Ruhuna. The filtration setup consisted of a grease trap, wire meshes, gravel and sand layer filter unit, bricks and sand layer filter unit, coco peat layer unit, and activated charcoal layer and a storage unit. A grease trap was designed to intercept most greases and solids before KWW enter to the treatment system.

There were four combinations in this treatment setup.

1. **Combination 1(T1)** - Raw KWW flows through a wire mesh to the sand layer and gravel layer filter unit (Fig. 1(a) & (b))

2. **Combination 2(T2)**- KWW flows through a wire mesh to the sand layer and bricks layer unit (Fig.2 (a) & (b))

3. **Combination 3(T3)**- KWW flows through the most effective combination among combination 1 and combination 2, and then coco peat layer unit for further treatment (Fig. 3 (a) & (b)).

4. **Combination 4(T4)**- KWW flows through the most effective combination among combination 1 and 2, coco peat and activated charcoal layer unit for the further treatment (Fig. 4 (a) & (b)).

Table 2: Four combinations of the treatment setup

| Combination	Setup	Figure
01 (T1)	sand and gravel layer filter unit	Fig. 1
02 (T2)	sand and bricks layer unit	Fig. 2
03 (T3)	the most effective combination among combination 1 and combination 2, and then coco peat layer unit	Fig. 3
04 (T4)	the most effective combination among combination 1 and 2, coco peat and activated charcoal layer unit	Fig. 4

(a) Schematic diagram   (b) Waste water treatment setup

Figure 1: Kitchen waste water treatment setup -T1 (a) Schematic Diagram (b) Waste water treatment setup
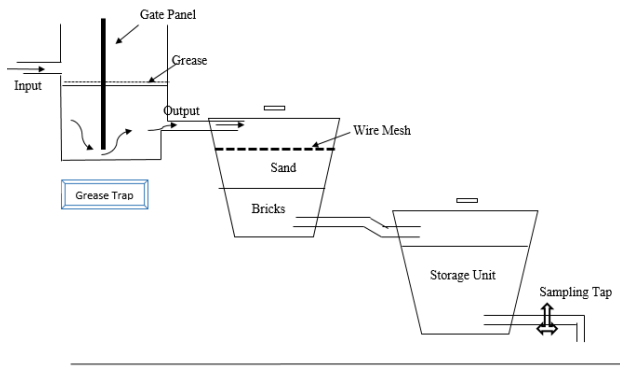
(a) Schematic diagram   (b) Waste water treatment setup

Figure 2: Kitchen waste water treatment setup -T2 (a) Schematic Diagram (b) Waste water treatment setup
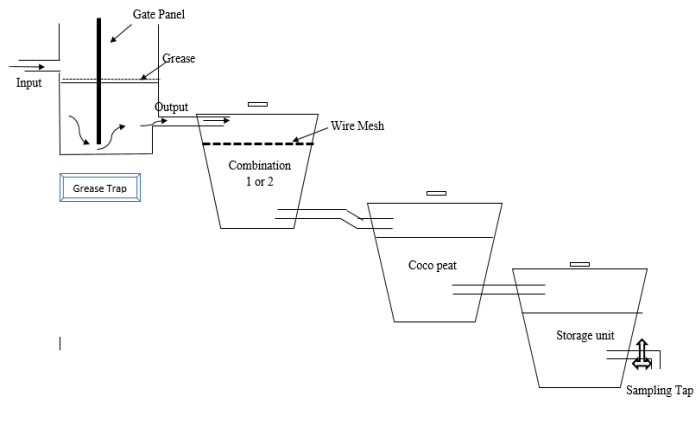

(a) Schematic diagram   (b) Waste water treatment setup

Figure 3: Kitchen waste water treatment setup -T3 (a) Schematic Diagram (b) Waste water treatment setup
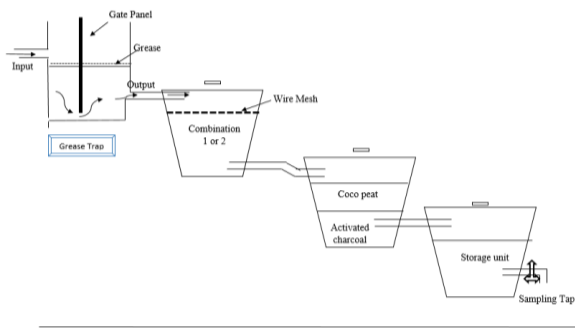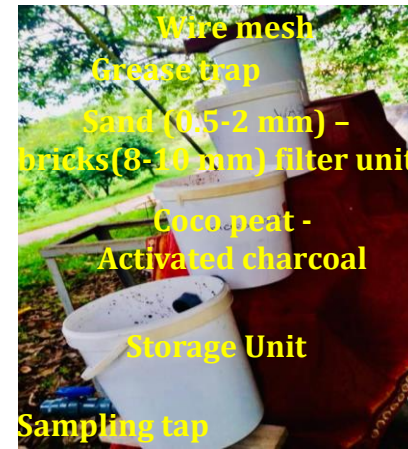
(a) Schematic diagram   (b) Waste water treatment setup

Figure 4: Kitchen waste water treatment setup - T4 (a) Schematic Diagram (b) Waste water treatment setup

Preparation of The Treatment Setup

The filtering treatment setup was consisted of four single filter units which were connected by PVC pipes. Filter units were prepared using 12 L plastic buckets. The filter was operated based on the gravity. As stated by Mohamed et al., (2013), three wire meshes (1 mm of diameter); to remove large particles, to avoid mixing coco peat with the treated water, and to avoid coco peat mixing with the activated charcoal layer were used during the process of the filtration.

A grease trap was designed in the inlet to intercept most greases and solids before KWW enter to the treatment system. In this treatment setup, no coagulants were added as it would disturb the biological processes in the filter. First stage was a screening process in the pre-treatment compartment. It contained of a 12 L bucket filled with gravel size range of 8-10 mm to a height of 70 mm from the bottom of the filter unit. A sand layer with size range of 0.5-2.0 mm was laid to a height of 70 mm on the top of the gravel. This is the first combination (T1) of the treatment set up (Fig. 1).

The gravel-sand filtering unit was connected with the grease trap by using 1-inch PVC pipe, two end caps and the relevant fittings. Likewise, all the filter buckets were connected with each other by using 1-inch PVC pipes, end caps and relevant fittings.

The storage unit also consisted with a 12 L bucket and the sampling tap was set at the bottom of the bucket.

T2 (Fig. 2) was very similar to the T1. The only difference between is that T2 consisted a layer of bricks (which its size range 8-10 mm to a height of 70 mm from the bottom of the filter unit) instead of the gravel layer of the first combination.

In T3 (Fig. 3), 70 mm height of a coco peat layer filter unit was added to the most effective combination among T1 and T2 for further treatment. In T4 (Fig. 4), an activated charcoal layer size range of 8-10 mm to a height of 70 mm filter unit was added to the most effective combination among T1 and T2 for further treatment from the bottom of the filter unit. A sand layer size range of 0.5-2 mm to a height of 70mm was laid on the top of the activated charcoal layer.

A grease trap was designed in the inlet to remove most oil and greases before kitchen waste water enter to the treatment system. In this treatment setup, any coagulant was not added as it would disturb the biological processes in the filter.

Activated charcoal is a very useful material in the waste water treatment process;

because it can remove the odor, color of raw kitchen water and reduce the turbidity of the raw kitchen waste water(Mohamed et al., 2013).

Parameters of KWW treatment setup

Before determining the water quality parameters, particle size distribution of filter materials and the average flow rate of the KWW treatment setup was calculated.

Performance Evaluation of the Domestic KWW Treatment Setup

Water samples were collected before and after treatment to evaluate the performance of the domestic KWW treatment setup.

Samples were tested for the physicochemical properties; pH, EC, temperature, TDS, COD, and oil content. Filter materials were washed with pure water after every experimental run, prior to the next run.

Water Sample Quality Parameters Analysis

The pH value, EC, temperature, TDS, COD and oil content of the KWW quality parameters were tested before and after feeding in to the treatment setup. Equipment or methods used to determine the water quality parameters are shown in (Table. 3).

Table 3: Water quality parameters and the equipment/methods used to determine the parameters

No	Parameter	Method/ Equipment used*
01	pH	pH meter (EUTECH)
02	Electrical conductivity	EC meter (HANNA)
03	Temperature	Thermometer
04	Total Dissolved Solids	Gravimetric method
05	Chemical Oxygen Demand	Optical Ultraviolet Absorption
06	Oil content	Partition Gravimetric method

*Method/ Equipment used: Dilip and Yadav, 2013; Mohamed et al., 2013; Parwin and Karar, 2020; Weisbrod, 2007

3. RESULTS AND DISCUSSION

Raw KWW Characterization

Average domestic water usage in kitchen is up to 100 L day^{-1} (Thathsaranee, 2017). The characteristics of domestic KWW depend on the type of meal prepared, the amount of water used in the cleaning process, etc. Gravel is an extremely effective filter media.It holds the ability to precipitate the contaminated water. Sand and gravel layer remove the bacteria and other small particles from wastewater (Pilgonde and Thakare, 2017). Activated charcoal can trap inorganic compounds and organic materials particularly (Allen et al., 2010).

For treating KWW, coco peat media can act as an effective, economical and sustainable option. Peat soil can be found as more organic and it can be served as a representative material of soft soils. It is derived of plant materials and it is a naturally occurring, highly organic substance. WW treatment of food processing by peat filtration system can be achieved COD, SS, and BOD$_5$ removals of 65%, 95% and 66% respectively. For high degree of purification process, there is a low volume required in peat filtration (Mohamed et al., 2013).

The filtration media is classified by its effective size and uniformity coefficient. Gravel, brick particles and activated charcoal particle size range was same, and all the layers were same size(70 mm) (Mohamed et al., 2013). Effective diameter is defined as the granule size at which 10% of the granules have a smaller diameter. The uniformity coefficient is defined as the ratio of the 60% percentile size (60% with smaller diameters) to the 10% percentile size (10% with smaller diameters). The ideal filter medium should be of such a size that it will provide a satisfactory effluent, retain a maximum quantity of solids with minimum head loss and be readily cleaned with a minimum quantity of water (Lim et al., 2015).

Raw KWW in new hostel was acidic as average pH was 4.8 (Table 4), which is reasonable because of usage of acidic foods such as lime and vinegar. Temperature of raw kitchen wastewater was near to air temperature as high amount of heat is not released to wastewater in domestic level. The COD value was very high in raw KWW. It means there were many organic matter, biodegradable and non-biodegradable materials in raw KWW. The relatively high oil content level in raw KWW (22.28 g) indicated that high levels of oil foods were used in the kitchen.

According to the data, comparison of average concentrations of water quality parameters found in raw KWW with literature data were shown below (Table. 4).

Table 4: Comparison of water quality parameters in raw kitchen waste water at new hostel, Faculty of Agriculture, University of Ruhuna with literature data.

Parameter*	Raw KWW		Literature data**
	Range	**Average**	
pH	4.56 - 5.1	4.8	4.4.-8.3
EC mS cm^{-1}	0.94 – 1.35	1.1	0.99- 2.4
Temperature ^{0}C	29 - 30	29.5	4-55
TDS mg L^{-1}	230.6 – 321.4	273.4	212-1320
COD mg L^{-1}	1680–2308	1943	717-1790
Oil content g L^{-1}	20.44 – 24.22	22.28	9.45- 101.3

* EC= Electrical Conductivity, TDS= Total Dissolved Solids, COD= Chemical Oxygen demand

**Literature data - Gurd et al., 2019; Mohamed et al., 2013; Parwin and Karar, 2020

Potential for raw KWW for irrigation

The statistical comparison between average raw KWW with the standards of the Central Environmental Authority (CEA) was shown in Table 5. The average pH value of raw KWW 4.8 was significantly lower than the CEA standards for irrigation. COD and oil content in raw KWW were observed as 1943 mgL^{-1}, 22.28 gL^{-1} respectively and it was significantly higher than the CEA standards at 5% confidence level and $\alpha=0.05$. Therefore, results showed that raw KWW in this study cannot be reused for irrigation (Fall et al., 2012).

Table 5: Comparison of water quality parameters of raw kitchen waste water with CEA standards for irrigation

Parameter	Average raw KWW	CEA standards*	*p* value**
pH	4.8	5.5-9	0.99
EC mS cm^{-1}	1.1	2.25, max	0.001
Temperature ^{0}C	29.5	40, max	0.00
TDS mg L^{-1}	273.4	2100, max	0.00
COD mg L^{-1}	1943.2	400, max	0.99
Oil content g L^{-1}	22.28	10, max	0.99

* Source: http://www.cea.lk/regulations

** (Comparison $\alpha=0.05$, 95% confidence level)

Average flow rate of the treatment setup

To calculate the flow rate of the treatment setup, three water samples were collected. The time taken to collect 10000 mL sample was recorded (Table. 6).

Table 6: Average flow rate of the treatment setup

Sample Volume (mL)	Time spent for collecting the sample (s)	Flow Rate (mL s^{-1})
10000	5630	1.776
10000	5750	1.739
10000	6245	1.601

Average flow rate = (1.776 + 1.739 + 1.601)/3 mL s^{-1}

$\qquad\qquad$ =1.705 mL s^{-1}

$\qquad\qquad$ =1.705 mL s^{-1} * 3600*24 s day^{-1} *10^{-6} m^3 mL^{-1}

$\qquad\qquad$ =0.147 m^3 day^{-1}

Performance of kitchen wastewater treatment setup

According to the results, T2 was more effective than T1 compared to the overall water quality parameters. In COD removal, bricks have played a major role. Because bricks can absorb water due to its highly porous and yet permeable qualities. Both T1 and T2 could assist with oil removal as the percentage removal recorded as 95.33% and 81.14% respectively. According to the results, gravel's oil removal was better than bricks. This might be due to that the oil can get attached and adsorbed in gravel surface.

Table 7: Average water quality parameters of treated kitchen waste water from different treatment combinations

Parameter-Unit	Average value				
	Raw KWW sample	KWW treated by T1	KWW treated by T2	KWW treated by T3	KWW treated by T4
1. pH	4.8	5.8	6.4	6.66	7.2
2. EC mS cm^{-1}	1.1	0.9	0.7	0.68	0.65
3. Temperature ^{0}C	29.5	29.5	29.5	29.5	29.5
4. TDS mg L^{-1}	273.4	262.1	242.6	236.6	230.1
5. COD mg L^{-1}	1943.2	783.8	452.5	405.5	365
6. Oil Content g L^{-1}	22.28	1.04	4.2	3.6	2.8

Table. 7 shows the overall results of the treatment setup. There was no difference of treatment from the coco peat. However, activated charcoal was effective in removing COD and improving other water qualities (Allen et al., 2010).

Performance of the filter setup for kitchen wastewater

CHAPTER 2 The alterations in water quality parameters of KWW after treatments are shown in (Table. 8).

Table 8: Comparison of water quality parameters of kitchen waste water after treatments

Parameter	Average raw KWW	After Treated KWW average	Total Effluent increase/ removal %	*p* value
pH	4.8	7.2	50	0.001
EC mS cm^{-1}	1.1	0.65	40.9	0.018
Temperature ^{0}C	29.5	29.5	-	0.000
TDS mg L^{-1}	273.4	230.1	15.84	0.125
COD mg L^{-1}	1943.2	365	81.22	0.001
Oil content g L^{-1}	22.28	2.8	87.43	0.001

 * Comparison α=0.05   95% confidence level

pH of the domestic KWW was significantly increased 50% by KWW treatment setup. During the treatment process, acidic raw KWW was reached to neutral condition (Dilip and Yadav, 2013). EC, TDS, COD and oil content of raw KWW were removed as 40.9%, 15.84%, 81.22% and 87.43% respectively by the T4 which was consisted of sand, bricks, coco peat and activated charcoal filter units. Large size organic matter and some amounts of dissolved organic matter were removed during treatment process, and then COD of the final effluent has reduced by 81.22%. According to the results, all the parameters except TDS were significantly reduced by KWW treatment setup (Table. 8).

Potential for reuse of treated kitchen wastewater for irrigation

The properties of treated water were compared with CEA standard to check suitability for reusing treated water for the irrigation purpose.

Table 9: Results of the t-test comparing treated kitchen waste water values with CEA standards for irrigation

Parameter	Treated KWW	CEA standards*	p value**
pH	7.2	5.5-9	0.000
EC mS cm^{-1}	0.65	2.25, max	0.000
Temperature ^{0}C	29.5	40, max	0.000
TDS mg L^{-1}	230.1	2100, max	0.000
COD mg L^{-1}	365	400, max	0.032
Oil content g L^{-1}	2.8	10, max	0.000

*Source: http://www.cea.lk/regulations

** Comparison $\alpha=0.05$ 95% confidence level

When KWW was treated with the designed treatment setup, the physicochemical parameters; pH, EC, temperature, TDS, COD and oil content were significantly lower than the CEA standards for irrigation (Table. 9).

Therefore, results showed that the treated KWW from the final effluent in this study can be reused for irrigation. Kumar et al., (2019) also reported that KWW can be reused for agriculture or gardening purposes.

Increase/ removal percentages of treatment setup (compared to raw KWW)

Fig. 5 shows the pH increase percentages and EC, TDS, COD and oil content removal percentages of the filter combinations compared to raw kitchen wastewater.
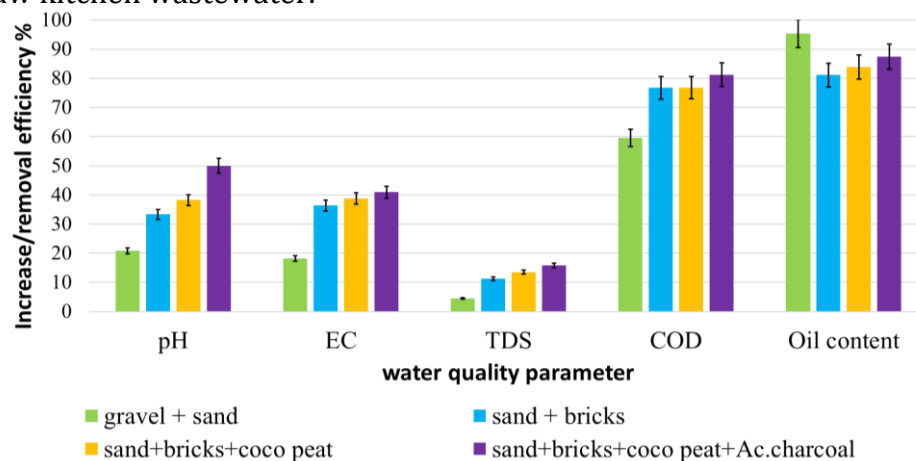
4. Conclusions

Kitchen waste water quality can be improved by newly designed low-cost domestic filter to reuse for irrigation purposes. Sand and bricks combination is more effective than sand and gravel combination, when considered the overall water quality parameters. Bricks have played a major role in COD removal, because bricks can reduce COD in water. Both T1 and T2 could assist with oil removal. Gravel's oil removal efficiency was higher than the bricks. Coco peat was not effective in removing oil. However, activated charcoal can improve the water qualities. Out of these combinations sand, bricks, coco peat and activated charcoal layer filter unit is the best combination.

Figure 5: Increase/removal percentages of treatment setup (compared to raw KWW)

The results indicated that sand, bricks, coco peat and activated charcoal layer filter unit (T4) is the best combination

Overall performance of the sand, bricks, coco peat and activated charcoal treatment

set up for kitchen GW is able to satisfactorily achieve reusable standards for irrigation in Sri Lanka.

5. Acknowledgment

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