Technical Report

Strategic In-Stream Systems (STRAINS)

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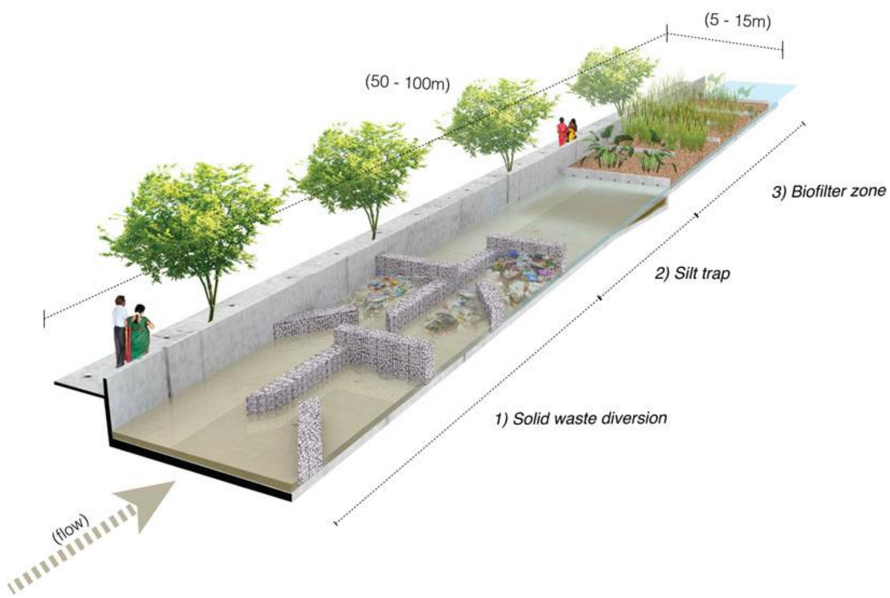

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Introduction

Bengaluru is in the midst of a serious urban water crisis. The city is not intersected directly by a perennial water source (such as a major river). Instead, surface water flows through a complex system of lakes and open channels (often referred to as the “Tank Cascade System”) which follow the natural slopes of the landscape as they flow into one another. Once used effectively for storm water storage and agricultural irrigation, the recent explosion of largely unregulated urban development in the past two decades has put immense pressure on these infrastructures. They now double as a defacto open sewer, receiving a daily deluge of untreated domestic and industrial effluents. This contamination hyper-accumulates as it makes its way through this interconnected system, causing a range of impacts on local ecosystems, livelihoods, and public health. These include toxic foam events and downstream impacts on human health and food systems. Strategic In-stream Systems (STRAINS) is a small-scale, low-tech, in-stream decontamination strategy that may be deployed in the future to address these problems. STRAINS use the insights of the Sowlkere studies to develop a series of larger interventions which can be placed directly with nallahs to prevent the contamination and eutrophication of urban lakes.

The project aims at 1) diverting and collecting solid waste, 2) slowing and settling sediment and suspended solids, and 3) lowering BOD, and COD levels through biofiltration using locally available aggregate materials. The goal of this phase of project development is to experiment with various material and design options to determine possible removal efficiencies and maintenance regimes for larger scale interventions. This pilot study focuses on a prototype of stage 3.

Objectives

- Evaluate the performance of STRAINS system with respect to materials(Gravel and Terracotta) in treating wastewater
- Optimize the design of STRAINS for efficient removal of contaminants
- Develop an approach to enhance community participation and to hand over the maintenance of systems to the communities. This will help in promoting community engagement that will lead to a greater impact.

Methodology

Experimental set-up

The semi-controlled field experiment is located near the inlet of a small urban lake in Bangalore’s southeast periphery (Sowlkere). It is conceived as a model nallah with a dimension of 8mx2mx1m (Horizontal sub-surface flow Constructed wetland (HSSF) constructed at the site. It provides a, but does not include the first two stages of the system that are dedicated to solid waste diversion and sediment removal.

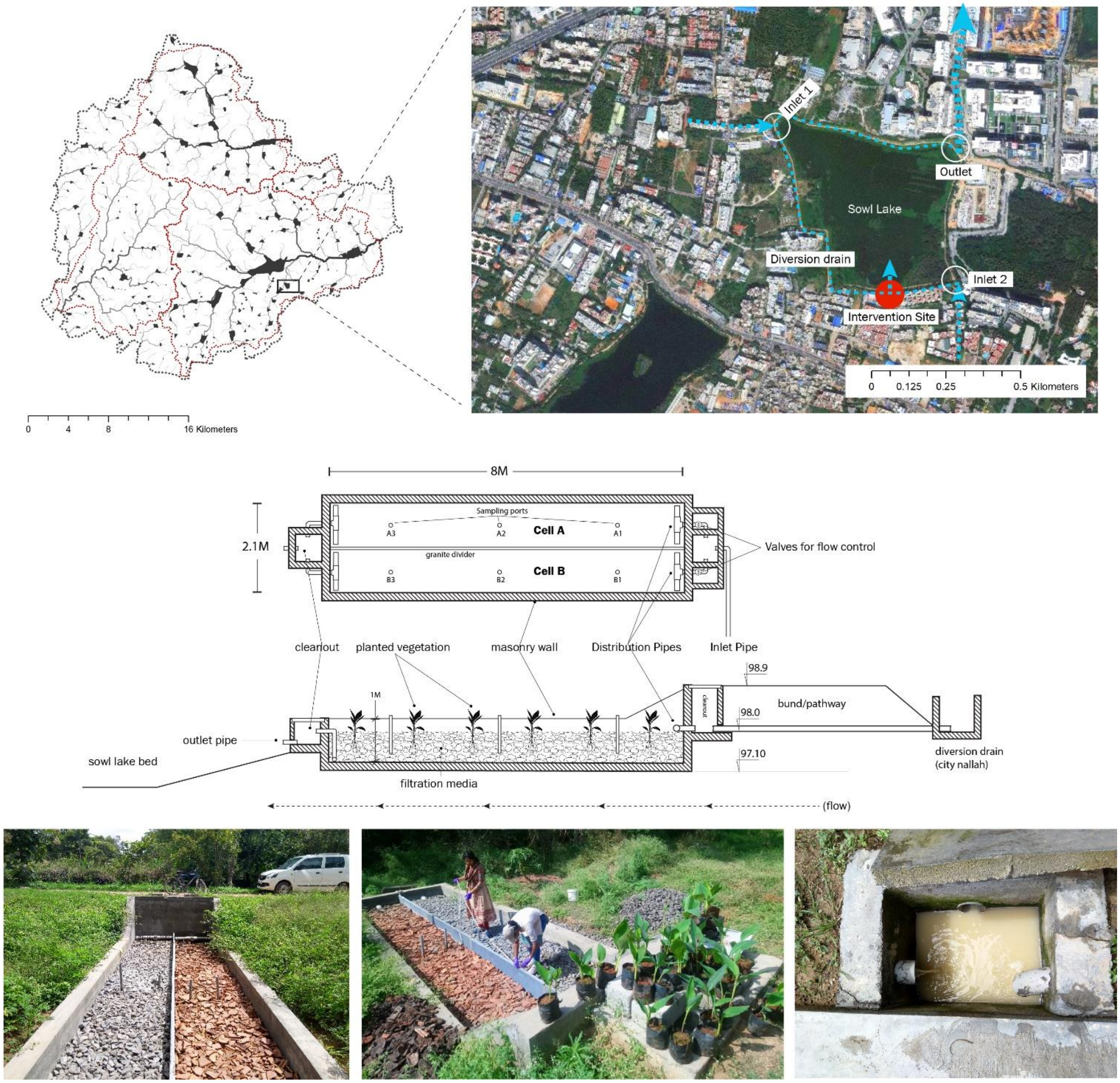


Figure 1: Context and construction of model nallah (STRAINS prototype) at Sowlkere

STRAINS is proposed as a flexible, inexpensive, and low tech engineered system that is designed and constructed to mimic the natural process of wetlands. Two different filter materials; gravel and terracotta, are evaluated in this field study. The capacity of materials filters to remove pollutants differs between materials due to different characteristics such as porosity, specific surface area, reactivity, adsorption capacity and ability to promote biofilm development (Rolland et al. 2009). Gravel is a high-density material with low porosity and terracotta is a lightweight porous material (Yang et al. 2017).The filter material gravel has a porosity of 40% and terracotta 50%.Porosity refers to the total volume of pores in a material. It is calculated using pore volume. Porosity for filter material was performed in ATREE’s Water and Soil Lab (Bangalore).

Porosity is the ratio of total void space/pore volume to the total bulk volume of a material (equation 1).

$$\text{Porosity} = \frac{\text{Pore volume}}{\text{Bulk volume}} \text{x}100 \qquad (1)$$

System operation and maintenance

The field study operated at a flow rate of 3KLD; flow rate is measured using a bucket flow method. Hydraulic loading rate (HLR) is calculated based on the flow rate, porosity and area. Average hydraulic retention time (HRT) of 0.80 days (19hrs) for gravel bed setup and 1.01 days (24hrs) for terracotta bed setup (Table 1).

The system receives wastewater from a manhole to which the wastewater streams from the nearby hotels and companies are connected (Figure 2). A mesh inserted in the pipe connecting the manhole to the system prevents large solids from entering the system. Mesh is cleaned twice in a day and the silt is removed from the system regularly. The system receives wastewater only during the daytime. Between July 2019 and May 2020, Rs.33460 was spent for maintenance of the system.

Table 1: Experimental design for efficiency evaluation of filtration setup

Filter material	HLR (m/day)	HRT (day)	Inflow (KLD)	Maximum Loading Rate(MLR)g/m^2/day							
				TSS	COD	BOD_5	NO_3-N	NH_4^+-N	TN	PO_4^{3-}P	TP
Gravel	0.38	0.80	3	4830	3699	268	3	22	62	4	23
Terracotta	0.38	1.01	3	4830	3699	268	3	22	68	4	28

Table 2: Characteristics of the wastewater

Water quality parameter	Mean ± SD
pH	6.45±0.45
Electrical conductivity (µS/cm)	1663±421
COD (mg/L)	2143±2569
BOD_5 (mg/L)	389±240
Nitrate-N (mg/L)	2.3 ±1.3
Total phosphorus (mg/L)	13.6 ±13.9
FC Log (MPN/100mL)	6.3 ±0.56

STRAINS before planting STRAINS after planting

Figure 1: STRAINS (8m x 1m x 0.75 m) deployed at Sowlkere

Water quality monitoring

Wastewater quality was monitored fortnightly between July 2019 and March 2020. Samples were collected from the inlet, midpoint and outlet of the gravel and terracotta setups. Seven sampling points (one from inlet, two from the midpoint of each setup and two from outlets) are provided along the system. The wastewater samples are analyzed for physical (temperature, turbidity and suspended solids), chemical (pH, conductivity, nitrate nitrogen(NO_3-N), ammonical nitrogen (NH_4^+-N), total nitrogen (TN), orthophosphates (PO_4^{3-}), total phosphorus (TP), chemical oxygen demand (COD), dissolved COD (D-COD), biochemical oxygen demand (BOD_5)) and biological parameters (fecal coliform (FC)). Standard methods for the examination of water and wastewater are followed to test the water quality parameters (APHA 2005). Samples for chemical and biological analyses were preserved with concentrated sulphuric acid to pH <2 (in table 3 * indicates the parameters for which samples were acid preserved), stored in the icebox and the temperature was maintained below 4 degrees during the storage and transport of the samples from the field to the Water and Soil Lab, ATREE.

Table 3: Water quality parameters

Parameter	Method	Sample analyzed	Indicator
pH	YSI Pro1030	Onsite	A general indicator of Alkalinity/Acidity of water
Temperature	YSI Pro1030	Onsite	A general indicator of water quality
Electrical Conductivity (EC)	YSI Pro1030	Onsite	Indicates the presence of dissolved salts/nutrients in the water
Turbidity	APHA (Nephloturbidity meter)	Offsite	Impervious land cover/ eutrophication /construction activities
TSS	APHA (Filtration apparatus)	Offsite	Impervious land cover/eutrophication/construction activities
Nitrates	Hach colorimeter	Offsite	Agricultural runoff/ Domestic sewage inflows
Nitrogen (Ammonia)*	APHA (Spectroquant Prove 600)	Offsite	Agricultural runoff/ Domestic sewage inflows
Total Nitrogen*	APHA (Spectroquant Prove 600)	Offsite	Agricultural runoff/ Domestic sewage inflows
Phosphates*	APHA (Spectroquant Prove 600)	Offsite	Agricultural runoff/Domestic sewage inflows
Total Phosphorus*	APHA (Spectroquant Prove 600)	Offsite	Agricultural runoff/Domestic sewage inflows
COD*	APHA (open reflux method)	Offsite	Strength of grey water and black water
BOD_5	APHA	Offsite	Domestic sewage inflows/runoff
Fecal Coliform (FC)	Idexx Colilert-18	Offsite	Presence of pathogens –either domestic sewage, livestock waste, runoff

After reaching an equilibrium state, the aggregates were planted with Canna lily on 26th December 2019 with an optimum planting density of 4 plants/m^2as suggested by CPCB (Resource recycling series:reres/ 06 /2003 - 2004).

Removal efficiencies were calculated as a percentage reduction in the concentration from influent to the effluent samples using Equation (2). The corresponding Mass Loading Rates (MLR) was also estimated. The MLR for the BOD_5, COD, TN and TP are calculated using the Equations (3).

$$\text{Removal Efficiency(RE)} = \frac{\text{Ci}-\text{Co}}{\text{Ci}} \text{ x } 100 \qquad (2)$$

$$\text{Mass loading rate (MLR)} = C_i \text{ x HLR} \qquad (3)$$

Where $C_{i=}$ Concentration of contaminant in the influent (g/m^3), C_0= concentration of the contaminant in the effluent (g/m^3) and HLR=Hydraulic loading rate (m/d)

Statistical tests

Test for significance in the contaminated removal efficiencies of two aggregate materials was evaluated using independent samples T-test for the normally distributed data at a confidence interval of 95%.

Table 4: Field visits and Samples collected

Date of visit	Remarks
18/06/2019	Installation of pipes in constructed wetland
05/07/2019	Construction of barrier in the manhole to let the water into the CW
July to December (2019)	12 samplings done before planting (7 samples collected each time)
26/12/2019	32 Canna lily plants planted
January to March (2020)	5 samplings done after planting (ongoing)

Results

Performance of gravel and terracotta in STRAINS during the course of experiment

Suspended solids removal

Suspended solids are removed through physical processes such as screening and settling (Singh 2015).It is important to achieve TSS removal as excessive TSS levels speed up the clogging process in the vegetated beds that result in reduced surface flow and lower treatment efficiency (Vymazal 2002).Figure 3a shows the temporal variations in TSS levels from both setups. The maximum and average TSS levels in the inflows are 2800mg/L and 672mg/L respectively. The influent levels observed are much higher in comparison to the influent levels (100-283mg/L) reported by

Michael et al. (2015).The variation observed might be due to the inflow of silt into the system from ongoing construction work in the catchment. During the course of the experiment significant difference in the TSS levels was observed between inlet and outlet of both the setups ($p < 0.05$).The average effluent level observed during the sampling period was 113mg/L for gravel setup and 158mg/L for terracotta setup. The average TSS level observed in both set up are higher than discharge limit recommended by KSPCB (KSPCB notification 05122015_4976).

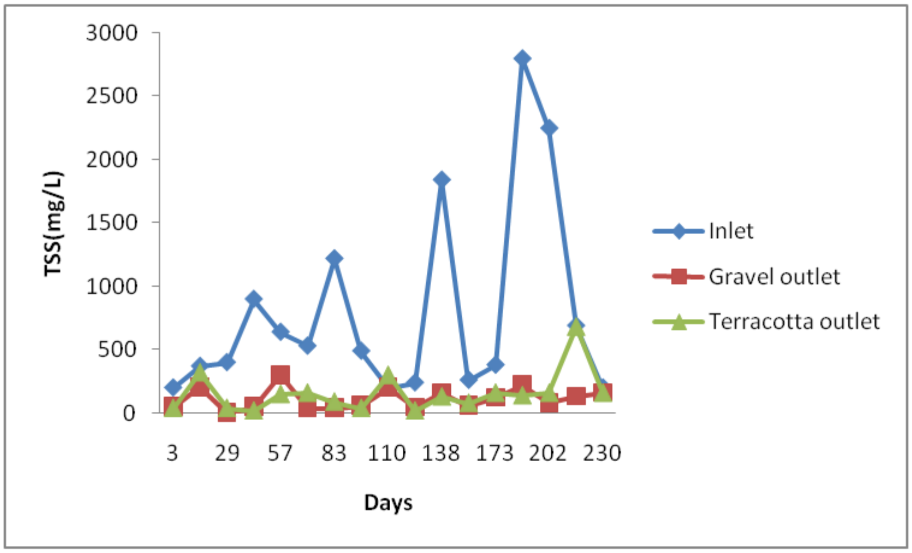
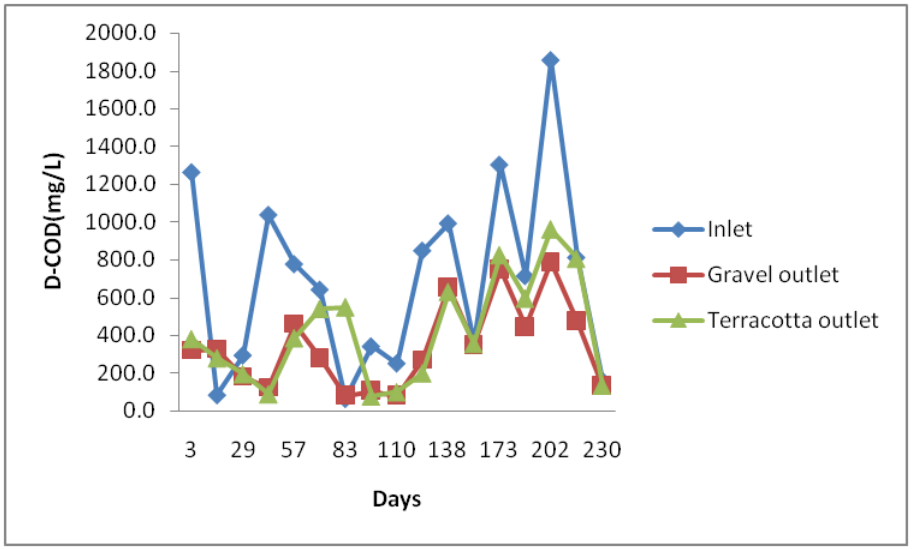


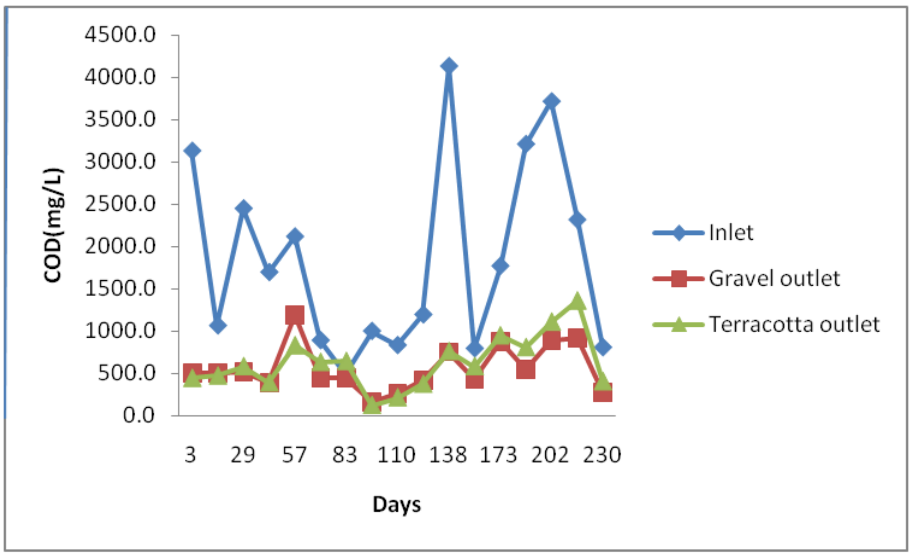
Figure 2a: Temporal variations in TSS levels at both setups

Organic matter removal

Biochemical Oxygen Demand (BOD_5) represents the biodegradable component of organic matter and COD represents both the biodegradable and non-biodegradable component along with chemically oxidisable components present in wastewater (Kim 1989).The temporal variation in organic matter at both setups is presented in Figure 3b. The COD levels observed in the influent and effluents were much higher than the BOD_5 levels. COD is normally higher than BOD_5because more organic compounds can be chemically oxidized than degraded by the microbes by biologically oxidation. Average influent concentration of 1856mg/L was observed for COD and 497mg/L for BOD_5. The average influent COD and BOD_5 levels are much higher than the grey water characteristics reported (250 -375mg/L for COD, 100 -180mg/L for BOD_5) in low income countries like India (Michael et al. 2018).High variability in the influent COD and BOD_5levels observed was due to the inflows of silt and dry weather runoff from the catchment into the system. The average effluent level of 554mg/L and 101mg/L was observed for COD and BOD_5 in gravel and 625mg/L and 102mg/L in terracotta setup. The effluents from the both setups do not meet effluent discharge standards for COD and BOD_5 set by Karnataka state Pollution control board (KSPCB)(KSPCB notification 05122015_4976). This is because of the extremely high contaminant loads entering the system unlike other studies where primary treated effluents are fed into constructed wetland systems. Considering that pilot setup was deployed to test effectiveness of gravel and terracotta aggregate material in removing contaminants, the existing field conditions helps us to assess the performance of the system under extreme stress (extremely high organic contaminant loading rate).

Significant reductions ($p < 0.05$) in the organic matter levels were observed in the effluent quality of both setups. Irrespective of the high variability /fluctuations the effluents from both systems showed stable BOD_5 levels. This can be attributed to reduced flow during night hours leading to increased contact time of contaminants with the biofilms and micro flora (Thalla 2019). Better oxygenation at the feeding point also resulted in the better removal of organic matter (Albuquerque2010).





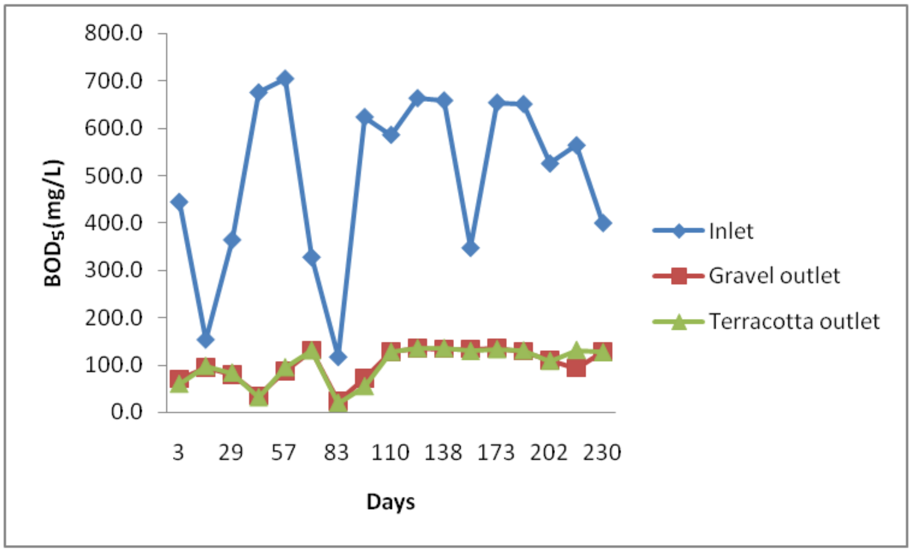


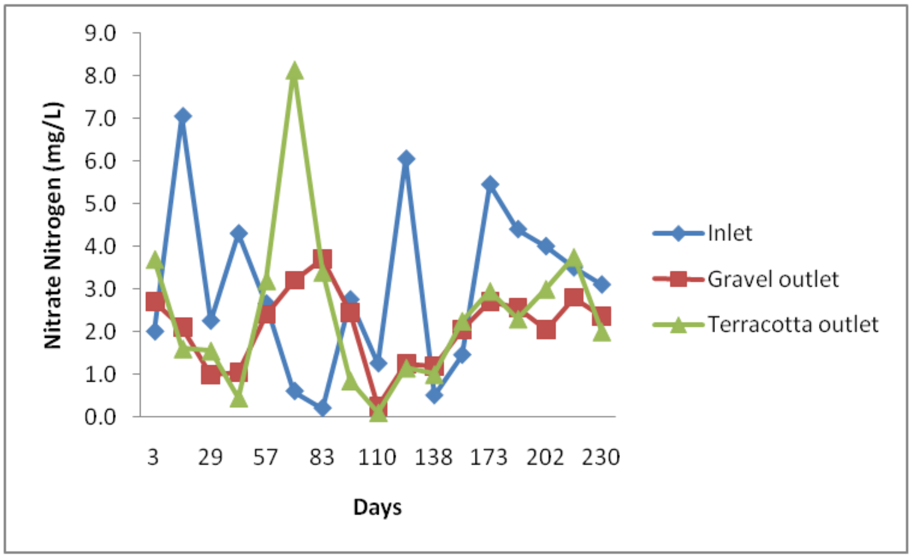
Figure 3b: Temporal variations in the organic matter levels at both setups

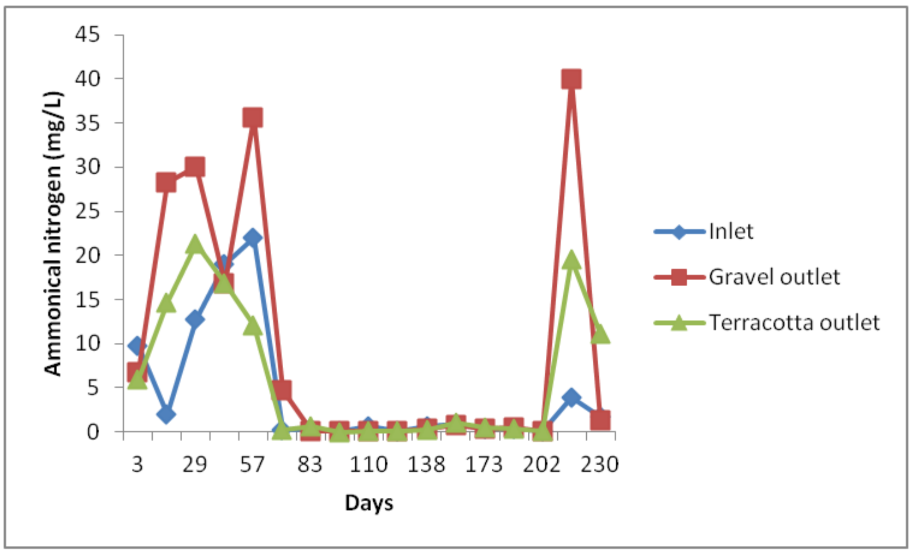
Nutrients removal and transformation

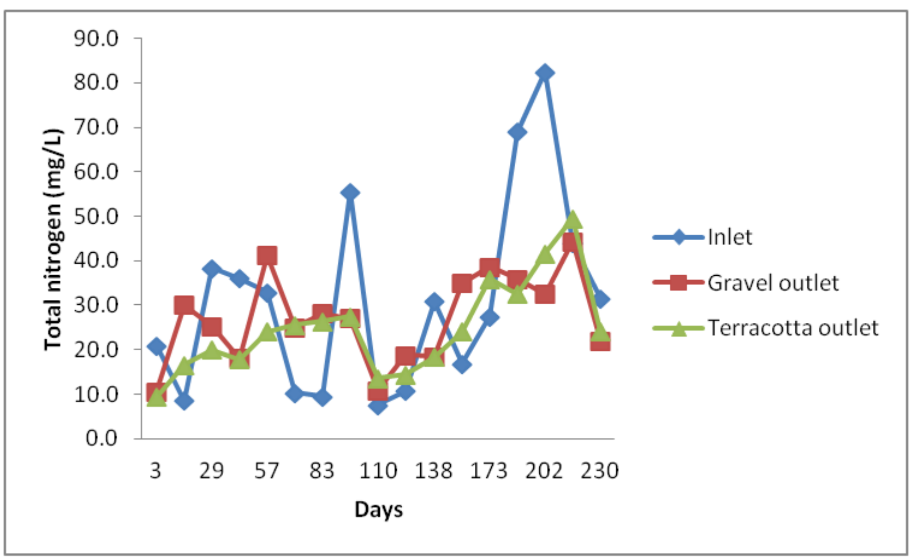
The average influent TN and TP levels was 31mg/L and 11mg/L with effluent levels being 27mg/L and 7mg/L for gravel and 25mg/L and 5mg/L for terracotta setup. During the10 months of monitoring not much removal of nutrients was observed in the systems (figure 3c). Ghosh (2010) reported a maximum of 98% of nutrients removal at 4 days of HRT and 40% at 1 day HRT. The STRAINS prototype system operated at low HRT of 19hrs for gravel and 24hrs for terracotta. Poor performance for nutrient removal could be attributed to low HRT.

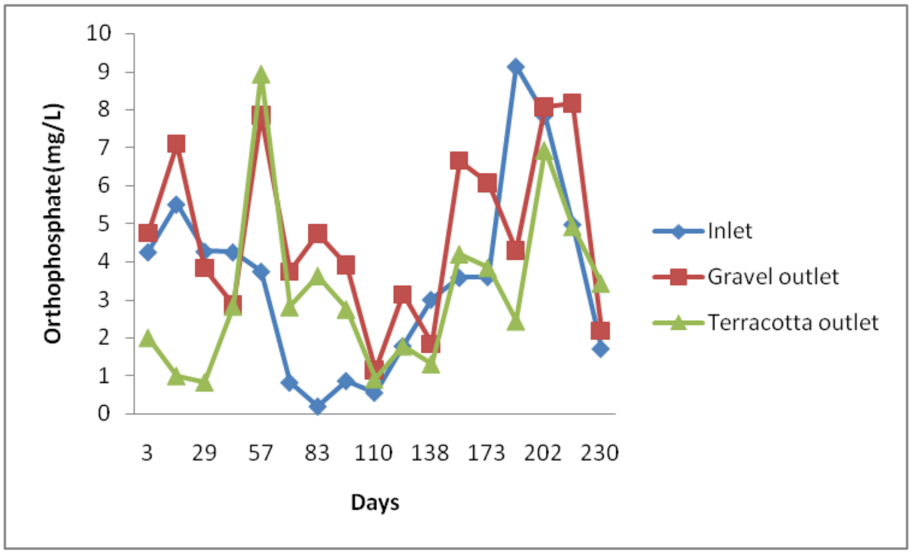
The most common pathways for the removal of ammonia and nitrate are nitrification (ammonia), denitrification (nitrate), plant uptake (both), assimilation into biomass (both), ammonia volatilization (ammonia), filtration and sedimentation (Vymazal and Kropfelova, 2008). The contribution of the latter four mechanisms is very low, when compared to biological removal pathways, plant uptake and adsorption. The loss of ammonia through volatilization is generally insignificant when compared to nitrification–denitrification, if the pH is below 8 (Vymazal and Kropfelova, 2008).

Removal of phosphate takes place mainly through sorption. The redox conditions present in the system might also affect the rate of phosphorous removal since aerobic conditions are more favorable for phosphorous sorption and co-precipitation by ligand exchange reactions hydrous oxides of iron and aluminium (Bostrom et al. 1982).


Nitrate Nitrogen (mg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
3
29
57
83
110
138
173
202
230
Days
Inlet
Gravel outlet
Terracotta outlet


Ammonical nitrogen (mg/L)
45
40
35
30
25
20
15
10
5
0
3
29
57
83
110
138
173
202
230
Days
Inlet
Gravel outlet
Terracotta outlet


Total nitrogen (mg/L)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
3
29
57
83
110
138
173
202
230
Days
Inlet
Gravel outlet
Terracotta outlet



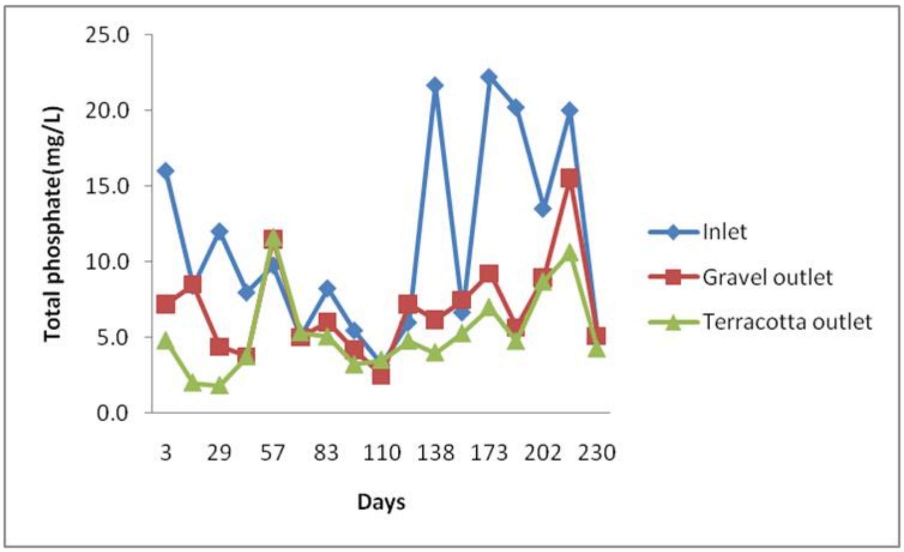


Figure 3c: Temporal variations in nutrient levels at both setups

Fecal coliform removal

Figure 3d presents temporal variations in fecal coliform levels at both setups. Not much difference in FC levels observed at the effluent when compared to the influent ($p > 0.05$).During the initial days' maximum 2 log order FC removal was observed in both the systems. After three months of operation, no FC removal was observed from both the systems. Coliform removal mechanism in the filtration system includes physical processes such as filtration, sedimentation, ultraviolet radiation; chemical processes such as absorption, oxidation, and natural die-off and die off due to toxins and biological activities, as well as ingestion by nematodes and protozoa (Karim et al. 2004; Wu et al. 2016).Considering that both the systems receives greywater without pre-treatment, high TSS would have resulted in clogging of the pore spaces on the surface of aggregate material.

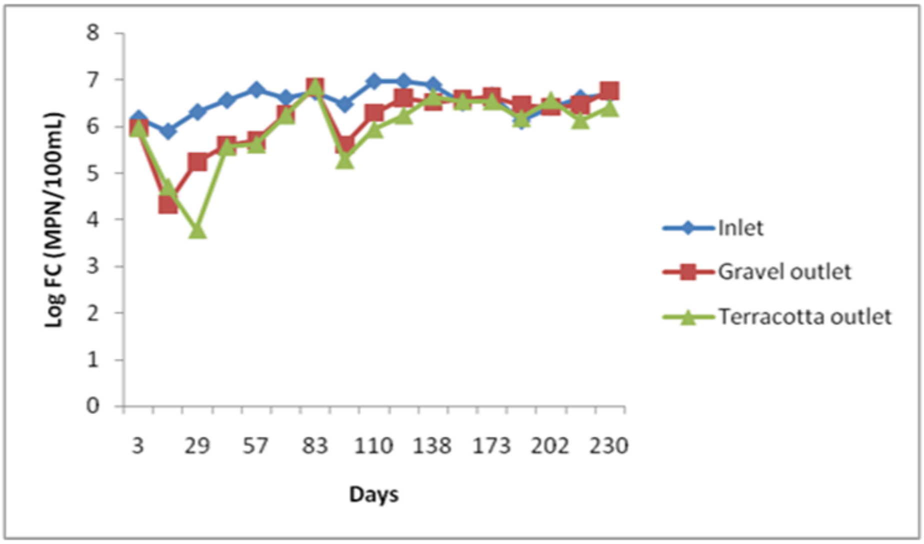


Figure 3d: Temporal variations in FC levels at both setups

Pollutant removal efficiency of STRAINS

The removal efficiency of STRAINS was investigated for the treatment of greywater. The average removal efficiency of pollutants in both the setups is shown in Table 5. TSS removal efficiency ranged from 20% to 96% with an average of 86% for gravel setup and from 20% to 98% with an average of 80% for terracotta setup respectively. Despite higher influent TSS level to the system, STRAINS achieved better removal efficiency showing high hydraulic and good settling conditions. Similarly removal efficiency of 70% and 66% was observed for COD in gravel and terracotta setup respectively. The BOD_5 level in the effluent reached an average percentage removal rate up to 80% for gravel setup and 79% for terracotta setup.

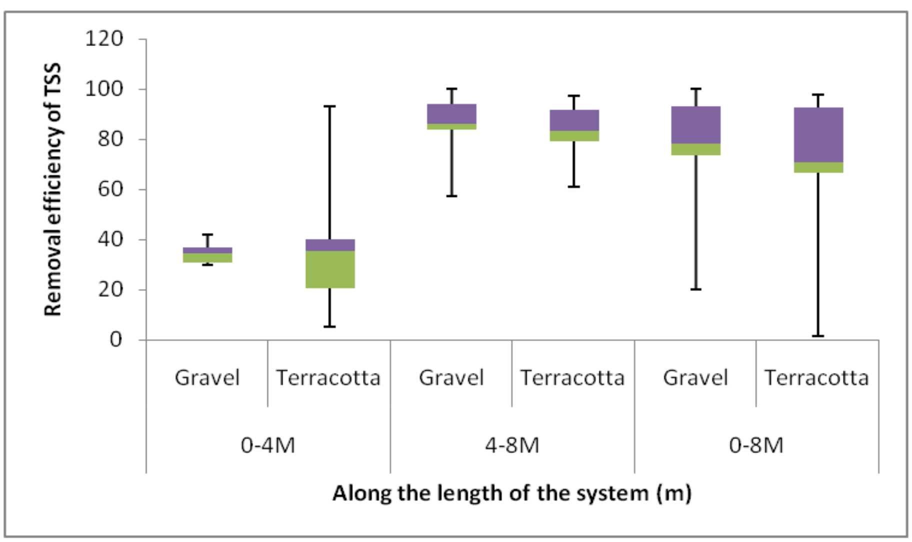
Modest Nitrate nitrogen and total nitrogen removal efficiencies are observed in both setups. Nitrate-nitrogen removal efficiency of 30% was observed in both setups. Total nitrogen removal was 13% for gravel and 26% for terracotta. Vymazal (2008) reported lower N removal as compared to organics and solids in constructed wetlands. This was attributed to the absence of oxic conditions for nitrification and anoxic conditions for denitrification simultaneously in CW. Average total Phosphorus removal efficiencies of 38% and 53% was observed for gravel and terracotta setup respectively. Orthophosphate removal efficiency of 9% and negative value was observed in terracotta and gravel respectively. As presented in figure 4, higher total phosphorus reduction is observed in terracotta compared to gravel indicating better assimilation of phosphorous into microbial biomass on terracotta. The gravel only adsorbs small amounts of phosphorus because it has a coarse texture (small surface-to-volume ratio) and generally contains low levels of Fe and Al (Garcia et al. 2013).This trend is consistent with other research findings where studies have shown that different matrices have different result for phosphorus release, generally varying between 40 and 80% (Pant 2001).

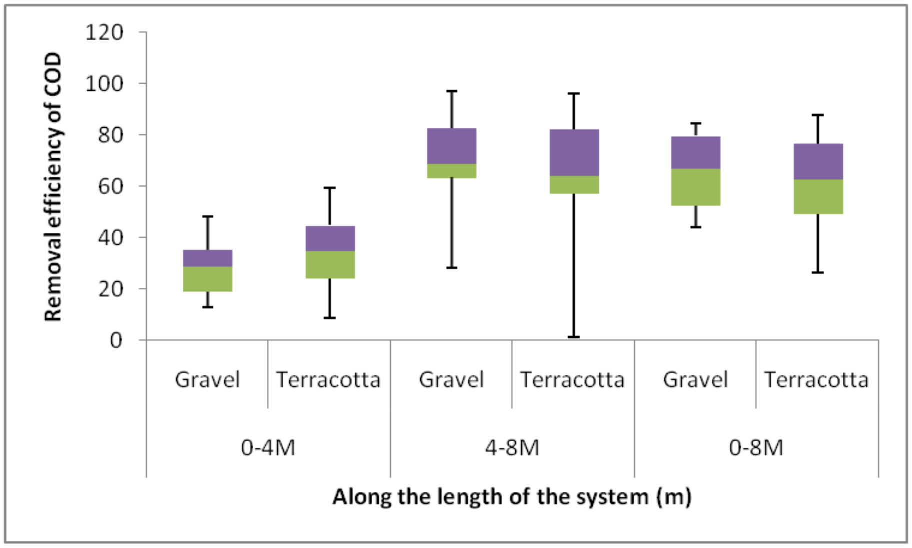
Fecal coliform removal along the length of the system was minimal. Hydraulic overloading and reduced HRT could decrease the ability of coliforms to adsorb to the biofilm (Wu et al. 2016). STRAIN system operates at low HRT of 19hrs for gravel and 24hrs for terracotta. This could have negatively impacted the removal efficiency of fecal coliforms from the filter media.

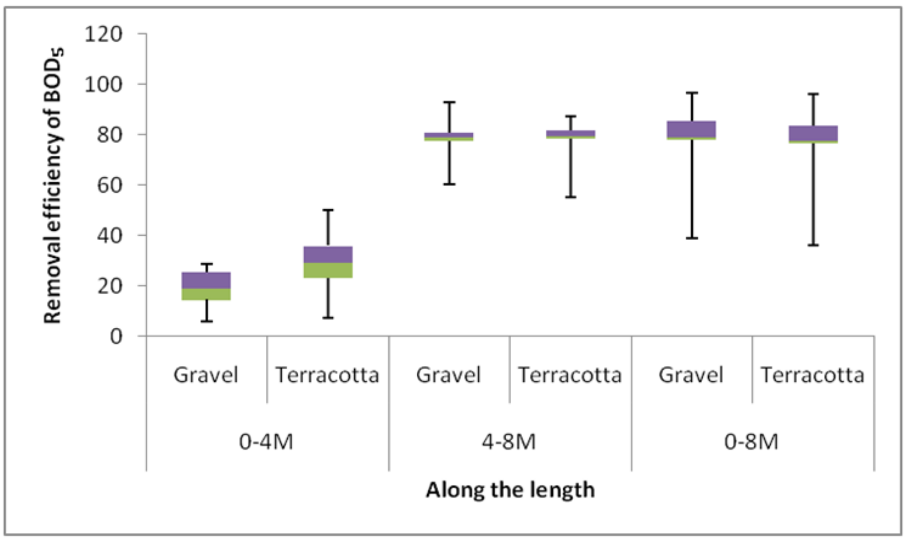
Figure 4 shows the removal efficiency of TSS, COD, BOD, TN, TP and FC along the length of the STRAINS. The pollutant (organic matter, suspended solids, nutrients and coliforms) removal efficiency observed in the lower half (4 -8 m) of the system was higher than overall efficiency (0-8m). Increase in contaminants levels were observed at the center of both the systems. This could be attributed to breaking down contaminants into simpler form as greywater moves towards the center of the system (Trang 2010). Short-circuiting leads to reduced HRT which could negatively impact the treatment efficiency of wetlands (Tanner et al., 1998).Ulrich et al. (2005) reported contribution of the clogging to hydraulic short circuiting in the horizontal flow subsurface constructed wetlands.

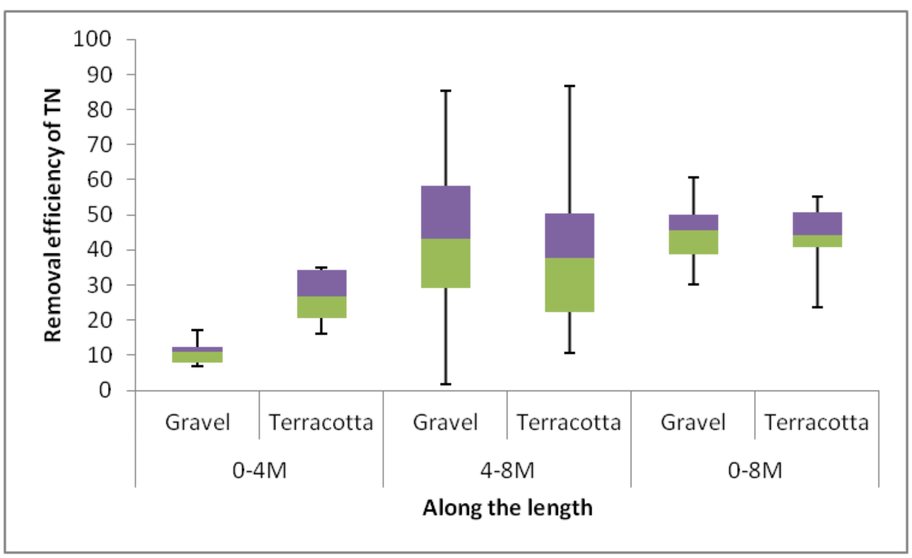
Table 5: Average removal efficiencies of each unit

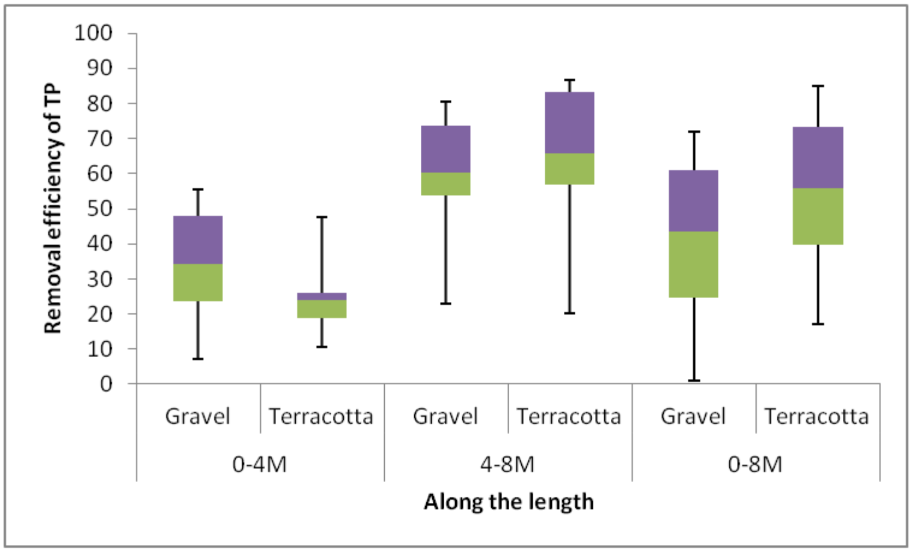
Parameter	**Efficiency of STRAINS (%)**	
	Gravel	**Terracotta**
TSS	86	80
COD	70	66
BOD	80	79
Dissolved COD	51	40
NO_3-N	30	30
NH_4-N	-122	-40
Total Nitrogen	13	26
PO_4^{3-}	-34	9
Total Phosphorus	38	53
Fecal Coliform (log reduction)	0	0




Removal efficiency of COD
120
100
80
60
40
20
0
Gravel
Terracotta
Gravel
Terracotta
Gravel
Terracotta
0-4M
4-8M
0-8M
Along the length of the system (m)


Removal efficiency of BOD5
120
100
80
60
40
20
0
Gravel
Terracotta
Gravel
Terracotta
Gravel
Terracotta
0-4M
4-8M
0-8M
Along the length


Removal efficiency of TN
100
90
80
70
60
50
40
30
20
10
0
Gravel
Terracotta
Gravel
Terracotta
Gravel
Terracotta
0-4M
4-8M
0-8M
Along the length



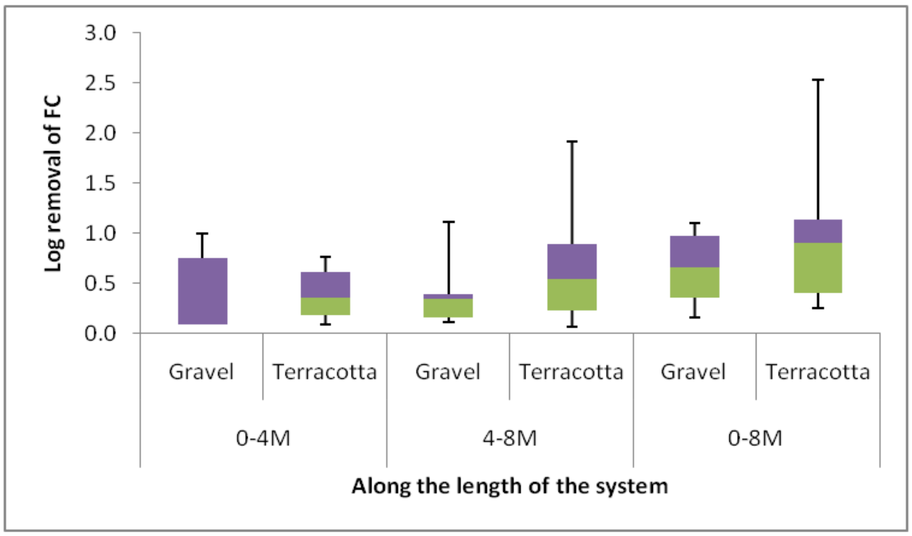


Figure 4: Removal efficiency of TSS, COD, BOD_5, TN, TP, and FC along the length of the STRAINS

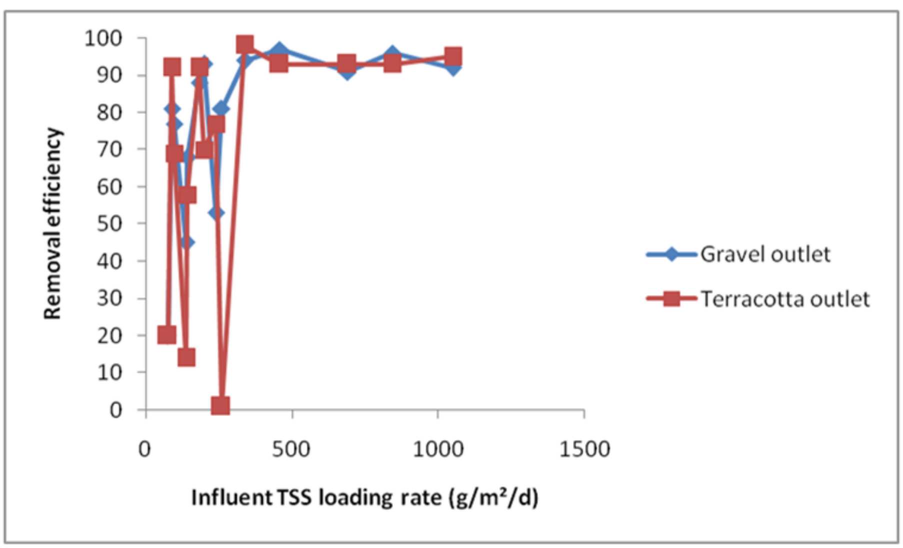
The effect of organic loading rate on the removal efficiency of the STRAIN system

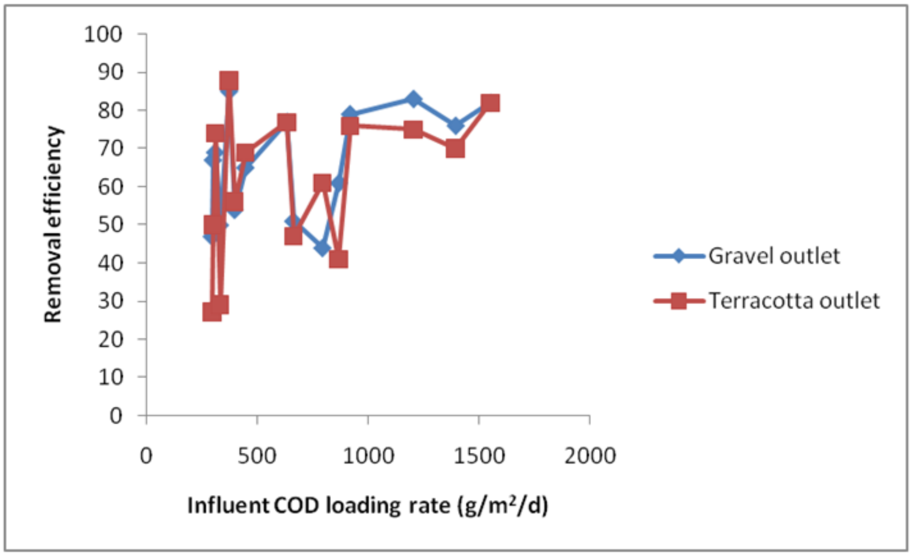
Figure 5 shows the effect of influent organic loading rates on the contaminant removal efficiencies. The pilot scale system is deployed in the natural environment with the construction activities going on in the catchment, the quality of inflows to the system were highly variable. For e.g. during the monitoring period the TSS levels varied from 56 g/m^2/d to 4830 g/m^2/d levels. The variation in the influent organic loading rates is the result of the changes in influent contaminant levels. The variation in greywater quality is reported as a result of changes in quality of water supplied and lifestyle and climatic conditions (Gross et al.2014).The influent COD loading rate varied between 300-1550g/m^2/d throughout the study. Despite the variation and high organic loading rate, gravel and terracotta setup achieved the COD removal efficiency up to 83 and 85% at HRT 19.2 and 24.2hrs respectively. The levels of removal efficiency observed throughout the study were consistent with the performance of other subsurface flow constructed wetland for greywater treatment. The maximum removal efficiency of 83% and 85% was obtained in gravel and terracotta when the system was loaded with 374 $g/m^2/d$ of COD. Likewise, results show the ability of STRAINS to remove BOD_5 from influent grey water in the range from 39 - 95% for gravel setup and 36 - 95% for terracotta. The maximum removal efficiency of 95% is achieved in both gravel and terracotta when the system was loaded with 253 $g/m^2/d$ of BOD_5 at retention time 19hrs and 24hrs respectively. The removal efficiency of TSS for gravel and terracotta substrate in STRAINS is in the range of 20 to 97 % and 20 to 98% respectively. The maximum removal efficiency was recorded at 458 $g/m^2/d$ and 338 $g/m^2/d$ for gravel and terracotta setup. The comparable removal efficiencies among BOD_5, COD and TSS are because of a significant amount of solids present in wastewater which is organic in nature, and consequently, reduction of solids corresponds with organic reduction (Neralla et al., 2000).

The maximum removal efficiency of TP for the gravel and terracotta setup was 72 and 85% respectively for corresponding loading rates of 8.1 and 4.5$g/m^2/d$. The maximum TN removal for gravel and terracotta setup was 61 and 53%. Nevertheless the average removal efficiency of STRAINS (both gravel and terracotta setup) to remove TP and TN was comparatively low. These results are in line with the literature review in which G.A.Edwin et al., (2015) reported the ability of constructed wetland to remove nutrients from greywater is much lower (25-40%). Vymazal (2007) reported that total nitrogen and phosphorus removal in most CW is low compared to organics and solids, it varied between 40-55% for nitrogen removal and 40-60% for phosphorus removal respectively. Also at the same loading rates, TP and TN is showing different removal efficiency (Figure 5) which might be due to the accumulated silt in the system which is affecting the performance of the system.

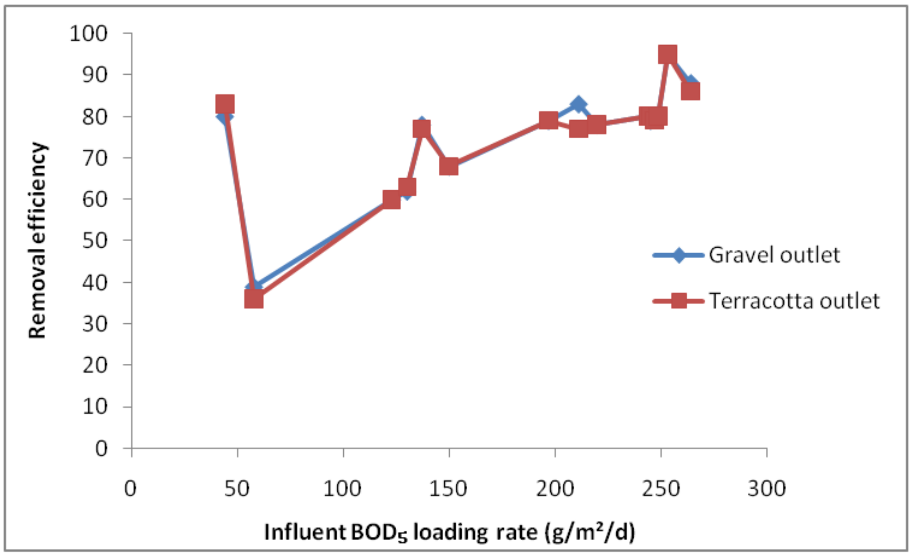
Table 6: Optimum loading rate for TSS, COD and BOD_5 in STRAINS and corresponding removal efficiencies

Parameters	Optimum loading rate ($g/m^2/d$)	Removal efficiency (%)	
		Gravel	Terracotta
TSS	140	68	58
COD	300	69	50
BOD_5	44	80	83

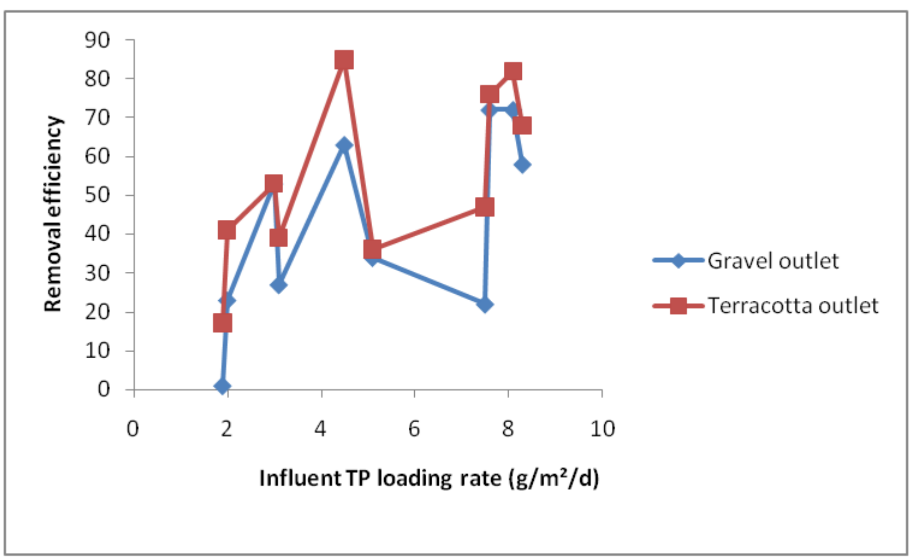




Removal efficiency
Influent COD loading rate (g/m²/d)
Gravel outlet
Terracotta outlet



Removal efficiency
Influent BOD5 loading rate (g/m²/d)
Gravel outlet
Terracotta outlet



Removal efficiency
Influent TP loading rate (g/m²/d)
Gravel outlet
Terracotta outlet

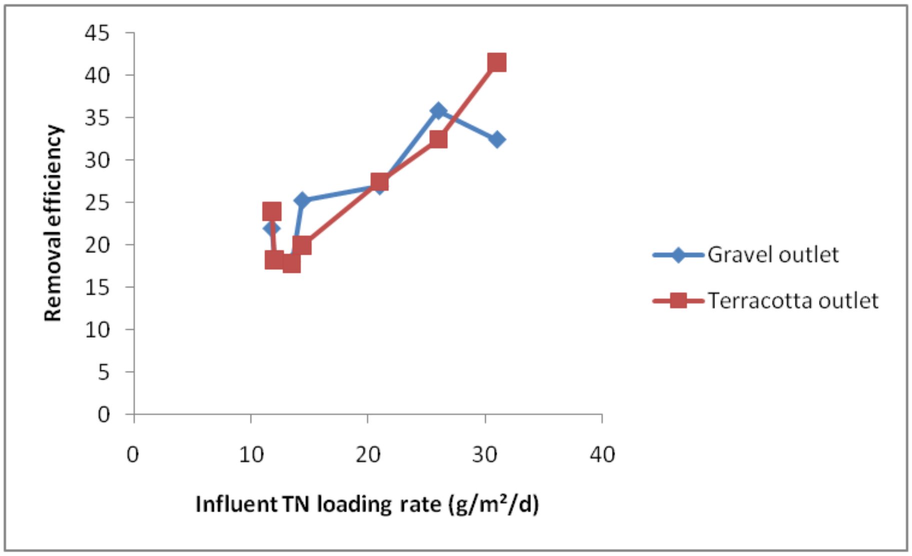
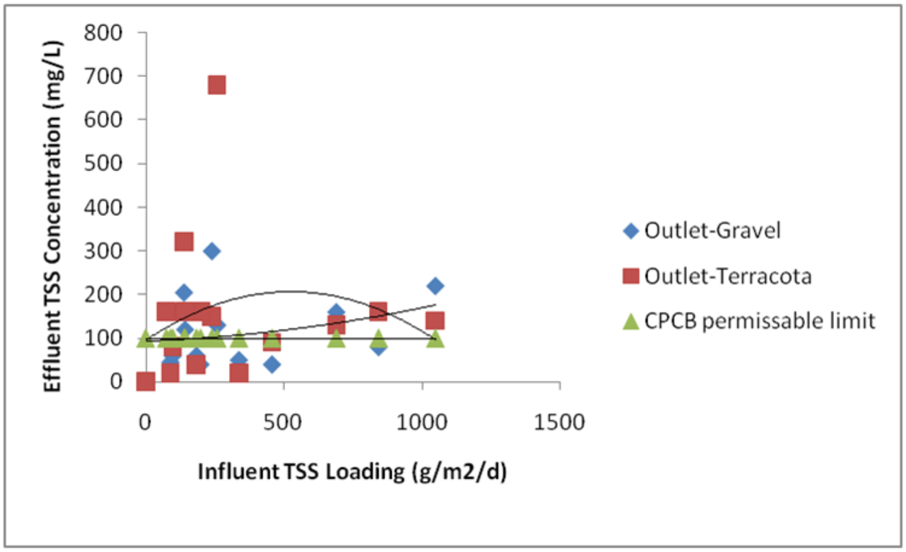


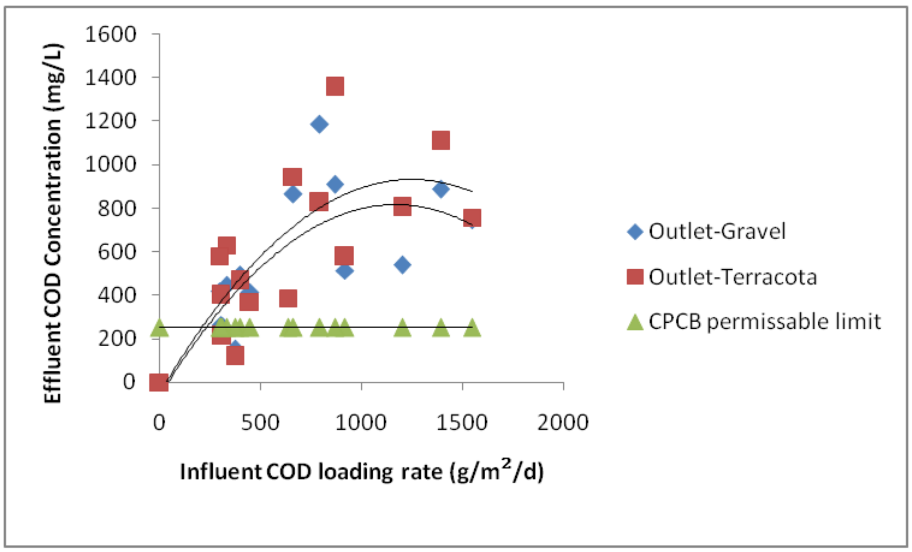
Figure 5: Relationship between influent loading rate and efficiency of the STRAINS

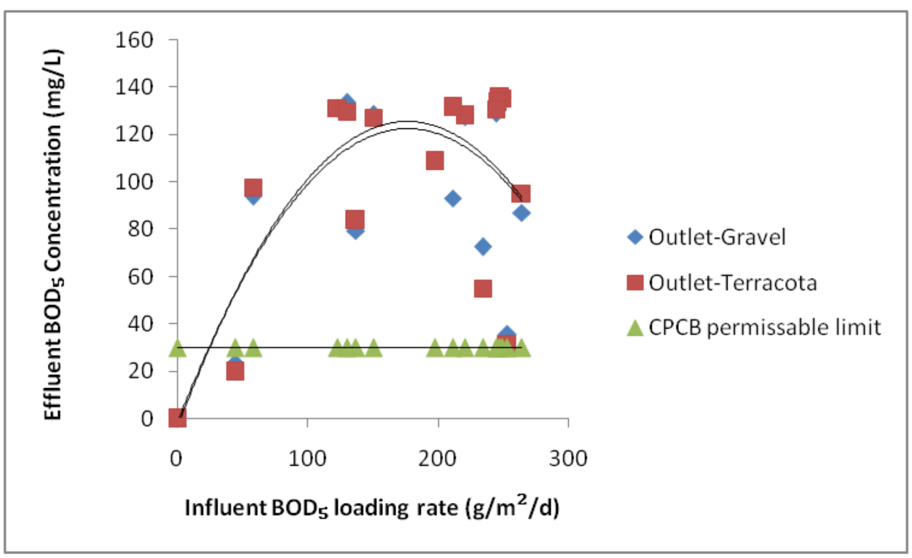
STRAINS overall treatment performance

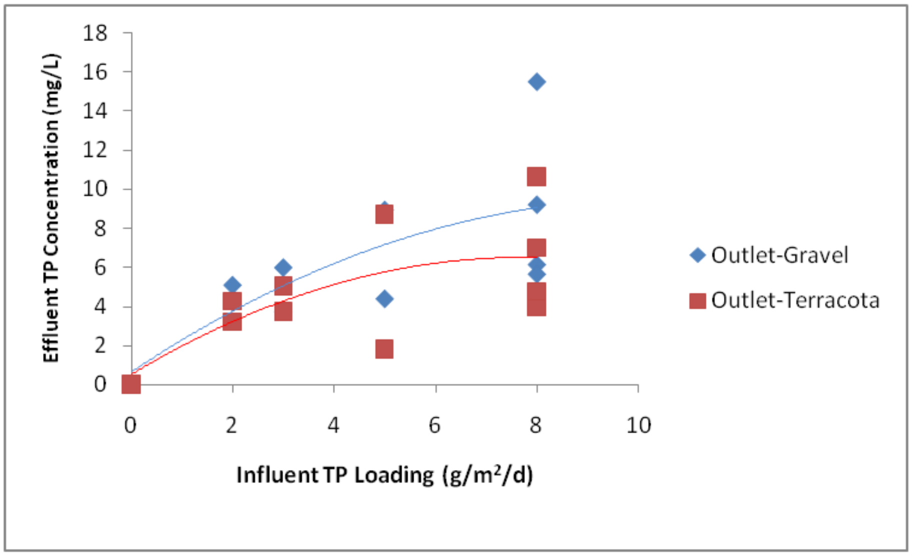
The Figure 6 illustrates the relationship between the influent loading rate and the outlet effluent quality. The areal influent COD loading is plotted in X-axis. The effluent COD concentration is plotted in Y-axis. The data points give bound lines that are based on polynomial fit curves that define 90 percentile of the data points for the data set. The bound lines were generated to provide guidance on STRAINS variability when choosing influent loading rates. From the graph it is understood that with increasing influent COD loading rate the effluent quality is deteriorating. Achieving lower effluent concentration requires reducing the loading rate. The CPCB effluent discharge standards set 250mg/L as the limit for disposal into inland surface water. The Figure 6 indicates that the system for both gravel and terracotta setup loaded with COD below 300g/m^2/d should be capable of meeting the discharge standard set by CPCB. Similarly to meet the discharge limit for effluent BOD concentration (30mg/L) and TSS(100mg/L) for both gravel and terracotta setup the system should be loaded below 50g/m^2/d and 100g/m^2/d respectively.

At present there are no uniform effluent quality standards set by CPCB for TP and TN. But some studies observed that the effluent quality is enhanced when a system loaded with low concentration of nutrients (Ronnie A. D.2010, Garcia et al., 2013). A statistical T-test showed significant difference between the inlet and outlet of both systems for all the parameters ($p < 0.014$). No significant difference was found between the performance of gravel and terracotta in the system ($p > 0.56$).


Effluent TSS Concentration (mg/L)
800
700
600
500
400
300
200
100
0
0
500
1000
1500
Influent TSS Loading (g/m2/d)
Outlet-Gravel
Outlet-Terracota
CPCB permissable limit


Effluent COD Concentration (mg/L)
1600
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
Influent COD loading rate (g/m2/d)
Outlet-Gravel
Outlet-Terracota
CPCB permissable limit


Effluent BOD5 Concentration (mg/L)
160
140
120
100
80
60
40
20
0
0
100
200
300
Influent BOD5 loading rate (g/m2/d)
Outlet-Gravel
Outlet-Terracota
CPCB permissable limit



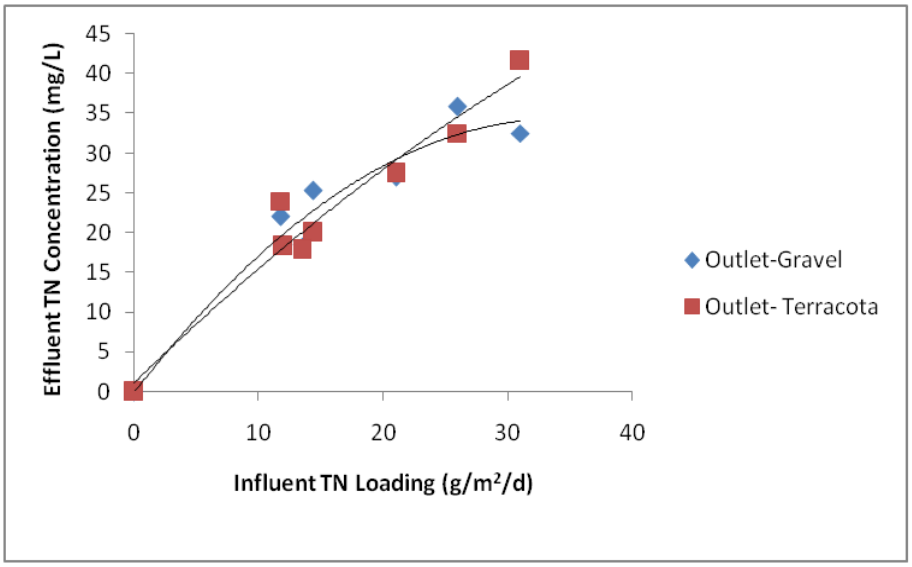


Figure 6: STRAINS Areal loading chart for TSS, COD, BOD, TP and TN

Conclusions

- STRAINS showed good potential for dealing with highly variable influent quality. The removal efficiency was good for TSS and organic matter and satisfactory for nutrients in both setups. According to the results an average percentage removal of pollutants from the system was found as follows: TSS- 86% for gravel,80% for terracotta;COD-70% for gravel,66% for terracotta; BOD - 80% for gravel,79% for terracotta; TN –13%for gravel,26% for terracotta; TP - 38% for gravel,53% for terracotta.

- STRAINS showed similar performance for gravel and terracotta setup for total suspended solids and organic matter removal ($p > 0.05$). According to the results terracotta showed better nutrient removal efficiency than gravel. It is suggested that either of these materials are suitable for use in future STRAINS interventions.

- Higher organic loading rate of highly soluble effluent is decreasing the treatment performance of TSS, COD, BOD_5, and nutrients. STRAINS achieved the better effluent quality when the system was loaded with COD ≤ 300g/m^2/d. The corresponding removal efficiency observed in both gravel and terracotta setup was 69% and 50% respectively. Similarly, the optimum loading rate for BOD_5 and TSS are found to be 44g/m^2/d and 140g/m^2/d respectively. At this optimum loading rate, the maximum removal efficiency of BOD_5 recorded in gravel and terracotta setup was 80 and 83% respectively. Meanwhile, the TSS removal efficiency of gravel and terracotta setup was found to be 68 and 58% respectively.

- The pollutants (TSS, organic matter, nutrients and coliforms) removal efficiency of pollutants in the lower half (4 -8 m) of the system was higher than overall efficiency (0-8m). Increase in contaminants levels were observed at the center of both the systems. This could be attributed to breaking down contaminants into simpler form as greywater moves towards the centre of the system.

- STRAINS system is a pilot system which is deployed in the natural environment, with the construction activities going in the catchment, the quality of inflows to the system were highly variable which is interfering with the effluent quality.

- The biofiltration stage of STRAINS was the primary focus of this study. However we found that in the absence of preliminary filtration negatively impacted performance and removal efficiencies due to the accumulation of silt and debris. Future studies and interventions should evaluate the increase in removal efficiencies that may be achieved by providing preliminary stages of solid waste diversion/removal and sediment capture upstream of the biofiltration stage.

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