A Laboratory-Scale Study of Residential Greywater Treatment with Sugarcane in a Constructed Wetland

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Research Article

Keywords: Greywater, Constructed wetland, Sugarcane, Phytoremediation, BOD, COD

Posted Date: July 20th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-630390/v1

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on April 19th, 2022. See the published version at https://doi.org/10.1007/s11356-022-20264-4.

Abstract

Water recycling is essential to reduce water scarcity in India due to population growth. Water for consumption is most crucial, it is equally important to provide water for irrigation to increase food production and livestock husbandry, to ensure food security for the increasing population. This paper deals with recycling and reuse of residential greywater (Wastewater from bathtubs, showers, hand washing basins and washing machines, kitchen sinks except for wastewater from toilet flushing system). In domestic wastewater 2/3 of wastewater is considered greywater. This greywater can be treated and reused for gardening, flushing, construction purposes, etc. Conventional treatment systems are highly sensitive and necessitate good monitoring and efficient process control. Hence, the natural wastewater treatment options such as treatment using aquatic plants are becoming quite attractive in this view. In this study, the sugarcane variety of CO86032 and CO 15027 were used for phytoremediation. Coarse aggregate (20 mm), Brick jelly (20 mm), and Red soil mixed with Coir pith (1/3 volume-based) were used as filter material of laboratory-scale constructed subsurface wetland system having size 0.92 m, 0.61 m, and 0.45 m of length, breadth, and depth respectively. The removal efficiency of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), and Total Nitrogen (TN) was 77–89%, 66–81%, 70–91%, and 68–84% achieved during a retention time of 2 hours to 48 hours.

1. Introduction

Water is becoming a rare resource of the world. As per the International water management institute, one in three-person live in India will be going to suffer severe water scarcity in 2025. Hence, we have to reduce the ground and surface water consumption to save water for the future. There are two ways to reduce this water consumption. One is rainwater storage and another one is the reuse of wastewater (NEERI 2007).

This paper deals with the reuse of greywater. Greywater is wastewater that comes from bathtubs, kitchen sinks, water closets, laundry, etc., except wastewater from the toilet flushing system (Eva et al. 2002; Gorgich et al. 2020). Greywater is low polluted wastewater, so it can be easily treated (Gorgich et al. 2020). In India, the amount of domestic water supply is 135 L per day. 80 % of the total water supply becomes wastewater from that 2/3 of the wastewater becomes greywater (CPHEEO 2013). There are many conventional methods available for the treatment of greywater. They necessitate very good monitoring and process control. The cost of such treatment is very high due to high power consumption (Kurniawan et al. 2021). The reliability of those systems becomes low due to frequent power failures in many countries. Hence, we need a technology that is simple in operation and maintenance, no power consumption, and low cost (Sezerino et al. 2012).

The constructed wetland using the aquatic plant is quite attractive in this view. There are two types of constructed wetland according to wetland hydrology. 1) Free water surface constructed wetland (FWS) 2) Subsurface flow constructed wetland (SSF). There are again two types in subsurface flow constructed wetland based on the direction of flow. 1) Horizontal sub-surface flow constructed wetland (HSSF) 2)

Vertical sub-surface flow constructed wetland (VSSF) and the latest is floating treatment wetland (FTW) (Tran et al. 2019; Vymazal 2010; U.S. EPA 1988).

In this study, the performance of horizontal subsurface flow constructed wetland has been studied. The flow was maintained in a sinusoidal manner by providing intermediate baffle walls further down. The baffle walls were provided to increase the flow distance and reduce the flow velocity (Bhamare et al. 2020). A constructed wetland has the positive characteristics of wetland in nature. It mimics the physical, chemical, and biological processes in the natural wetland system. It is a complex assemblage of wastewater, filter media, vegetation, and an array of microorganisms (U.S. EPA 1988).

The subsurface constructed wetlands mostly comprised of sand and graded gravel as filter media (Adeniran et al. 2014). Vegetation plays a vital role in the wetlands as they provide gas transport mechanism in wetland plants, root release of oxygen (Iijima et al. 2016), influence on soil hydraulic conductivity, plant uptake of nutrients, and other macrophyte functions like reducing water current velocity thereby providing an opportunity for sedimentation of suspended solids, prevents clogging of medium and provides a suitable environment for microbial growth and filtration (Hans 1994). Commonly used vegetation in constructed wetlands are *Cannaindica* (Tran et al. 2019), *Iris Pseudacorus* (Hans 1994; Shen et al. 2020), *Phragmites australis*(Wagner et al. 2020; Gajewska et al. 2020), *Salix viminalis* (Gajewska et al. 2020), *Lepironia Articulata* (Wurochekke et al. 2014) *Caladium bicolor, Rhoe discolor, Sansevieria trifasciata, Heliconia psittacorum* (Perdana et al. 2020), *Colocasiaesculenta, Juncusbufonius, etc.*, (Koranne 2018). The commonly used wetland plants are ornamental aquatic plants. However, there is little information on the use of the bioenergy crop *Saccharum officinarum* (sugarcane) as vegetation in the constructed wetland. Hence, this study focus on the treatment of greywater with sugarcane as vegetation in a constructed wetland. Sugarcane can be growing in the soil where some metals are accumulated (Agnes Oppong et al. 2018). Sugarcane as vegetation in the constructed wetland is a possible alternative to produce a bioethanol raw material without the use of irrigation water, while it maintains the wastewater treatment capacity of constructed wetlands (Mateus et al. 2016). Pollutants are removed within the wetlands by several complex physical (sedimentation, filtration, adsorption, and volatilization) chemical (precipitation, adsorption, hydrolysis, and oxidation/reduction), and biological processes (bacterial metabolism, plant metabolism, plant absorption, natural die-off) (Adeniran et al. 2014).

2. Material And Method

2.1. Constructed wetland

As per the design (Zbigniew 2017; Gajewska et al. 2020), the laboratory-scale constructed wetland was fabricated by using Acrylic sheet material having a thickness of 5mm. The size of the fabricated wetland is 0.92 m x 0.61 m x 0.45 m in length, breadth, and depth respectively. The depth of the freeboard is 0.1 m from the top. The size of three intermediate baffle walls is 0.61m x 0.24m with series of 5mm diameter holes at the bottom to drain off full water from the wetland. The baffle walls were laid at an equal spacing of 0.23 m respectively. The capacity of constructed wetland after filling the filter media is 60 L. The hydraulic loading rate (HLR) was maintained at 0.11 m/d. The inlet and outlet pipes were given at the bottom of either end of the wetland and the flow was controlled using ball valves. The fabricated constructed wetland is shown in Fig. 1.

2.2. Sedimentation tank

The sedimentation tank was fabricated for the pretreatment of greywater before it allowed into a constructed wetland. The laboratory-scale sedimentation tank was fabricated by using Acrylic sheet material having a thickness of 4mm. The size of sedimentation tank is 0.9 m x 0.45 m x 0.5 m. The fabricated sedimentation tank is shown in Fig. 2.

2.3. Filter media

In the constructed wetland, three layers of filter materials were used as filter media for physical removal of contaminants through settling, entrapment of particulate matter in the void spaces in the gravel or sand media and it also supports the vegetation used in a constructed wetland. The total depth of filter media in the constructed wetland is 0.35 m or 35 cm. The water level in the wetland was maintained below this level. The layers of aggregates were thoroughly washed before it placed into the constructed wetland to remove silt particles that adsorbed on the surface of the aggregate.

2.3.1. Bottom layer

The 20mm size of coarse aggregate was used as the bottom layer of filter media for a depth of 20cm and it is shown in Fig. 3.

2.3.2. Middle layer

The 20mm size of brick jelly was used as the middle layer of filter media, for a depth of 5cm, because it is waste residue and by-product resulting from civil construction and it was selected due to its availability and low cost and also clay bricks contain minerals like CaO, Fe_2O_3, K_2O, MgO, MnO, Na_2O, and TiO_2 may contribute the growth of plants (Mateus et al. 2016). It is shown in Fig. 4.

2.3.3. Top layer

The red soil was mixed with one-third volume of coir pith to increase the permeability and used as the top layer of filter media to support the vegetation for a depth of 10 cm. The coir pith is waste product from dried coconut husk widely used as growing media in horticulture industry (Barrett et al. 2016). The top layer is shown in Fig. 5.

2.4. Vegetation

In this study, two varieties of sugarcane were used as vegetation that is CO86032 and CO15027. These sugarcane varieties were suggested and bought from Sugarcane Breeding Institute, Coimbatore. These varieties are popular nowadays in high production. The single budded sugarcane seedlings were grown for one month in a plastic germination tray. After one month, in Jan 2021 the seedlings were transplanted into constructed wetland (14 plants/m^2). The constructed wetland was filled with potable water until the experiment started 60 days after the transplantation. During 60 days the crop and microorganisms in constructed wetland adapted to the wetland environment (Wang et al. 2020). The experiment was started on March 2021. The transplanted sugarcane seedling is shown in Fig. 6.

2.5. Greywater

The sampling of greywater was done at an apartment building having nine residents near Vadavalli, Coimbatore. Where the pipelines are separated for greywater and septic tanks. The collection of greywater has done by using 35L water canes. After sampling, the raw greywater was immediately tested in the laboratory to infer the influent characteristics. The collection of greywater is shown in Fig. 7.

2.6. Methodology

The greywater was collected and poured manually into the sedimentation tank. Where the suspended particles were settled down. Then it was allowed to pass into the constructed wetland by gravity for the treatment after two hours of retention time. The treated greywater was collected from the constructed wetland with several intervals of retention time that was 2 hours to 48 hours. The characteristics of collected treated greywater were immediately tested in the laboratory. After the week of treatment, the wetland was completely drained off and the new sample of greywater was added into the wetland for the next week of treatment. The experiment lasted for 4 weeks. The laboratory tests were carried out for the first and third weeks of the sample. The full setup of constructed wetland is shown in Fig. 8.

3. Result And Discussion

3.1. Characteristics of filter materials

The particle size distribution of the filter materials was evaluated using standard sieve analysis techniques, and the values of d_{10}, d_{30}, and d_{60} of the top layer were determined. The sand percentage of red soil mixed with coir pith was obtained as 97 %. In addition, the particle size distribution curve is also given in Fig. 9. From manual sieve analysis, the size of the middle and bottom layer of brick jelly and coarse aggregate was evaluated as approximately 20mm.

D_{60} = 1.419, D_{30} = 0.813, D_{10} = 0.458 ($D_{60,}$ $D_{30,}$ D_{10}–Effective grain size of particles obtained from graph)

Coefficient of curvature (Cc) = 1.016 $1 < Cc < 3$

Coefficient of uniformity (Cu) = 3.096 $Cu < 4$

Hence, the top layer (Red soil mixed with coir pith) is *poorly graded gravel* (Very pervious).

3.2. Characteristics of raw and treated greywater

The greywater is collected from an apartment building near Vadvalli, Coimbatore. The collected raw greywater is tested in the laboratory to find its characteristics before the treatment. As well as the characteristics of treated greywater are also tested in several intervals of retention time to find the efficiency of the wetland. The results are tabulated in Tables 1 and 2.

Table 1
Performance of wetland in the first week after treatment

PARAMETER	*RAW GREYWATER*	*2 HOURS*	*24 HOURS*	*48 HOURS*
pH	7.87	7.95	7.48	7.45
BOD mg/L	397.5	93	48	42
COD mg/L	640	218	196	122
TSS mg/L	850	150	86	76
TDS mg/L	1250	1000	994	934
EC μS/cm	1618	1600	1600	1580
TN mg/L	20.017	6.450	3.478	3.203

pH has no unit, mg/L– Milligram per liter, μS– Micro Siemens

Table 2
Performance of wetland in the third week after treatment

PARAMETER	*RAW GREYWATER*	*2 HOURS*	*24 HOURS*	*48 HOURS*
pH	7.65	7.45	7.85	7.13
BOD mg/L	270	60	42	30
COD mg/L	532	160	150	100
TSS mg/L	850	250	220	160
TDS mg/L	1450	1050	880	850
EC μS/cm	1789	1785	1780	1765
TN mg/L	25.060	6.057	5.031	4.570

pH has no unit, mg/L– Milligram per liter, μS– Micro Siemens

The removal efficiency of the BOD, COD, and TN has been calculated from the above results by using an equation that is $\text{Removal efficiency } (\%) = ((\text{Cin} - \text{Cout}) \div \text{Cin}) \times 100$. Where Cin (mg/L) is the inlet concentration and Cout (mg/L) is the outlet concentration (Perdana 2020). The percentage of removal efficiency is tabulated in Tables 3 and 4.

Table 3
The removal efficiency of constructed wetland (First week)

PARAMETER	*2 HOURS*	*24 HOURS*	*48 HOURS*
BOD %	76.60	87.92	89.43
COD %	65.93	69.38	80.94
TSS %	82.35	89.88	91.06
TN %	67.77	82.62	83.99

Table 4
The removal efficiency of constructed wetland (Third week)

PARAMETER	*2 HOURS*	*24 HOURS*	*48 HOURS*
BOD %	77.78	84.44	88.89
COD %	69.92	71.80	81.20
TSS %	70.59	74.12	81.18
TN %	75.83	79.92	81.70

The characteristics of raw and treated greywater are compared with the irrigation standard from the Environment protection rules (EPR 1986). The few effluent standards of EPR 1986 are tabulated in Table 5.

Table 5
Irrigation standards as per EPR 1986

PARAMETER	*IRRIGATION STANDARD (Environmental Protection Rules 1986)*
pH	5.5-9.0
BOD mg/L	100
COD mg/L	-
TSS mg/L	200
TDS mg/L	2100
EC μS/cm	2250
pH has no unit, mg/L– Milligram per liter, μS– Micro Siemens	

The raw and treated greywater parameters are compared with irrigation standards (

EPR 1986) and it is shown in chart 1 and chart 2.

3.3. Performance of Physicochemical parameters

3.3.1. Potential of hydrogen (pH)

From Tables 1 and 2 there was no appreciable difference in influent and effluent pH value. In the first week of treatment, the influent pH 7.87 is reduced to 7.45 in effluent collected at 48 hours of retention time similarly, the pH 7.65 is reduced to 7.13 in the third week of treatment and both are within EPR standards (Table 5). This observation implies that the treatment process of constructed wetland improves the alkalinity of the sewage from a slight alkalinity level to an acceptable slightly above neutral level.

3.3.2. Biochemical oxygen demand (BOD)

BOD is used to measure the amount of dissolved oxygen consumed by aerobic biological organisms to break down the organic matter present in the wastewater. In the current study, the BOD value of raw greywater is decreased by increasing retention time. From Tables 1 and 2 the influent BOD values 397.5 (mg/L), 270 (mg/L) of first and third week was reduced to 42 (mg/L), 30 (mg/L) after 48 hours of retention time. The highest removal efficiency of BOD was achieved at 89.43 (%), 88.89 (%) during the first and third week of treatment as shown in Tables 3 and 4. There was no appreciable difference in removal efficiency of the first week and third week of treatment. The result is consistent with the result obtained by (Laaffat et al. 2019; Wurochekke et al. 2014). Charts 1 and 2 show the comparison of raw and treated greywater parameters with irrigation standards. From the charts, the BOD limit of raw greywater exceeds the limit of irrigation standards, and the treated greywater is collected during different intervals of retention time within the standards. The removal of BOD_5 occurs rapidly by settling and entrapment of particulate matter in the void spaces in the filter media. Soluble BOD_5 is reduced by microbial growth on the filter media surfaces and attached to the plant roots and rhizomes penetrating the bed (Adelere et al. 2014)

3.3.3. Chemical oxygen demand (COD)

COD is the total quantity of oxygen required by the sewage to decompose active as well as inactive organic matter present in sewage. In this study, the COD value of raw greywater is reduced by increasing retention time. From Tables 1 and 2 the influent COD values 640 (mg/L), 532 (mg/L) of first and third week was reduced to 122 (mg/L), 100 (mg/L) after 48 hours of retention time. The highest removal efficiency of COD was achieved 80.94 (%), 81.20 (%) during the first and third week of treatment as shown in Tables 3 and 4. There was no appreciable difference in removal efficiency of the first week and third week of treatment. The result is consistent with the result obtained by (Laaffat et al. 2019; Wurochekke et al. 2014). A decrease in COD can occur through degradation carried out by both aerobic and anaerobic microorganisms and also due to physical processes like sedimentation, filtration, and deposition. The physical processes are more important to reduce COD than biological processes (Perdana et al. 2020).

3.3.4. Total suspended solids (TSS)

The total suspended solids in raw greywater were reduced from 850 (mg/L) to 76 (mg/L) and 160 (mg/L) during a retention time of 48 hours in the first and third week of treatment shown in Table 1 and 2. The removal efficiency of TSS is calculated as 91.06 (%) and 81.18 (%) for the first and third week of treatment. The results are consistent with (Laaffat et al. 2019). The highest removal efficiency occurred in the first week of treatment shown in Table 3. The low removal efficiency of TSS is may be caused due to the low hydraulic retention time (HRT). Low HRT causes less duration of contact time with wastewater and filter media so that the physical process does not occur ideally (Perdana et al. 2020).

3.3.5. Total dissolved solids (TDS)

There is no significant difference in TDS from the observed results of the first and third week of treatment shown in Tables 1 and 2. The influent TDS of 1250 (mg/L), 1450 (mg/L) was reduced to 934 (mg/L) and 850 (mg/L) for first and third week of treatment. Both influent and effluent concentrations are within the limit of irrigation standards shown in charts 1 and 2.

3.3.6. Electrical conductivity (EC)

EC of water is its ability to conduct an electric current. The salts and other chemicals dissolved in water can break down into positive and negative charged ions. These free ions in water conduct electricity, hence the water EC depends on the concentration of ions. EC influences a plant's ability to absorb water.

From Tables 1 and 2 the influent 1618 (µS/cm), 1789 (µS/cm) slightly decreased to 1580 (µS/cm) and 1765 (µS/cm) in the first and third week of treatment during the retention time of 48 hours. The efficiency of removal is consistent with (Laaffat et al. 2019).

3.3.7. Total Nitrogen (TN)

The total nitrogen present in raw greywater from the first and third-week samples is 20.017 (mg/L) and 25.060 (mg/L) shown in Tables 1 and 2, which is consistent with the total nitrogen concentration range in greywater in India suggested by (Boano et al. 2020). The highest removal efficiency of total nitrogen of the first and third week is 83.99 (%) and 81.30 (%) during a retention time of 48 hours shown in Tables 3 and 4. The remaining nitrogen in water after treatment may contribute to the growth of irrigation of green areas. Hence, they can be considered as a positive contribution to the reuse of greywater (Laaffat et al. 2019).

4. Conclusion

The laboratory-scale constructed wetland having a size of 0.92m × 0.61m × 0.45m was fabricated and the experiment was carried out in March 2021.

The highest removal efficiency of BOD, COD, TSS, and TN was 77–89%, 66–81%, 70–91%, and 68–84% achieved during a retention time of 2 hours to 48 hours.

The treated greywater meets the effluent standards of Environmental protection rules (EPR 1986).

The treated greywater can be reused for gardening, flushing, construction purposes, etc.

It is concluded that sugarcane can be used in constructed wetlands instead of ornamental aquatic plants without changing the operability and performance of constructed wetlands in the treatment of greywater.

5. Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and materials: It is available with the corresponding author

Competing interests: The authors declare that they have no competing interests.

Funding: NIL

Author's contribution: The research work and, the manuscript were done by NB. The overall guidance was given by RK.

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Figures

Figure 1

Fabricated constructed wetland

Figure 2

Fabricated sedimentation tank

Figure 3

The bottom layer of 20 mm size coarse aggregate

Figure 4

The middle layer of 20 mm size brick jelly

Figure 5

The top layer of red soil mixed with coir pith

Figure 6

Sugarcane seedling

Figure 7

Collection of greywater

Figure 8

Full setup of constructed wetland

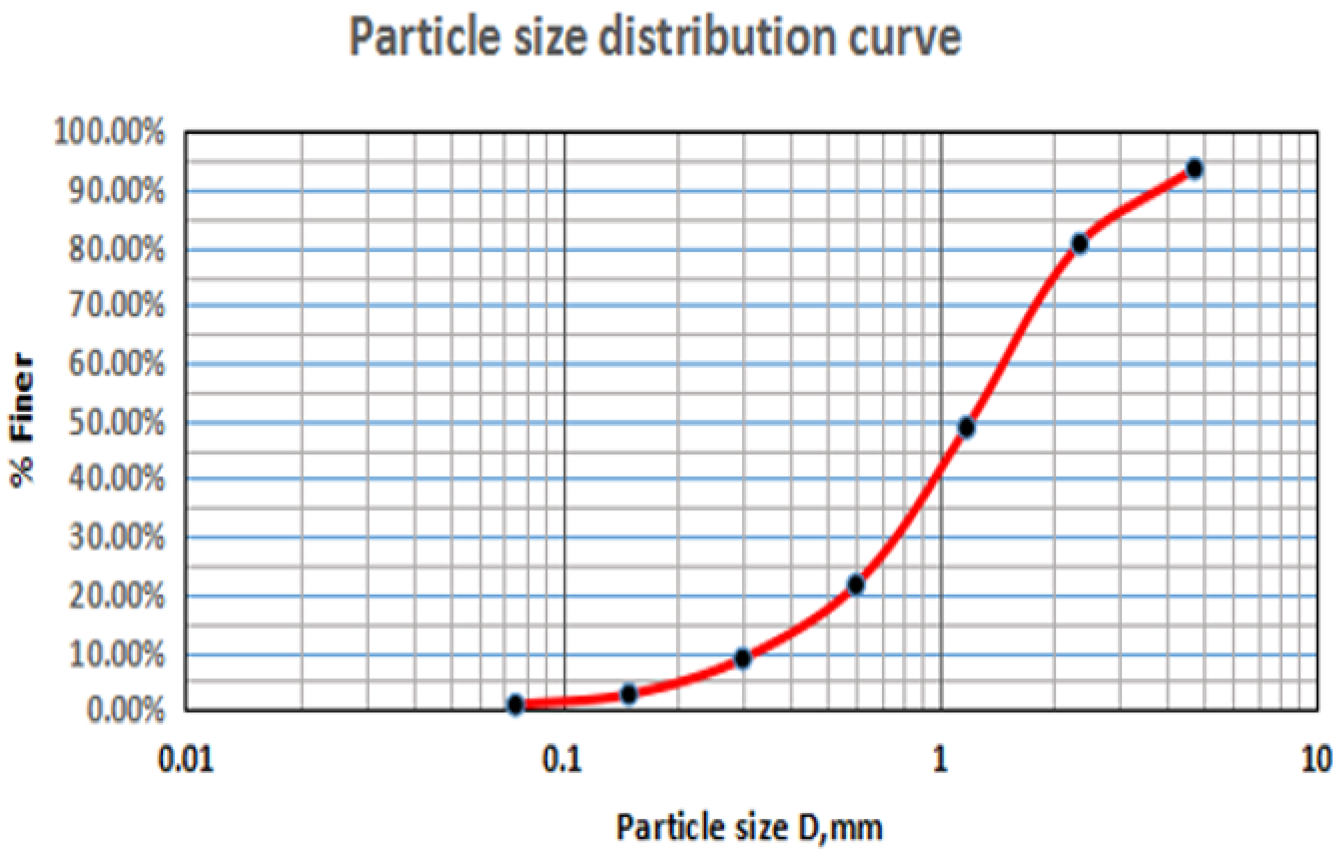
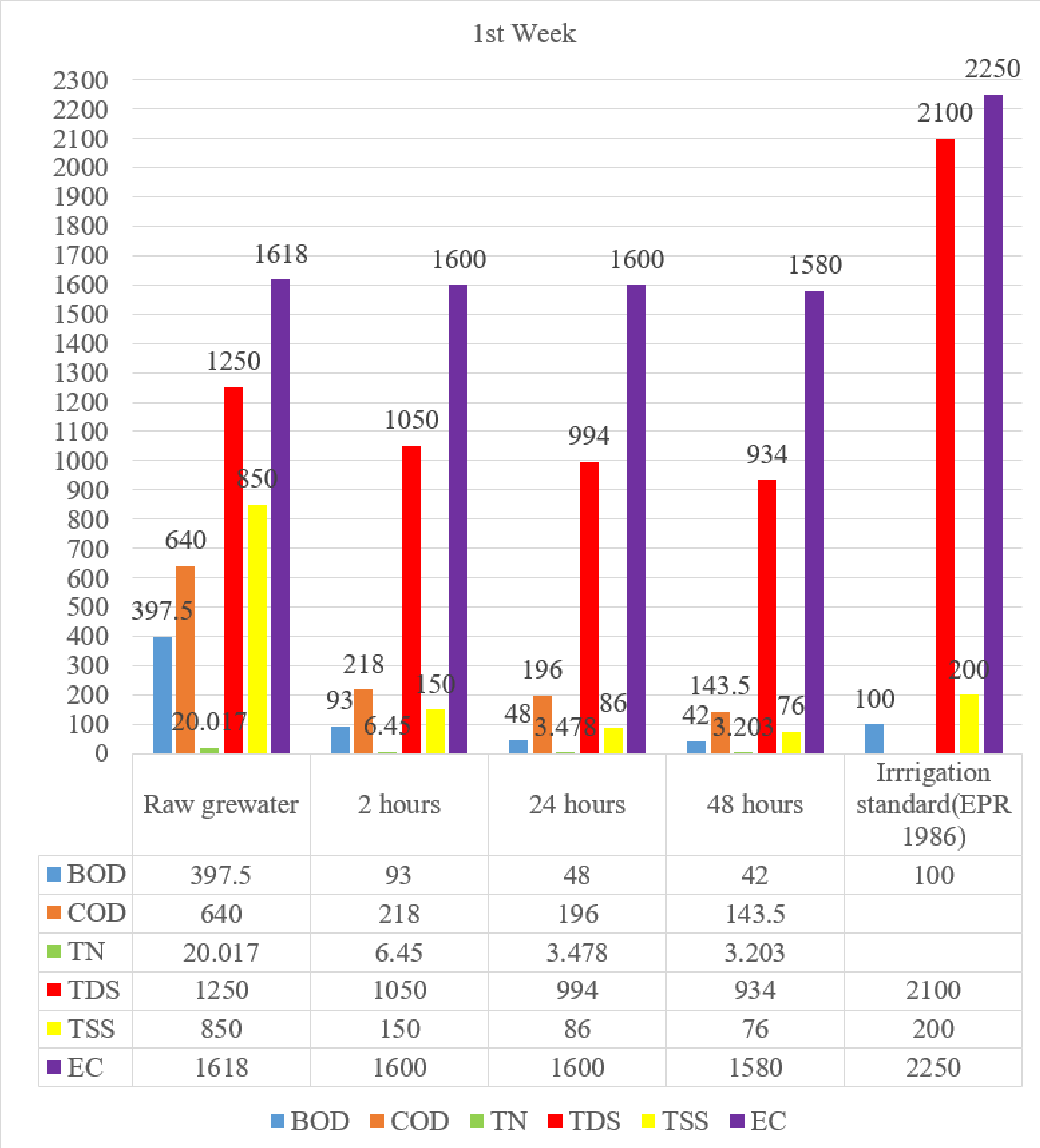


Figure 9

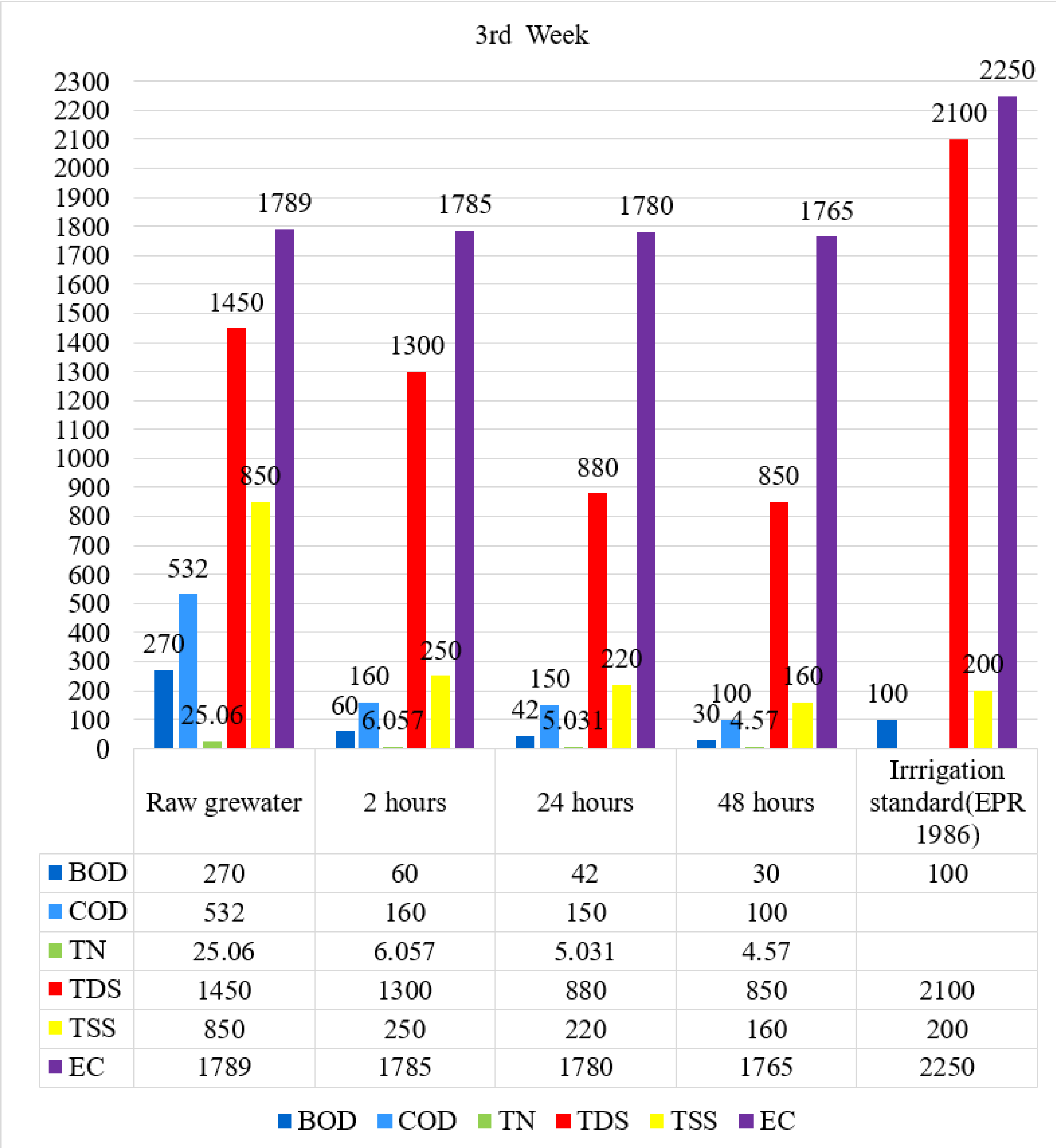
Particle size distribution curve



	Raw grewater	2 hours	24 hours	48 hours	Irrrigation standard(EPR 1986)
BOD	397.5	93	48	42	100
COD	640	218	196	143.5	
TN	20.017	6.45	3.478	3.203	
TDS	1250	1050	994	934	2100
TSS	850	150	86	76	200
EC	1618	1600	1600	1580	2250

Figure 10

Comparison of parameters with irrigation standards (EPR 1986)



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TSS	850	250	220	160	200
EC	1789	1785	1780	1765	2250

Figure 11

Comparison of parameters with irrigation standards (EPR 1986)