Integrated Constructed Wetland (ICW) System a Sustainable Novel Technique for Urban Wastewater Management

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Research Article

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Abstract

The present study focuses on various aspects of Integrated Constructed Wetland System (ICW) systems with reference to its efficiency, and eco-friendliness in the treatment of domesticwastewater. The biological oxygen demand (BOD) impurity level is in the ranged from 383 mgl-1 to 248 mgl-1, chemical oxygen demand (COD)420 mgl-1 to 340 mgl-1, Total Phosphorus (TP) 10.2 mgl-1 to 5 mgl-1 and Total Nitrogen (TN) 18.9 mgl-1 to 14.8 mgl-1 respectively over a period of one year (SRM University). The influent contaminants are degradable in nature especially with high TP and TN concentrations. Six units of Constructed Wetland System (ICW)units are built with uniform dimensions of 2×1× 0.9 m based on EPA and TVA.The wetland plants chosen are*Typha Latifolia* and *Phragmites Australis*. Among the wetland units, *Typha* oriented units are observed to perform better with a reduction efficiency of 87% for BOD, 86% for COD, 70% for TP and 78% for TN proving that *Typha Latifolia*is a better aquatic plant for overall wastewater treatment. The removal efficiency increases with time and reaches maximum in 192 hrs. To substantiate the experimental study output, Statistical analysis (ANOVA) and multiple regression analysis with normality plot has carried out. It isevident that thepercentage removal of many parameters especially organic parameters over a period of time in treating with different wetland units is highly significant.

1. Introduction

Due to rapid urbanization and industrialization the available quality and quantity of water resources is continuously deteriorating. There is a vital need to maintain proper water quality and also to conserve the fast dwindling water resources through judicious utilization. The physical and chemical properties of water make it unique and indispensable for all living beings/life form (Paranychianakis et al. 2016; Ilyas and Masih 2017). The rate of fresh water usage has increased manifold during the last few decades due to rapid population growth, industrialization and economic development. Industries are one of the major sources of water pollution worldwide besides inadequate sewage treatment plants and many more. Proper management of available water resources and recycling of wastewater is therefore gaining importance in many parts of the world (Jhansi, S. C., & Mishra, S. K. (2013). By using water efficiently in day-to-day life, a good amount of water can be conserved (Ameeila, 2001; Adera et al. 2018; Hamisi et al. 2019). For low cost wastewater treatment, Integrated constructed wetlands (ICW) are beneficialto treat domestic, low TDS contaminated water.(Kalbar, P. P. (2021). Recycling and reusing water assumes the significance but the challenges posed by cost, power and operational hazards necessitate guidance from/the involvement of city planners and engineers (Metcafe and Eddy, 2017, Fuji 2007; Ramprasad and Rangabhashiyam 2020).

Natural water treatment systems like slow rate system; rapid infiltration system, overland flow system and aquatic treatment systems come under this the low hazard geochemical treatment category (Metcafe and Eddy, 2017). The wastewater is applied to vegetated land for treatment and also to meet the growth needs of vegetation. Part of the influent undergoes evapotranspiration and the remaining water percolates the soil profile. The surface runoff is collected and reapplied to the wastewater treatment system. This system depends on hydraulic loading rate, vegetation selection and management. ICW systems are designated as per the objective of wastewater treatment with effective 'treatment' as the main objective. The method has prompted research on the development of low-cost technologies, improved design. Percolation through combined vegetation and biologically active soil leads to purification of wastewater. Wastewater undergoes slow changes due to many activities (Fuji, 2007).

Aquatic macrophytes are the biological component of such systems. Bacterial transformations and physico-chemical processes including sedimentation, absorption, and precipitation are involved in the water treatment process (EPA 2002, IWA 2003). The aquatic treatment systems are classified into natural wetlands, aquatic plant systems and constructed wetlands. The discharge of water is limited to preserve the ecosystem (Shyam et al., 2006).Usually in constructed wetlands, robust types of macrophytes are used. Combination of various CWs with other treatment technologies can also become a pathway to tackle the individual drawbacks to achieving improved function of the entire system.

The two different types of constructed wetlands are Subsurface Flow Constructed Wetland and Sub-Surface flow Constructed Wetland with vegetation of free-floating plants, emergent plants and submerged plants. Subsurface Flow constructed wetlands are further classified as vertical subsurface flow, horizontal subsurface flow and integrated subsurface flow. Wastewater in this type of wetland is fed in at the inlet, it flows slowly through the porous substrate under the surface of the bed in more or less horizontal path until it reaches the outlet zone (Zein et al., 2016, Sudarsan et al., 2018). Horizontal flow wetland system can effectively remove pollutants like TSS, BOD, and COD from wastewater. (Pakshirajan and KerTang and Pakshirajan, 2018)

Vertical flow Constructed Wetland comprises of a flat bed of sand /gravel, trapped with sand /gravel and vegetation. These types of systems also effectively remove the pollutants. The hybrid system or integrated system (HF + VF) (ICW) offers the advantage of both horizontal and vertical CW., it displays good operating performances, always at the highest level for Constructed Wetland (ICW) technology with a low need of superficial area (Gross et al. 2007; Pakshirajan et al. 2014; Sochacki and Miksch, 2016, Huma and Masih, 2018).

The statistical analysis made through ANOVA, Duncan's Multiple Regression Test are used and interpreted the importance between factors at various significant level. The multiple regression analysis relates the correlation and variation of influent characteristics between the parameters (Yu et al. 2000; Liu et al. 2014; Bhowmick et al. 2017).

2. Methodology

Design and construction, transplantation of suitable vegetation and startup, operation and monitoring, sampling and analysis are the key elements/consideration involved in the methodology with focus on performance-based design algorithms. Project setting, wastewater characteristics, treatment goals, climate, and allowable inflow, selection of wetland types, pre and post treatments requirements are the chief elements of design which determine the efficiency of constructed wetlands (Merlin et al. 2002).

Location of the study area

The project setting of this work was executed inthe education institution campus located in Kanchipuram District, Tamil Nadu, India. It is situated between 12° 9’N to 12° 49’N latitudes and 18° 2’E to 18°3’E longitudes with temperatures ranging from 20^{O}C to 40^{O}C. The area (15 sqmetre) experiences an average rainfall of 1330 mm.

The efficiency of the ICW units in terms of its reduction of organic and inorganic pollutants and pathogens is evaluated by analyzing the results of sampling both at the inlet and the outlet of the experimental Constructed Wetland (ICW) units. The experimental units are installed at the experimental site and are open to the atmosphere (Sudarsan et al., 2015). The retention time is a maximum of 8 days for a batch mode loading and hence there is no other external due to temperature and rainfall during variations during the study. In order to design an appropriate treatment process, the first and foremost step is characterization of wastewater (Duncan Mara, 2013).

The sampling days are scheduled for uniformity in influent strength. The sampling of source wastewater is done for a period of one year. The sampling is scheduled at 24, 48, 72, 96, 144, 192 hours in the morning. Table.1 lists the characteristics of influent values of domestic wastewater (APHA 1995; Merlin et al., 2002).

Table.1 Characteristics of Domestic wastewater and Comprehensive Model Permit

Description/ Constitution	Domestic wastewater (mgl^{-1})	Comprehensive Model Permit
pH	7–12	5.5–9.0
BOD	190.0	40.0
COD	258.0	25.3
TSS	257.0	35.0
TDS	223.0	120.0
TN	43.0	25.0
TP	8.0	1.0
TVS	—	90.0

Treatment Goals: Before designing constructed wetlands an in-depth knowledge of regulations is needed. The treated water needsto be let into reservoirs which are termed as primary receivers of ground water, the surface water and the irrigation water.(Narella et al 2000.,) The required quality of treated water specification has to be met before the treated water is let off into these receivers. A Central Pollution Control Board permit is mandatory for point discharges of water/wastewater into water bodies of India. The permit specifies discharge standards of the water.

A CPCB permit is obtained from Tamilnadu Pollution Control Board (TNPCB) to identify target concentration for evaluating treatment performance parameters for ICW system. It was designed for treating constituents of wastewater. The Inflow and outflow of the system are sampled. From the obtained data the treatment performance of the ICW system can be evaluated by comparing the parameters with the model permit. The treatment goals are fixed based on comprehensive model permit formulated from effluent discharge standards of CPCB as given in the same Table 1.(CPCB 2015)

Constructed Wetland System (CW) units & experimental set up: Six units are built for the purpose of this investigative study. All the units are integrated hybrid system combining both horizontal and vertical flows [Figure 2.a]. The horizontal and vertical flow are achieved by providing baffles and allowing only horizontal or vertical flow. Each wetland unit is a rectangular channel [Figure 2.b] with an inlet chamber, wetland chamber and an outlet chamber. The inlet and outlet chamber are provided with the facility for entrance and exit of wastewater. The middle chamber is separated into three zones by providing stone baffles for achieving integrated flow, eight holes are provided in each baffle [Figure 2.c]. The plants are grown in two layered medium of sand and gravel in one case, sand and hollow polythene tube embedded in gravel in the other. The plants are transplanted to wetland units and again allowed to grow sufficiently before the wastewater treatment is started.

Establishment/Function of the Integrated Constructed Wetland (CW) at the Site

The designed ICW is put together at the project site. The vegetation is the principal component of the wetland system. The wetland vegetation chosen for this study are two macrobytes *Phragmites Australis* and *Typha Latifolia*. They are collected, transplanted and established as mentioned earlier. Wastewater is added slowly to the plants and to accumulate in the wetland cell. The wastewater is fed in batch mode once in retention time (RT) cycle to accumulate the soil microbes and to support growth of plants. The system is monitored three times a week and weeds are periodically removed.

Design of constructed wetland

Some of the design procedures in vogue are (1) Louisiana method (2) TVA method (3) Plug and flow model and (4) EPA model for setting up a Constructed Wetland (ICW) for wastewater treatment (IS2012015;US EPA (United States Environmental Protection Agency, (2005).

The EPA and TVA Model

The EPA and TVA models designed based on Darcy’s law. Extensive details have been are reported by many researchers (Sudarsan et al., 2018).

Media Type Used: Top layer is 30 cm local wetland soil on which the wetland vegetation will grow. The second layer is 60 cm of ¾, gravel or crushed stone. At the bottom, a compact soil liner or HDPE liner should be provided if the permeability of the underlying soil is more than 10 cm / day.

Additional Design Detail: Vertical perforation or slots `are provided to deliver water from the surface down to the subsurface. These raisers should have maximum spacing of 4.6 m. The minimum diameter for the central raiser is 30 cm and for the end raiser it is 15 cm (Figure. 3).

Selection of vegetation

Free water surface (FWS) and subsurface flow (SSF) system are two basic types of wetland systems. They maintain 4–18 inches of water above the soil and stay saturated. As the horizontal and vertical constructed wetland systems are not effectively functioning if the Industrail wastewater was treated (Paulo et al., 2008). So, the Integrated Constructed Wetland System (CW)has been chosen for this research study. This system has the advantages of both horizontal and vertical flow regimes.

Collection/Growth of Wetland Vegetation prior to Treatment

The stems of *Phragmites Australis* and *Typha Latifolia* are collected from areas near the campus and transplanted into the polythene bags containing natural soil [Figure 4a]. The plants are watered on alternative days for establishment. *Typha* is grown in standing water. After a month, the plants are transplanted to a natural bed and nurtured there. Wastewater is slowly added to acclimatize them. The plants are closely monitored until they show robust growth and periodic weeding is done [Figure 4.b]. Proper functioning of the system requires the pretreatment of inflow for the effective survival of the wetland system.

Other Aspects of designing a CWL

Hydraulic Design

The theoretical application of Darcy's law is limited owing to the following factors. The flow discharge 'Q' is constant and uniform in a laminar flow condition. But the turbulent flow occurs in very coarse gravel media. The input vs. output may be inconsistent due to evaporation, precipitation and seepage. Owing to unequal porosity short circuiting may occur. Medium sized substrate is used in the experimental constructed wetlands along with sand and soil (EPA, 2005).

Aspect Ratio: While designing subsurface flow constructed wetlands, the main consideration is aspect ratio (L:W). The ration of less than 10:1 has to be provided to avoid surface flow in subsurface flow constructed wetlands system. The hybrid Constructed Wetland System (CW) system is designed with an aspect ratio of 2:1 (Paulo et al., 2008, EPA, 2005). All the experimental constructed wetlands systems are designed with a bed slope of less than 1% at the bottom. The type of media used in constructed wetlands system are medium gravel, sand and native soil.

Detention Time

It initiates the performance (IS2012015, CWDM, 2010), six to seven days detention time is ideal for primary or secondary treatment of wastewater (IS201215). Short detention time does not provide adequate time for pollutant degradation to occur and long degradation time may lead to the occurrence of stagnant aerobic conditions. However, the present study is conducted with a detention time of 8 days for domestic wastewater in the experimental unit.

Treatment of Wastewater

The wastewater is subject to primary treatment (skimming and primary sedimentation) prior to being let into the input chamber. The wastewater is allowed to stay in the wetland chamber according to RT corresponding to unit’s capacity after which it is sent to the outlet chamber as usual.

Sampling and Analysis

Samples of domestic wastewater are collected over a period of 12 months in each inlet and outlet at 24, 48, 72, 96, 144, 192 hours in the morning.The samples are then analyzed for COD, BOD, TSS, TN and TP, as per standard methods of water and wastewater examination. Table 2 presents the wetland units used for the experimental study and the naming conventions used in this study.

Table 2
Wetland units used for the study

Wetland Unit	Fillers	Named as
Control – 1	Gravel and Sand	CGS
Control – 2	Gravel, Sand and Hollow tubes	CGPS
Phragmites – 1	Gravel, Sand and *Phragmites* plants	PGS
Phragmites – 2	Gravel, Sand, Hollow Tubes, and *Phragmites* Plants	PGPS
Typha – 1	Gravel, Sand and *Typha* plants	TGS
Typha – 2	Gravel, Sand, Hollow Tubes, and *Typha* Plants	TGPS

Statistical analysis

Statistical analysis and multiple regression analysis with normality plot also carried out to differentiate the different treatment units on the basis of treatment performance and substantiate the efficiency of experimental output and the working of the prototype unit (Vymazal and Brezinova, 2014).

PostHoc Duncan’s Multiple Range Test

DMRT is conducted for pairwise comparison of parameters before and after the treatment. To safeguard against false negative (type II error in Hypothetical significance) DMRT is performed at the risk of making type-I error. This test is conducted for all the datasets and F and P scores are calculated. The minimum percentage of P values ensures the significance of the results.

Physical, chemical and biological compositions are the major criteria that characterize wastewater (Duncan Mara 2013). The physical, chemical and biological properties are interrelated; they are listed in Table 3.

Table 3
Domestic Wastewater Characteristics

Parameters	Standards (mgl^{-1})
BOD	383.0
COD	420.0
TP	10.2
TN	18.9

The parameters for discussion fall within the domestic wastewater limit i.e. TP, TN, COD and BOD being 20, 40, 400 and 600 mg L^{-1} respectively. Two broad categories of constituents, i.e., Organic and Inorganic constituents are present in domestic wastewater. COD, BOD, TOC and bacteria are grouped under organic pollutants while N, P and solids and metals fall under inorganic pollutants. (Qdais and Moussa, 2004). Oxygen demand method and organic carbon method are used to determine organic content in the wastewater. (Ouellet-Plamondon et al., 2006)

The total content of organic matter can be ascertained from the COD and BOD values (Sudarsan et al. 2015). This is the most widely used parameter in organic pollution estimation. BOD tests results are used to measure the measure the efficiency of the treatment process and to determine the compliance with wastewater disclosure permits (Wang et al., 2013).

Nitrogen and phosphorus are the backbone of microorganism, plants and zanimals (Xiong et al. 2011). They are both needed for plants and bio-organisms at values of 4–16 mgl^{-1} of P (Zhang et al., 2018). This value may be high where soaps and detergents with high phosphorous contents are used by the community, whose target water is taken for consideration.

3. Results And Discussion

The wastewater is subjected to primary treatment (skimming and primary sedimentation) prior to being let into the constructed wetland. The designed quantity is into the input chamber. The wastewater is allowed to stay in the wetland chamber according to the designed retention time corresponding to the units capacity after which it is sent the outlet chamber. Samplesare collected at 24, 48 72, 96, 144 and 192 hours in the morning for domestic wastewater. 19 samples each are collected each at inlet and outlet. Wastewater samples were analyzed for the following parameters - COD, BOD, TP and TN (APHA.,2017 Zhang et al., 2018, IWA, 2000).

All the systems are maintained with uniform loading throughout the study period based on the capacity of the unit. Sampling is the most important consideration for the proper characterization of wastewater for pollutant removal. Utmost most care is taken to maintain average characteristics under different periods. As the retention time is 192 hours (8 days), seasonal differences do not have any appreciable influence on the influent and effluent characteristics. Preservation is yet another consideration for getting accurate results. Sampling is followed by preservation as and when collected. Before analysis the samples should be preserved properly. The length of time that a constituent in wastewater will remain stable is related to the characteristics of the constituent and preservation method used. The samples are preserved as per standard guidelines in current practice/vogue (APHA., 2017, IWA,2000).

Impact of Retention Time(RT) on Reduction Efficiency

The outcome efficiency of the function of ICWunit is a function of retention time among other factors A RT of 6–8 days has been reported to be optimal for the treatment of primary and secondary waste (All the six units of the Constructed Wetland System (CW)operate under RT of 1, 2, 3, 4, 6 and 8 days. Diaz et al., (2012). The average percentage of reduction of BOD, COD, TP and TN is compared for TGPS and PGPS units in which the *Typha Latifolia* and *Phragmites Australis* are used as vegetation; the performance of TGPS is marginally better than its counterpart PGPS unit in terms of reduction efficiency which can be inferred from Fig. 5 (a) to 5 (f).

Maximum reduction of BOD 87.63%, COD 86.21%, TN 78.37% and TP 62.74% is achieved in TGPS unit with a retention time of 8 days. From day 1, the average percentage of reduction for BOD is 38.63%, COD 42.21%, TN 38.58% and TP 28.74%. An increasing trend is observed, till the maximum reduction is reached on day 8, except for TP which shows stagnation after day 3 owing to the reason discussed earlier. Similar decline in P removal efficiency over time was noted in earlier studies (Seung et al., 2012, Diaz et al., 2012, Prasanna et al., 2017, Hong et al., 2018, Yuan et al., 2019).

Treatment efficiency of the chosen wetland species can be compared using the results of PGPS and TGPS wetland units, whose wetland plants are *Phragmites Australis* and *Typha Latifolia* respectively. In PGPS unit the average percentage removal on day 1 is BOD 23.84%, COD 26.26%, TP 24.59% and TN 27.58%. After 192 hours RT, the average percentage of pollutant removal is 82.35 % for BOD 77.47%, for COD, 53.59% for TP and 74.74% for TN. Similarly, for TGPS, pollutant removal is 87.63% for BOD, 86.21% for COD, 62.74% for TP and 78.37% for TN. Though both units are effective in removing pollutants, TGPS unit has an edge over the PGPS unit thereby projecting *Typha* as a better plant than *Phragmites.* Since both the wetlands are maintained at water stagnated condition with equal RT, *Typha* seems to be more efficient than *Phragmites* which indicates that *Typha* capable of showing better performance in water stagnated condition while the latter is favored in non-stagnated condition. *Typha Latifolia* exhibits a good survival rate demonstrating a vigorous spread in few weeks after planting, more roots with adequate rhizosphere leads to better reduction. There is some variability in treatment for both *Phragmites* and *Typha* at 96 hours and 144 hours RT. At 192 hours RT there is some stability compared to other RTs (Shyam et al., 2006). *Typha* exhibits more variability than *Phragmites*. This is also proved by analyzing the variance of *Phragmites*.

The nutrient uptake of plants (Phyto-remediation) depicted in the Figs. 6 and 7 comprehends that the absorption rate of root is comparatively higher than the stem and Leaf and stands good for both *Phragmites Australis* and *Typha Latifolia*.

According to Figs. 8 and 9, It was found the uptake of all the macronutrients is maximum in the case of root followed soil, stem and leaf. The major reason as to why the uptake of macronutrients is maximum by root is due to the presence of symbiotic microorganisms in the roots of the plants responsible for nitrogen fixation and other processes.

The uptake by the plants can be correlated to the reduction in the nutrient content in the wastewater. As much reduction in the nutrient content is found in the set-up planted with Typha, the uptake by the plant parts is also more (Vymazal, 2005, 2010,2013). The uptake of the macronutrients by *Phragmites* was found in a similar manner like that of Typha i.e., root had maximum uptake followed by soil, stem and leaf. This is in accordance with the previous finding; also, compared to Typha the uptake was less which can be correlated to the lesser nutrient removal from the wastewater (Ramprasad, et al. (2017).

Statistical Analysis:

Statistical analysis ANOVA shows the credibility of the percentage removal for different parameters over a period of time for different wetland units. It is noted that the value of the parameter TP for TGPS unit has decreased from 6.58 on day 1 to 2.48 on day-8 with SD value varying from 1.74 to 0.84 on day 8. The F value for TP has progressively increased. Similarly, with regard to all the parameters in this study, P value is 0.01 indicating the best level of significance in the outcome of the experimental wetland units.

Post Hoc – DMR test is performed to ascertain the significant differences with the dependent factor or with the interaction between independent and repeated factors. A statistical program (IBM SPSS 2000) is used to compute the data. Hypotheses are tested at 5% and 1% significance level. Differences are considered to be statistically significant when $P < 0.05$. In a broad sense, there is a significant difference between removals of inorganic Vs organic components wherein the percentage of removal is more in BOD and COD when compared to TP and TN. Also, there is significant difference between non-planted wetland (control) units and planted wetland units (*Typha* and *Phragmites)*. With specific reference to parameters, on day 1, w.r.t. TP, the TGS wetland unit significantly differs from all other wetland units at 5% level followed by PGPS showing better variance than others. On day 2, PGPS, TGS, TGPS are significantly varied when compared to CGS, CGPS and PGS. Also, PGS differs from the first two. On rest of the days, TGS and TGPS show a greater significance than other ICW units (Ilyas and Masih, 2017).

TN: On day 1, the TGS and TGPS wetland units differs significantly with that of CGS, CGPS, PGS and PGPS at 5% and PGPS shows significant variance than CGS, CGPS and PGS. On day 2, planted wetland units shows substantial variation than non – planted wetland units. On day3, expecting the controlled units, the rest of the wetland units demonstrate better performance. From day 4 till 8, PGPS, TGS and TGPS are significantly different at 5% level than the other units. COD: On all the days, TGPS depicted significant variance than other treatment units. Followed by TGS, PGPS and PGS depicted variance at 5% level than the Controlled units.BOD: On all the days, TGPS exhibits substantial variance than the other treatment units. Followed by TGS, PGPS and PGS represent variance at 5% level than the controlled units (Wang et al., 2013; Sudarsan et al., 2015).

Test for Normality

The normality test was conducted for all the wetland treatment units using the MATLAB norm plot function. The above statistical analysis depicts that T-GPS has an edge over other treatment units. The Fig. 10 shows the efficiency of the T-GPS with reference to the different parameters – TP, TN, COD and BOD.

TN, BOD and COD appear to be normally distributed with the samples falling on almost straight lines. TP is not fully normally distributed as the reduction percentage is comparatively low than the other parameters.

Multiple Regression Analysis

MRA is done to evaluate the relationship between each set of variables with respect to the parameters – TP, TN, COD and BOD for which the treatment units CGS, CGPS, PGS, PGPS, TGS and TGPS are taken up for study. R, F and P values and the regression equations are computed and the other details are furnished in Table S2. It also depicts the relationship between the actual and predicted values of the influent characteristics.

The coefficient R value being ≥ 0.6 indicates positive relationship between characteristics and the retention period. Excepting TP, the other parameters show a higher R value representing higher % of degradation. However, TP shows close to average confiscation in TGPS wetland unit. TGS and TGPS show a higher percentage of all parameters followed by PGS and PGPS. From this, it is evident that vegetation plays an important role in TP, TN, BOD and COD reduction, wherein TGS and TGPS show a very good efficiency when compared to PGS and PGPS.Statistical analysis helps to quantify the results and to match them the experimental results for more accuracy (Seung et al., 2012, Zein et al., 2016, Huma and Masih, 2018). It is evident from the statistical analysis and experimental results the ICW system are very effective treating the domestic wastewater. It is one of the sustainable novel technique can be implemented in urban center especially in the developing countries like India. Ramprasad et al. (2017)

5. Conclusion

Based on the research outcome, it is clear that there is a good removal of all components by Day 8, with around 60 to 80% for inorganic compounds and close to 90% for organic compounds.

Integrated constructed wetlands (ICW) system proves to be effective withhigher treatment efficiency. The reduction percentages of BOD, COD, TP and TN in case of domestic wastewater in the experimental ICW system are 87%, 86%, 70% and 78%, respectively. As the experimental study was carried out in a smaller system with less area the reduction efficiency is slightly less.

Good reduction percentage are achieved in the *Typha* GPS unit (TGPS). Similar reduction was also achieved by earlier researchers and has been documented in literature. Though *Typha Latifolia* shows more BOD reduction than *Phragmites Australis*, there is a large difference between the planted and unplanted setup.

Typha exhibits more variation in treatment than *Phragmites*.*Typha Latifolia* also shows marginally better performance than *Phragmites Australis* in terms of reduction efficiency which has also been documented in literature.

The present study proves that multicultural plant species like *Phragmites Australis* and *Typha Latifolia* can help in good pollutant reduction and will work very well in wastewater treatment systems.

6. Declarations

Ethical Approval: Here, the authors not used any human or animal sample for this study.

-Consent to participate: the authors agree to take part of this publication
-Consent to publish: the authors agree to publish this work in ESPR.
-Authors Contributions: (1) Asst.Prof. Dr. J.S.S, First author contributed ground and experimental work(nearly 40 %) of work, (2) Prof.Dr.R.A, second author contributed guidance of work, and valuable suggestions (35%) and the (3) third and last author Asst Prof Dr.S.N, compiling work, typesetting and corrections with communications contributed (30%) of over all work.
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-Competing Interests: The authors has no conflict of interest.
-Availability of data and materials: The datas will be supplied upon the reasonable request.

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Supplemental Tables

Supplemental tables are not available with this version

Figures

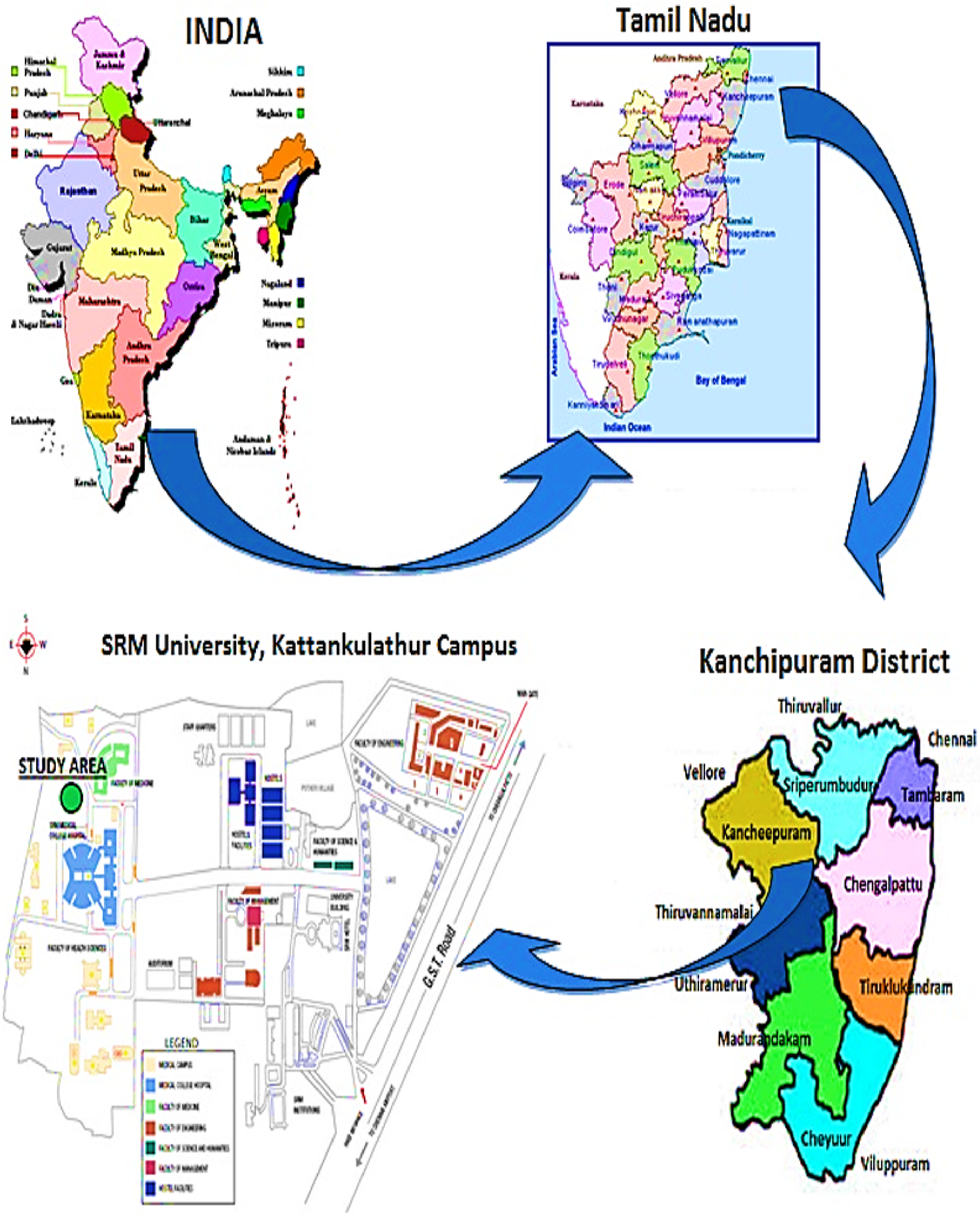


Figure 1

Location of the study area

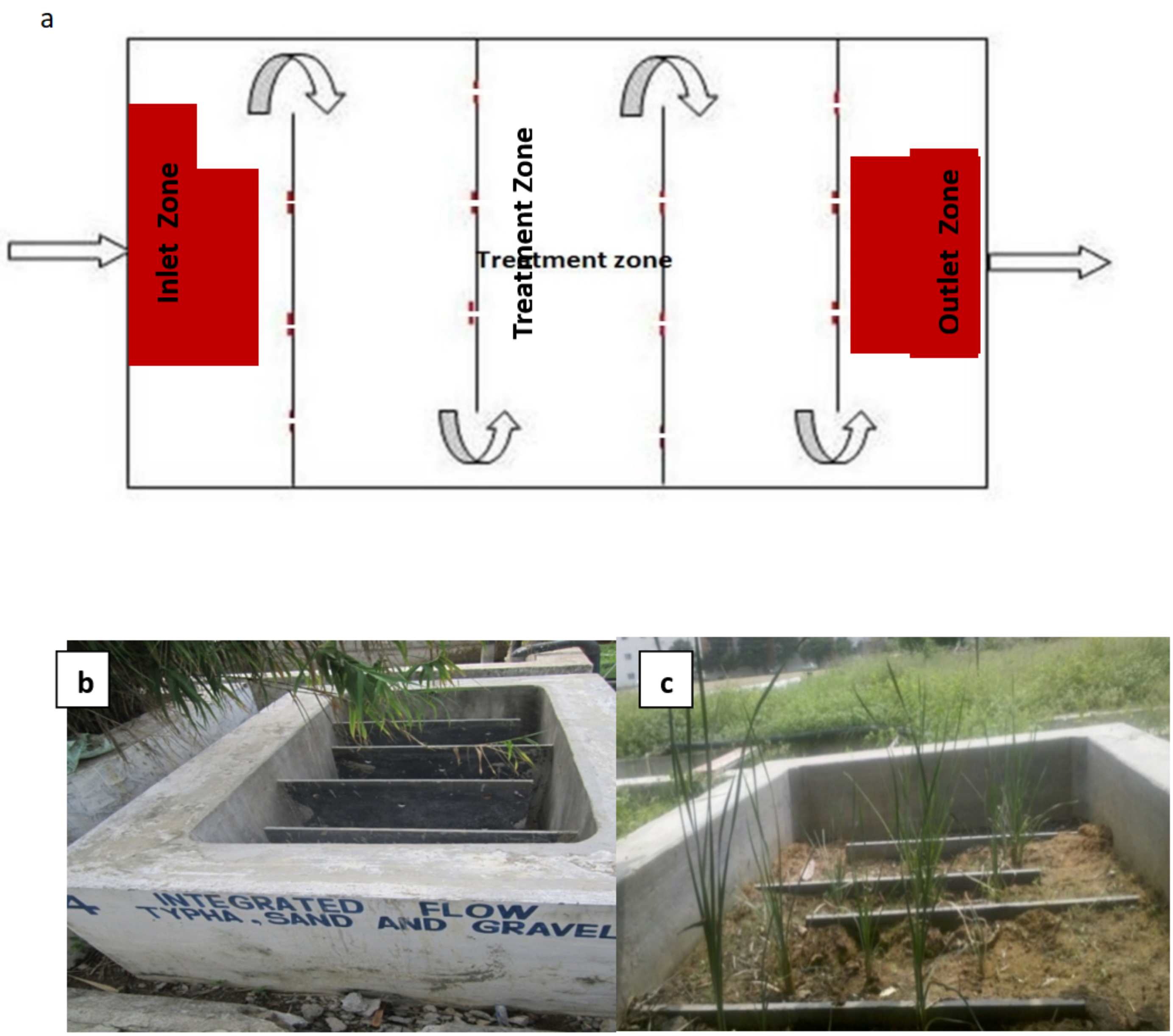


Figure 2

a Integrated Wetland unit design, b. Constructed Wetland System (CW)(3 chambers), Figure 2 (c). Plants transplanted to wetland unit

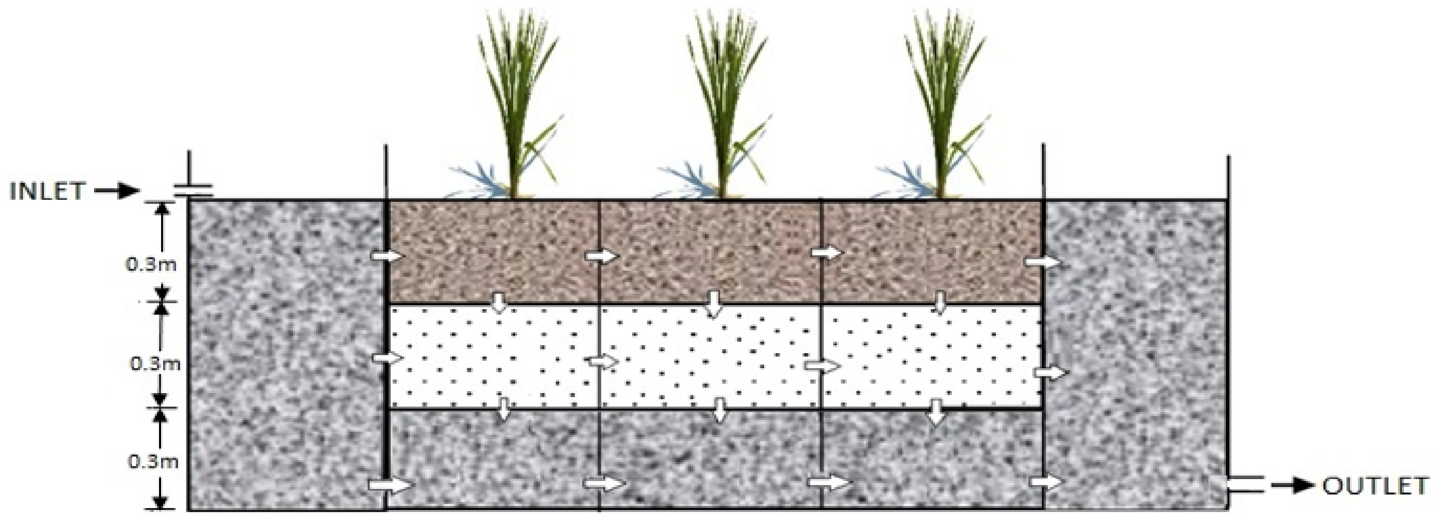


Figure 3

EPA model

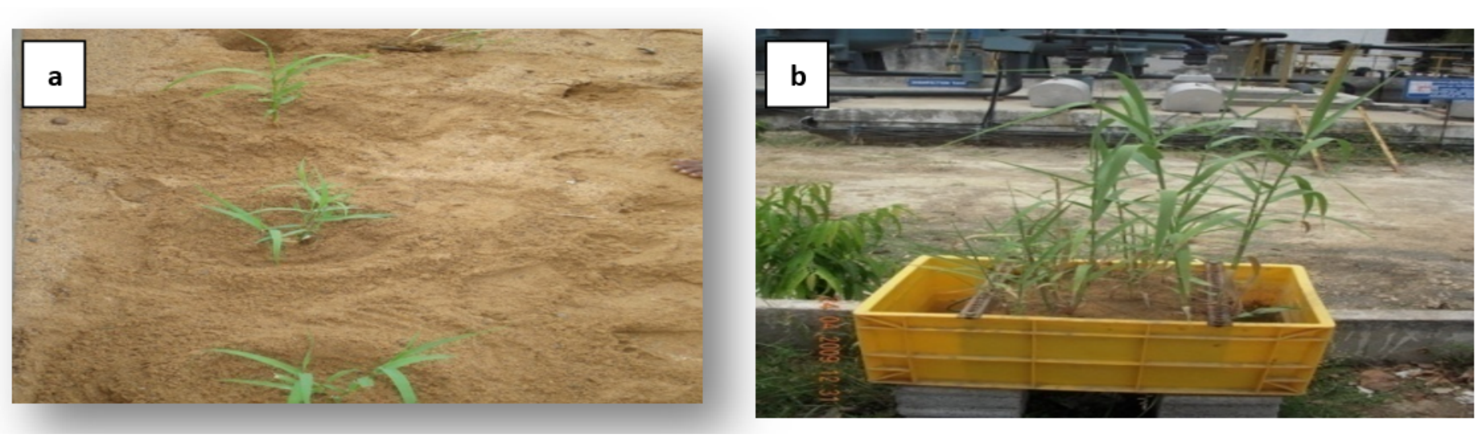


Figure 4

Growth of (a) Phragmites and (b)Typha

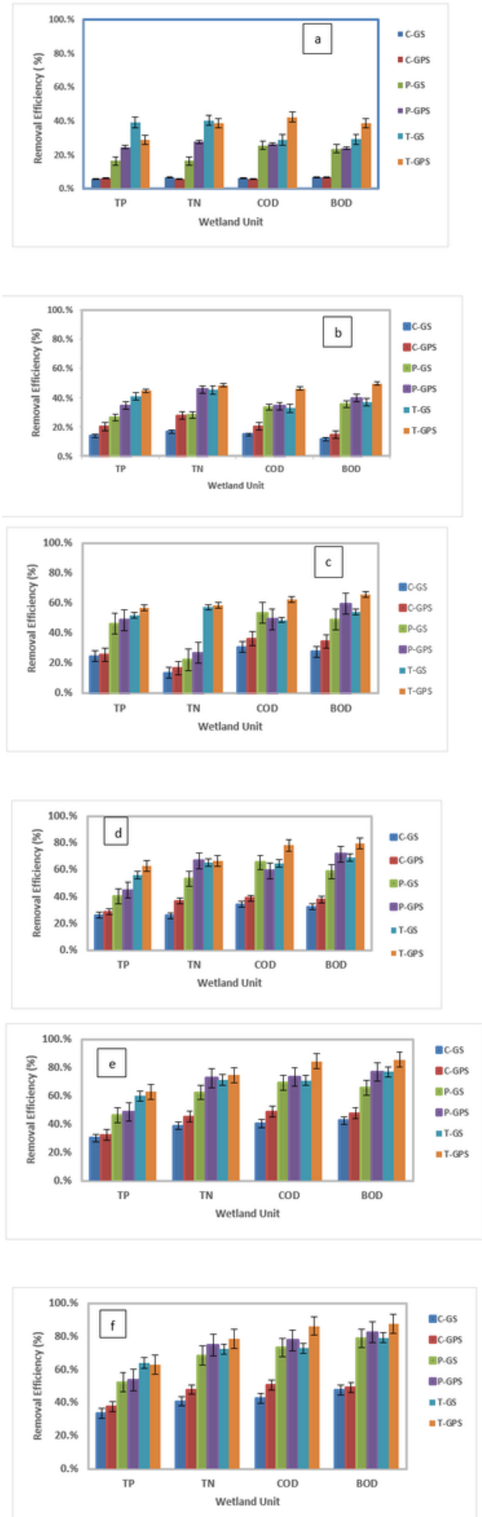
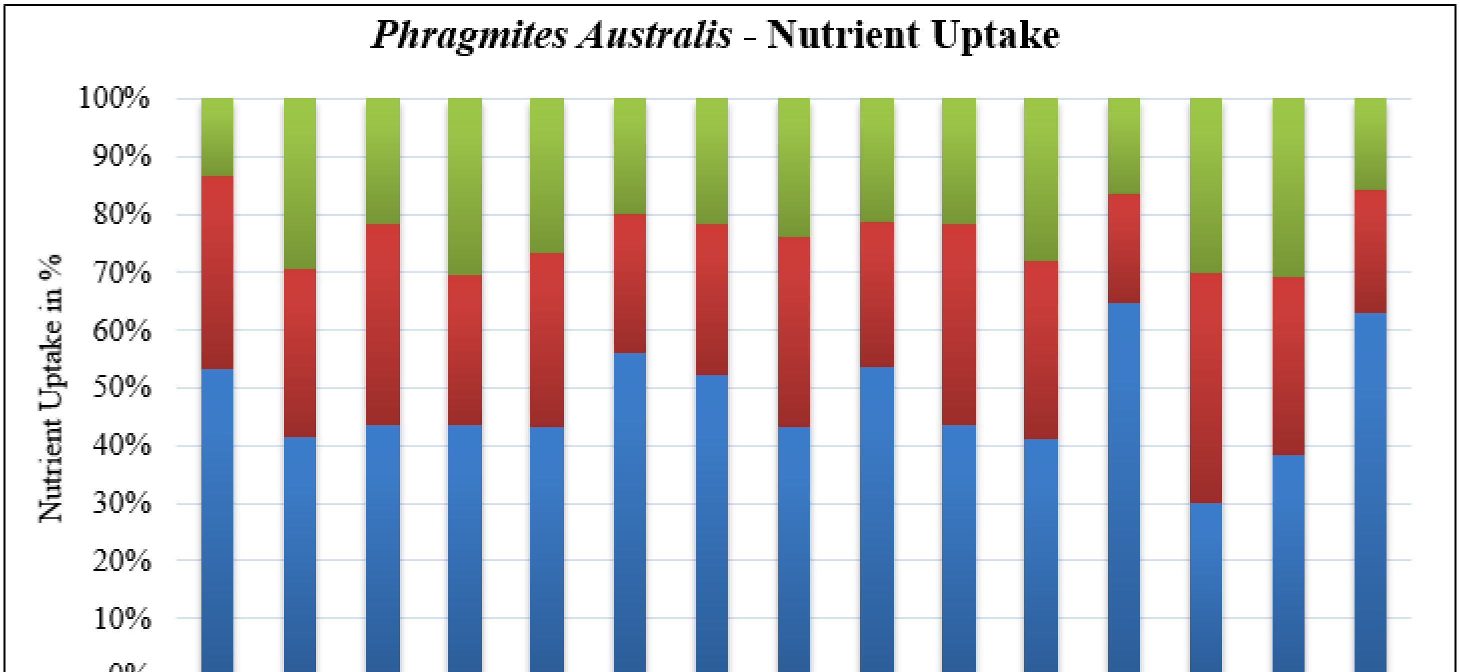


Figure 5

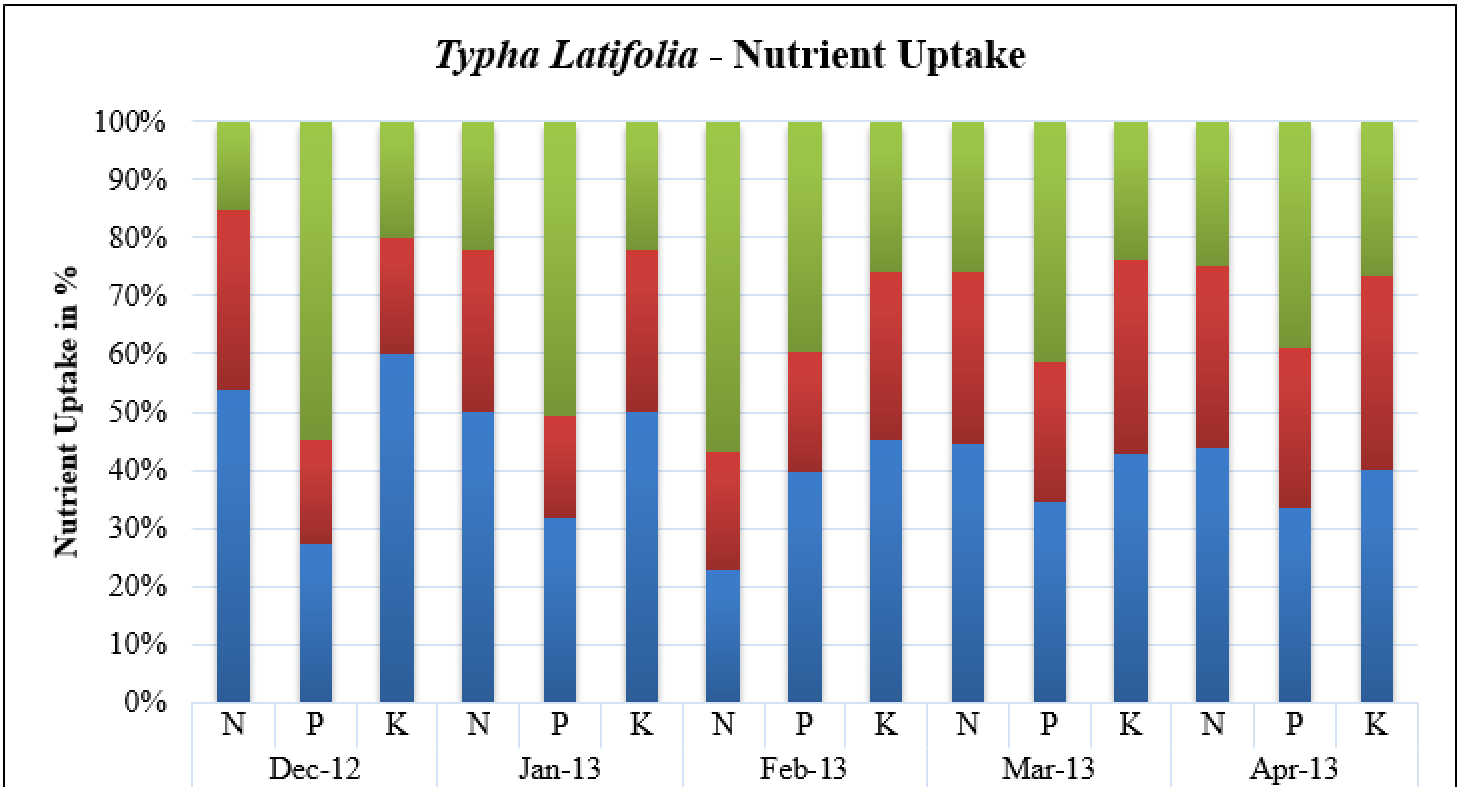
Retention time (RT) of (a) 24, (b) 48, (c) 72, (d)96, (e) 144, (f) 192 hours



	Dec-12			Jan-13			Feb-13			Mar-13			Apr-13		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Leaf	0.02	0.26	0.05	0.07	0.24	0.1	0.1	0.32	0.12	0.2	0.54	0.18	0.6	0.8	0.3
Stem	0.05	0.26	0.08	0.06	0.27	0.12	0.12	0.44	0.14	0.32	0.6	0.2	0.8	0.8	0.4
Root	0.08	0.37	0.1	0.1	0.39	0.28	0.24	0.58	0.3	0.4	0.8	0.7	0.6	1	1.2

Figure 6

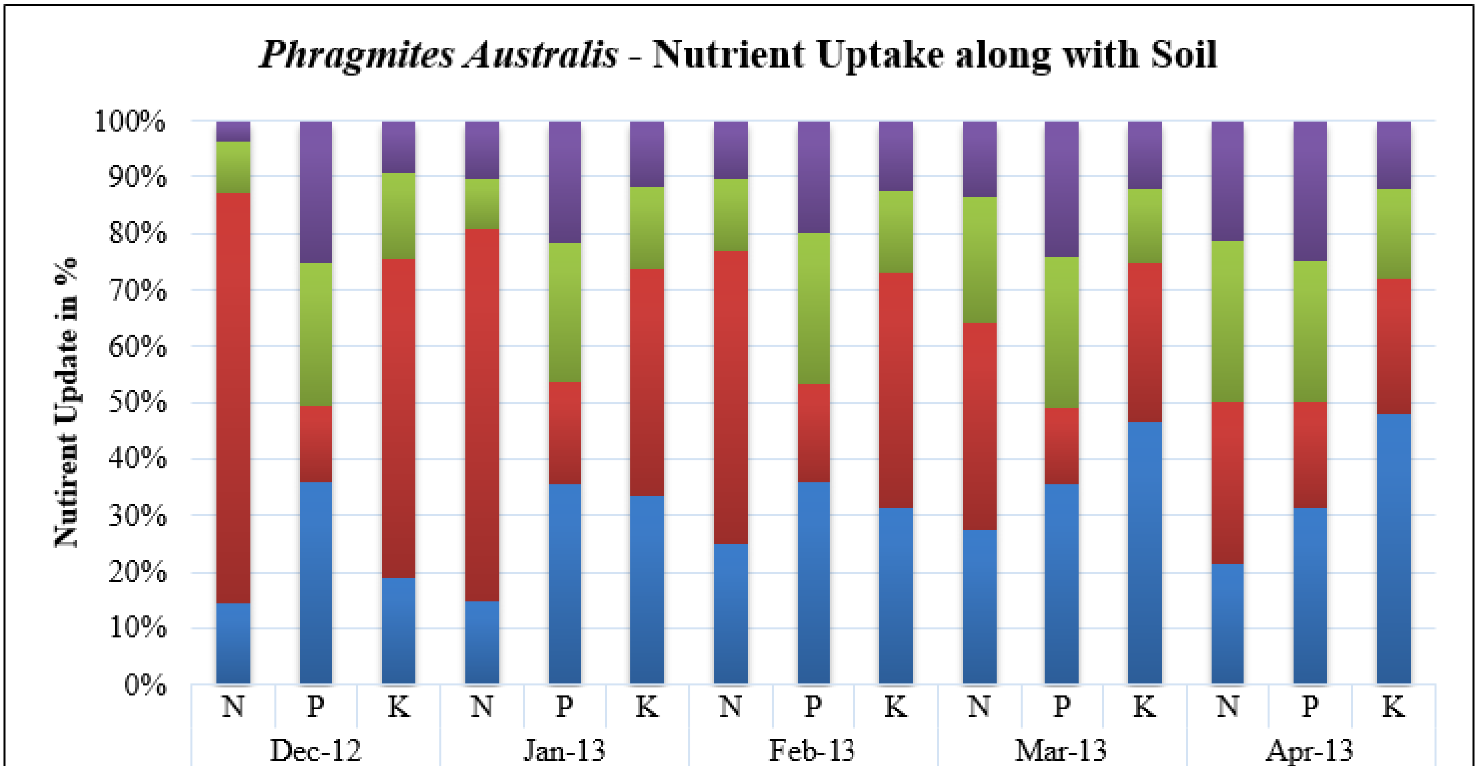
Nutrient Uptake: Phragmites Australis



	Dec-12 N	Dec-12 P	Dec-12 K	Jan-13 N	Jan-13 P	Jan-13 K	Feb-13 N	Feb-13 P	Feb-13 K	Mar-13 N	Mar-13 P	Mar-13 K	Apr-13 N	Apr-13 P	Apr-13 K
Leaf	0.04	0.58	0.04	0.08	0.61	0.08	0.5	0.8	0.16	0.7	1.2	0.5	0.8	1.4	0.8
Stem	0.08	0.19	0.04	0.1	0.21	0.1	0.18	0.42	0.18	0.8	0.7	0.7	1	1	1
Root	0.14	0.29	0.12	0.18	0.38	0.18	0.2	0.8	0.28	1.2	1	0.9	1.4	1.2	1.2

Figure 7

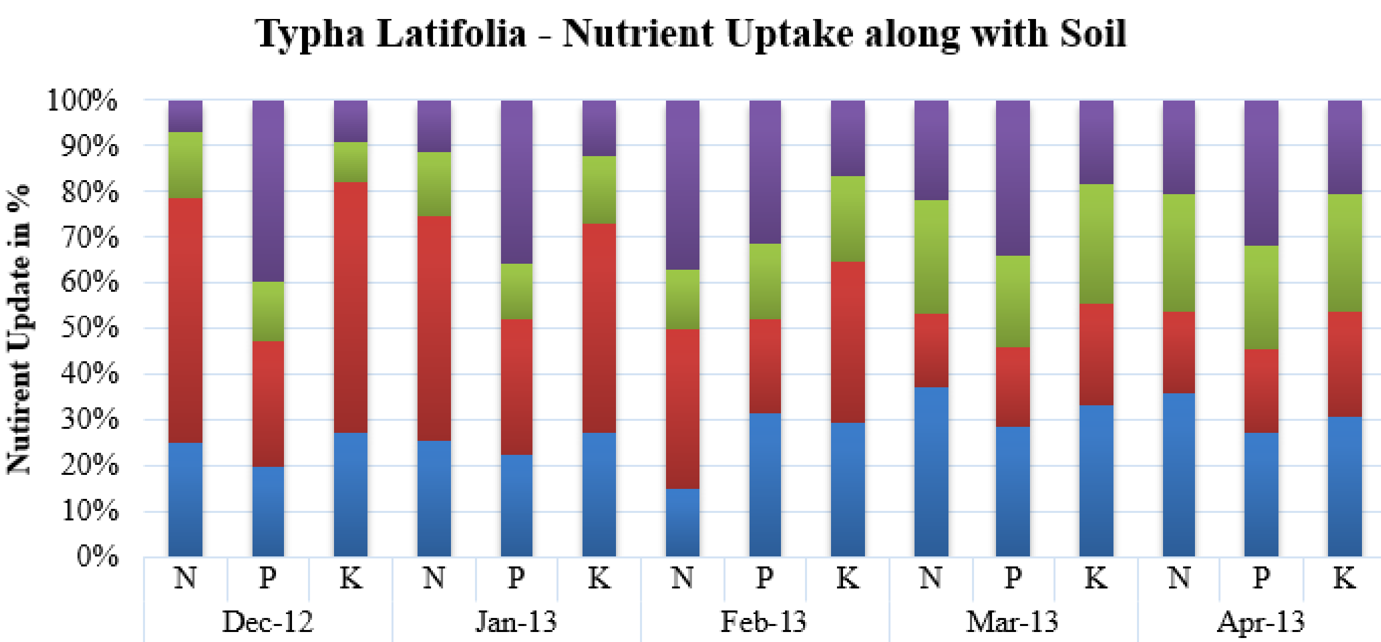
Nutrient Uptake: Typha Latifolia



	Dec-12			Jan-13			Feb-13			Mar-13			Apr-13		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Leaf	0.02	0.26	0.05	0.07	0.24	0.1	0.1	0.32	0.12	0.2	0.54	0.18	0.6	0.8	0.3
Stem	0.05	0.26	0.08	0.06	0.27	0.12	0.12	0.44	0.14	0.32	0.6	0.2	0.8	0.8	0.4
Soil	0.4	0.14	0.3	0.45	0.2	0.34	0.5	0.28	0.4	0.54	0.3	0.42	0.8	0.6	0.6
Root	0.08	0.37	0.1	0.1	0.39	0.28	0.24	0.58	0.3	0.4	0.8	0.7	0.6	1	1.2

Figure 8

Nutrient Uptake with Soil: Phragmites Australis



	Dec-12			Jan-13			Feb-13			Mar-13			Apr-13		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Leaf	0.04	0.58	0.04	0.08	0.61	0.08	0.5	0.8	0.16	0.7	1.2	0.5	0.8	1.4	0.8
Stem	0.08	0.19	0.04	0.1	0.21	0.1	0.18	0.42	0.18	0.8	0.7	0.7	1	1	1
Soil	0.3	0.4	0.24	0.35	0.5	0.3	0.47	0.52	0.34	0.52	0.6	0.6	0.7	0.8	0.9
Root	0.14	0.29	0.12	0.18	0.38	0.18	0.2	0.8	0.28	1.2	1	0.9	1.4	1.2	1.2

Figure 9

Nutrient Uptake with Soil: Typha Latifolia

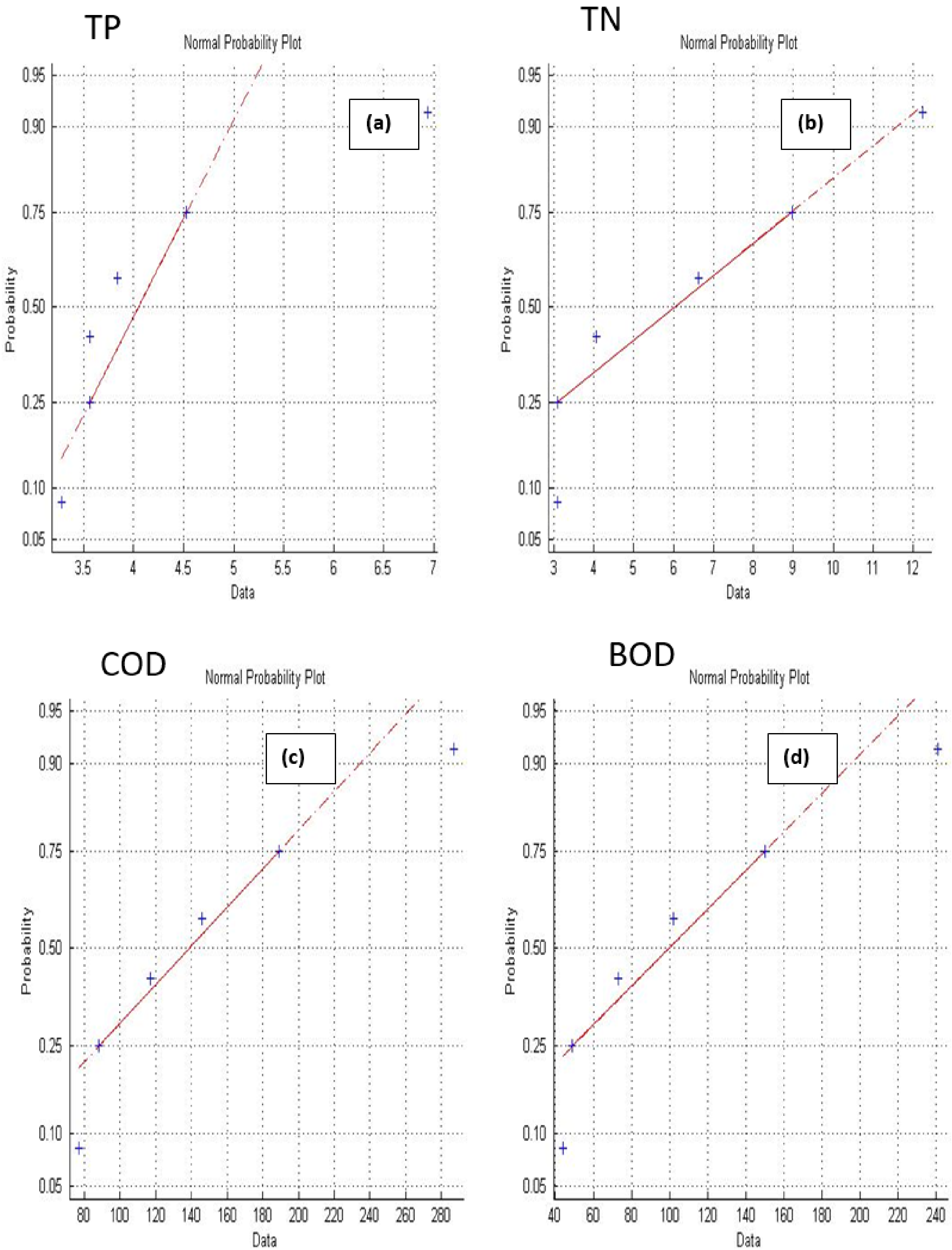


Figure 10

Efficiency of the T-GPS with TP, TN, COD and BOD