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Performance Efficiency of a Large-Scale Integrated Constructed Wetland: Designed for Domestic Wastewater Treatment

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Abstract

Wastewater treatment plants are used to reduce pollution depending upon their effectiveness, treatment-efficiency, available-land, energy-sources, topography, climate and prevailing-winds, seasonal and climatic variations, and principal-cost. Integrated constructed wetlands (ICWs) are diversely used for wastewater treatment because of their increased treatment efficiency. Purpose of the study: This study comprises of large-scale-ICW located at NUST Islamabad, Pakistan. Purpose of study was to monitor and identify the nutrient removal over the period of six month from October 2018 to March 2019. Samples were taken from each compartment of HSSF-CW (Horizontal Sub-Surface Flow Constructed Wetland) and FILTER technology (Filtration and Irrigated cropping for Land Treatment and Effluent Reuse) of treatment system. Different parameters including EC (Electrical conductivity), NO_3 (Nitrate), NO_2 (Nitrite), TKN (Total Kjeldahl Nitrogen), PO_4^{3-} (Phosphate) were measured. Removal efficiency of above discrice parameters was recorded 3, 0, 43, 43 and 27% of HSSF-CW respectively, while FILTER- technology contribute in removal by 6, 75, 19, 23 and 37% respectively. Spatial, temporal and plantation variation was calculated and results showed that effluent concentrations were significantly varied. TKN and Phosphate showed significant spatial and temporal variation, and also significantly varied due to presence and absence of plantation while no significant spatial variation was recorded in EC and Nitrite. Correlation was observed between physicochemical and weather parameters.

Keywords: Integrated constructed wetland, Domestic wastewater, Spatial and temporal variation, HSSF-CW, FILTER technology

1 Introduction

Pollution of water affects drinking water, lakes, river and oceans all over the world. According to World Health Organization, 780 million people lack access to safe water and about 2.5 billion lack access to clean sanitation (1). Increasing population, rapid urbanization, industrialization and improper waste dumping are one of the most persistent issues that imparting immense pressure on the quality and quantity of existing water sources. Best solution to maintain quality and quantity of water is wastewater treatment systems. (2). There is a need to treat wastewater, not only to stop its intrusion into surface water bodies but also to decrease water demand in agriculture sector, like reusing it for horticulture. Wastewater reclamation can be achieved through intensive conventional systems or natural, ecologically engineered treatment systems depending upon their effectiveness, treatment efficiency, available land, energy sources, topography, climate and prevailing winds, seasonal and climatic variations, and principal cost. Biological treatment systems preferred over others due to minimum energy requirements, low capital, operation and maintenance costs. This study comprises of large-scale integrated constructed wetland located at National University of Sciences and Technology (NUST) Islamabad, Pakistan. Purpose of study was to monitor the nutrient removal over the period of six month and identify the treatment efficiency in different steps of the treatment system. Two types of treatment systems 1. HSSF-CW and 2. FILTER technology were used in this study. HSSF-CW is further divided into 8 ponds and was selected because, sub-surface flow CWs are highly recommended over other types of CWs due to their removal efficiency (3). Filter technology is diversely used in Australia and China from 1997 and basically designed for high volumes of wastewater. It is also used to reduce nitrogen and Phosphate in effluent and further reuse for irrigation (4).

Increasing interest in integrated constructed wetlands has been observed and preferred over single-stage CWs for efficient removal of harmful contaminants and their associated compounds (5). Integrated wastewater treatment systems are diversely used for efficient removal of contaminants for domestic wastewater since 2000 (6).Large scale integrated constructed wetlands still needs further research with respect to weather pattern of specific area. Contaminant removal especially nitrogen and phosphate removal is one of the major concerns (7), because of eutrophication and higher concentration can affect surface water quality (8). Objectives of the study was to identify 1). percentage removal efficiency

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of treatment systems, 2). effect of weather on removal efficiency and 3). effect of spatial, temporal and plantation variation during treatment.

2 Methodology

2.1 Wastewater treatment plant and description

Large scale Integrated Constructed wetland consists of two technologies, Horizontal Sub Surface-Flow Constructed Wetland (HSSF-CW) and FILTER-technology. HSSF-CW is further divided into 8 ponds. Study area is located at NUST H-12 campus Islamabad Pakistan. Operation started in 2013 with the funding of UNESCO and is being maintained by PMO NUST. Wastewater from institutes and residential area was directed towards integrated constructed wetland according to its capacity and mean hydraulic retention time (HRT) as describe in **Error! Reference source not found.**. Primary treated domestic wastewater from mesh pass through 8 ponds of HSSF-CW (P1-P8) and further treated from FILTER technology as shown in Figure 1. Treated water is further used for horticulture and extra water discharge into nearby stream. Reed beds of HSSF-CW are filled with substratum composed of fine and coarse gravel and polyethylene terephthalate (PET) sheet. While FILTER-technology composed of top layer of soil, then sand, gravel and layer of pipes covered with geotextile membrane as shown in Figure 2. Vertical structure of HSSF-CW and FILTER technology is shown in Figure 2. Depending upon tolerance, root structure and nutrient removal efficiency four macrophytes *Typha latipholia*, *Pistia stratiotes*, *Centella asiatica* and *Typha angustifolia* were selected. Pond 1 was cultivated with *Typha latifola*, Pond 2,5,6 and 7 cultivated with *Pistia stratiotes*, Pond 3 and 4 cultivated with *Centella asiatica*, while aerators were attached in pond P8. FILTER-technology was cultivated with *Typha angustifolia* as shown in

Table 2. During the sampling period plantation (*Pistia stratiotes*) from pond 2, 5, 6, and 7 was absent during January, February and March because it is sensitive to frost. Weather parameters including temperature, rainfall, global horizontal irradiance (GHI) and relative humidity were considered to ensure their effect on treatment efficiency. Daily mean data of temperature, rainfall, GHI and relative humidity was measured from October 2018 to March 2019 on each day of sampling (see Figure 2).

Table 1: Topographical characteristics of Integrated Constructed Wetland

Location	NUST, H-12 Islamabad
Latitude, Longitude	33.6417767, 73.0035925
Climate	Subtropical
Area of ICW	3065.80 m^2 (0.76 Acre)
Size of HSSF-CW	36.75 m x 30.4 m
Size of FILTER-technology	51.8 m x 36.5 m
Capacity	283.90 m^3/day
HRT	3.7 days

Table 2:Structrural specifications of ICW

Description		Substrate	HRT (hours)	Length, Width, Depth	Plantation
HSSF-CW	Pond 1	Fine and Coarse Gravel	6.87	13 m, 7 m, 1.7 m	Typha latifola
	Pond 2		10.30	13 m, 7 m, 1.7 m	Water lettuce
	Pond 3	Soil, Sand and Gravel	9.16	13 m, 7 m, 1.7 m	Penny wort
	Pond 4		11.44	13 m, 7 m, 1.7 m	
	Pond 5	Fine and Coarse Gravel	14.88	13 m, 7 m, 1.7 m	Water lettuce
	Pond 6		10.07	13 m, 7 m, 1.7 m	
	Pond 7		9.16	13 m, 7 m, 1.7 m	
	Pond 8		5.61	13 m, 7 m, 1.7 m	Empty
FILTER Technology		Soil, Sand and Gravel	11.44	51.8 m, 36.5 m, 1.7 m	Cattail

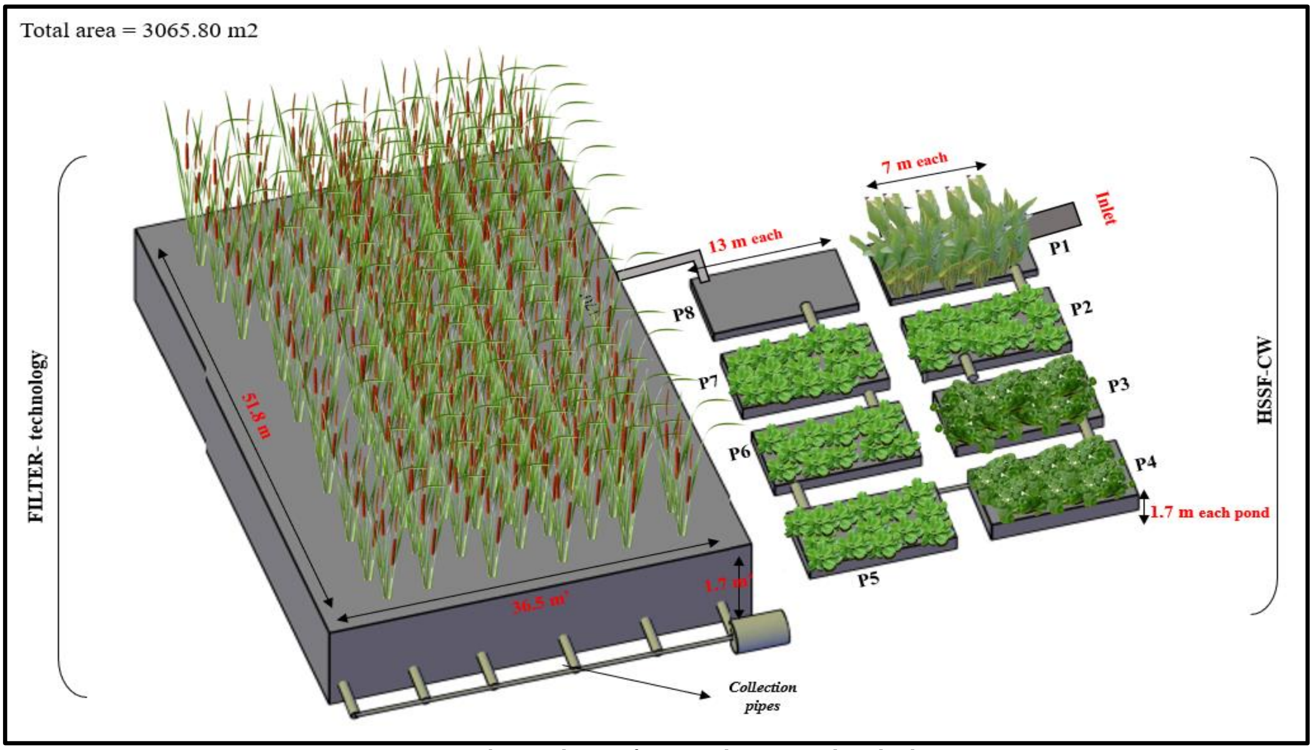


Figure 1:Schematic layout of Integrated Constructed Wetland

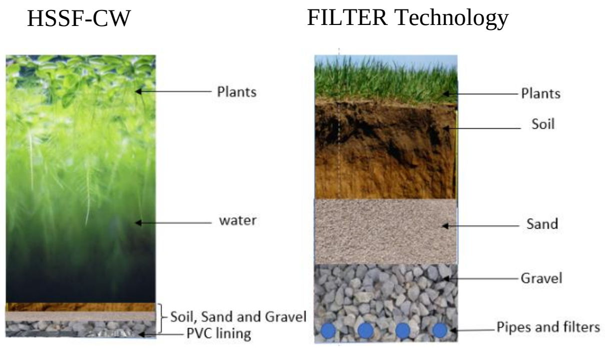


Figure 2: Vertical Structure of HSSF-CW and FILTER-technology

2.2 Sample collection and Statistical analysis

Sampling of Integrated Constructed wetland was organized twice in a month, from October 2018 to March 2019. In each visit, total of 10 Wastewater samples were collected in sterile bottles from the inlet of HSSF-CW, effluent of each pond 1-8 and FILTER-technology as shown in Figure 1. Onsite analysis of pH and temperature were carried out by using HANNA HI 83141. EC was determined by WTW Cond-3210 while DO was measured using HANNA oxy-check HI 9147 and samples were immediately transfer to the laboratory for further analysis of TKN, Nitrate, Nitrite, and Phosphate using standard method for water and wastewater (9). Statistical analysis of data was performed using IBM SPSS 17.0. Statistical methods include correlation, among physicochemical parameters and weather parameters. Multi-variate analysis of variance (MANOVA) was performed to identify the significant difference of selected parameters among spatial, temporal and plantation (present/absent) variations.

3 Results

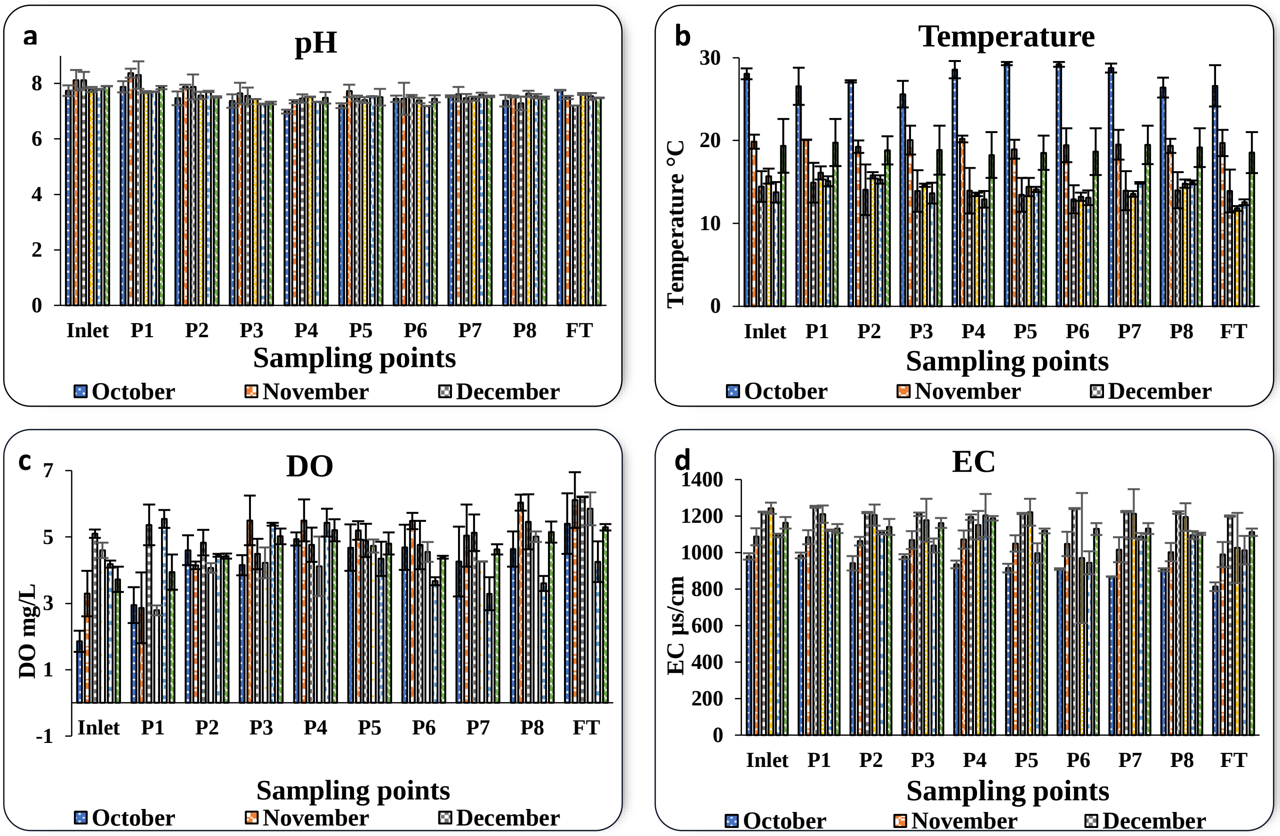
3.1 Percentage removal efficiency of treatment system

Pollutant removal across HSSF-CW and FILTER-technology for the duration of 6 month (October to march) is shown in **Error! Reference source not found.**. pH values range between 7-7.9 with in the whole treatment system that is ideal for vast diversity of microbes and also hampered microbial degradation processes (10). Moderate temperature is important for effective microbial degradation and plant mechanism activity (11) whereas degradation rate slows down as temperature decreases. Although, temperature during October, November and March was better for microbial degradation while temperature was slight decrease in December, January and February. In terms of DO, mean concentrations increased gradually over the treatment system from pond 1 to FT as shown in **Error! Reference source not found.** and maximum values was recorded in effluent (FT). Plant roots, and diffusion through air increase dissolved oxygen that enhance microbial degradation (12). EC removal is effected through absorption and uptake by roots, degradation, and sedimentation of suspended particles. HSSF-CW shows 3% and FILTER-technology shows 6% removal efficiency as shown in Table 3. Varied influent values are mainly because of dilution effect due to increased water consumption and frequent water pumping at source (13). Temperature and evapotranspiration of plant may effect EC in different ponds.

Consistent decrease in TKN values was observed from ST to P8 and lowest value was detected in final effluent of collection pond. While only in the month of January and March, increased TKN was observed in pond 2. Removal efficiency of TKN varied in HSSF-CW and FILTER-Technology due to aerobic or anaerobic conditions. Its removal efficiency of HSSF-CW and FILTER-Technology was 43% and 23% however removal efficiency of ICW was 55% as shown in Table 3. Minimum values of Nitrite were recorded in effluent while in December January and February increased values show disturbed microbial activity at lower temperature. Nitrite is an unstable form of nitrogen and converts into Nitrate or ammonia. Nitrite removal efficiency was 43% in HSSF-CW and 19% in FILTER-technology while overall removal efficiency reported was 47%. Nitrate in influent values range between 0 – 9.6 while it increased from P1 and sudden decrease was observed in FT. These variatons may be subjected to the well-suited conditions of nitrosomonas. Nitrate removal efficiency in HSSF-CW and FILTER-technology was 10% and 73% respectively while Pond 1, 2 and 4 shows negative removal efficiency that shows active nitrification process that convert ammonia into nitrate. whole treatment efficiency was 37%. Other study also shows that nitrate increased at stage-1 and decrease in stage-2 irespective to the type of technology (15,16). pH, temperature, DO (anaerobic conditions) and fcultative microbes effect overall production of nitrate. Removal of nitrogen in sub-surface flow treatment wetlands is mainly microbially induced (17). Phosphate removal shows consistent decrease in each sampling point and minimum value recorded at FIlTER technology. Phosphate removal efficiency in HSSF-CW was 27%, but few of the ponds shows negative removal of Phosphate may be due to change in microbal activity, adsoprption to substate with respect to temperature (18).

3.2 Effect of weather on removal efficiency

Weather effect is more prominent in large scale treatment system than a lab scale treatment system. Temperature is one of the dominating weather parameter that not only effect the treatment efficiency of system but also the pollutant load. In this study temperature varied from modrate 25ºC-30ºC to low temperature 10ºC-15ºC. Temperature shows strong negative corelation with EC (r = -0.509) and Nitrate(r = -0.375) at $P<0.01$. It shows increased EC and nitrate values at lower temperature. Increased water consumption and frequent pumping at source are main factors that cause dilution effect on EC values at moderate temperature. (13).While weak negative corelation exist with rainfall (r = -0.114), pH (r = -0.110), DO (r = -0.184), Nitrite (r = -0.158) and phosphate (r = -0.050) that shows less temperature effect on rainfall, pH, DO, Nitrite and Phosphate. Temperature shows positive corelation with GHI (r = 0.885) and relative humidity (r = 0.276) as shown in Table 4. Rainfall effect the performance efficiency of wetland through increasing the inflow and diluting wastewater. It shows strong negative corelation with EC (r = -0.261) and TKN (r = -0.724) that shows increased rainfall will decrease the concentration of polutents in wastewater. while weak negative corelation exist with pH (r = -0.140), DO (r = -0.231), , nitrate (r = -0.181), nitrite (r = -0.014) and phosphate (r = -0.147). Rainfall also shows negative corelation with GHI (r = -0.105) and positive corelation with relative humidity (r = 0.234). GHI show strong positive corelation with temperature (r = 0.885) and relative humidity (r = 0.489). It shows strong negative corelation with EC (r = -0.516) and Nitrate (r = -0.344) while weak negative corelation exist with rainfall (r = -0.105), pH (r = -0.117), DO (r = -0.182), TKN (r = -0.062), Phosphate (r = -0.084) and Nitrite (r = -0.075). Table 4.



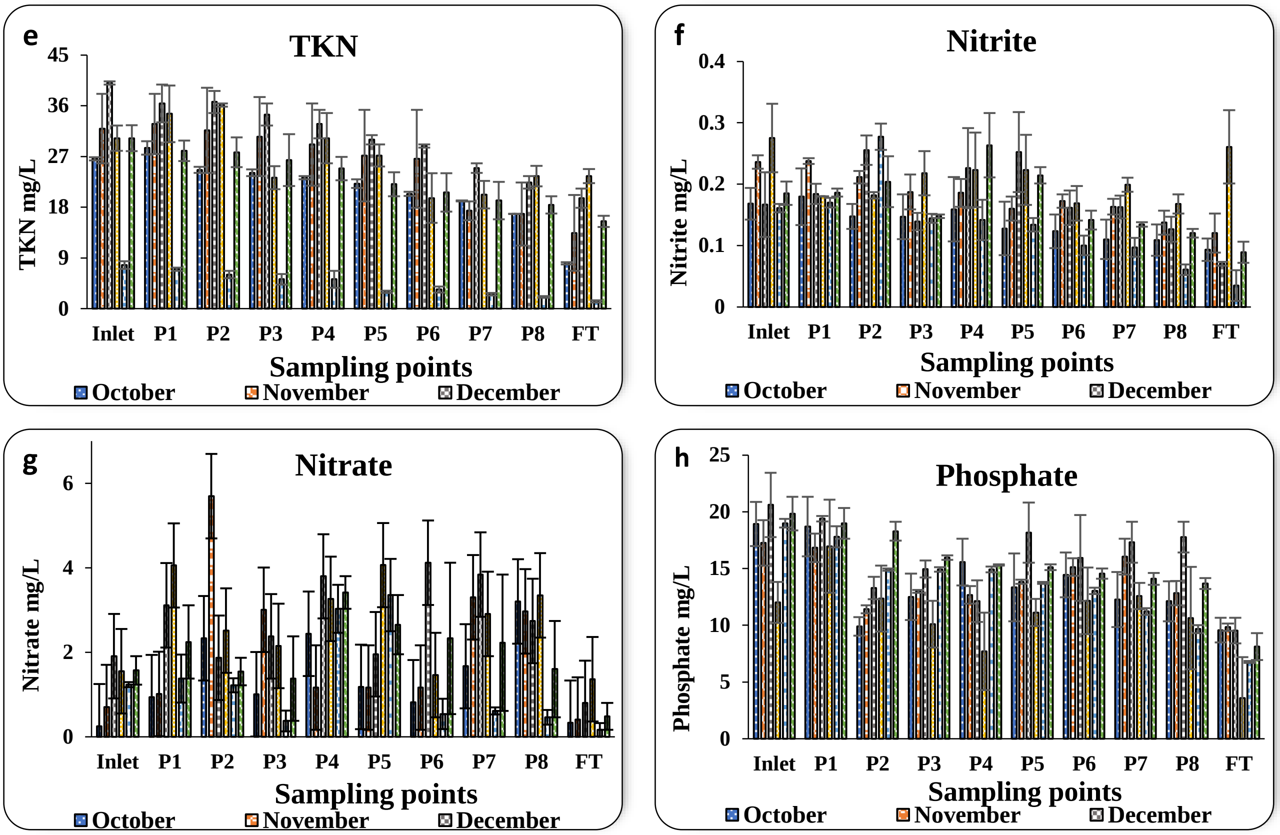


Figure 3: Effluent concentrations of a) pH, b) temperature, c) DO, d) EC, e) TKN, f) nitrite, g) nitrate, h)Phosphate among different sampling points inlet, Pond 1-8, FT (FIlTER technology/ final effluent)

Table 3: Percentage removal efficiency of Integrated Constructed Wetland

Parameters	Integrated Constructed Wetland										System removal %
	HSSF-CW								Total (HSSF-CW)	FILTER-Technology	
	P1	P2	P3	P4	P5	P6	P7	P8			
EC	0%	2%	1%	-1%*	3%	4%	-5%*	0%	3%	6%	8%
Nitrate	-100%*	-82%*	29%	-176%*	15%	13%	65%	3%	0%	75%	77%
Nitrite	6%	5%	22%	0%	10%	21%	4%	17%	43%	19%	47%
TKN	0%	4%	11%	1%	14%	6%	14%	5%	43%	23%	55%
Phosphate	-4%*	26%	-4%*	4%	-13%*	-1%*	2%	8%	27%	37%	56%

*negative removal due to increased effluent values

Table 4: Pearson corelation between physicochemical and weather parameters

Parameters	pH	DO	EC	Nitrate	Nitrite	Phosphate	TKN	Temperature	Rainfall	GHI	Relative Humidity
pH	1										
DO	-.080	1									
EC	.203*	.097	1								
Nitrate	.106	.213*	.439**	1							
Nitrite	.046	.060	-.035	.063	1						
Phosphate	.285**	-.149	.445**	.217*	-.137	1					
TKN	.364**	.038	.361**	.103	.039	.387**	1				
Temperature	-.110	-.184*	-.509**	-.375**	-.158	-.050	.068	1			
Rainfall	-.140	-.231*	-.261**	-.181*	-.014	-.147	-.724**	-.114	1		
GHI	-.117	-.182*	-.516**	-.344**	-.075	-.084	.062	.885**	-.105	1	
Relative Humidity	-.171	-.190*	-.186*	-.138	-.039	-.029	-.385**	.276**	.234*	.489**	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

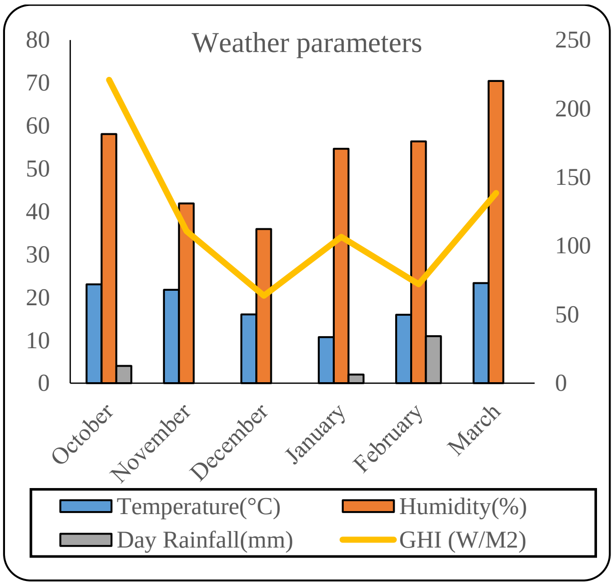


Figure 4: Monthly mean data of temperature, rainfall, GHI and relative humidity, measured from October 2018 to March 2019 on each day of sampling

Relative humidity shows negative corelation with pH(r = -0.171), DO (r = -0.190), EC (r = -0.186), nitrate (r = -0.138), nitrite (r = -0.039), TKN (r = -0.385) and phosphate (r = -0.029). While it shows positive corelation with temperature (r = 0.276), rainfall (r = 0.234) and GHI (r = -0.489).

3.3 Effect of spatial, temporal and plantation variation

pH values show decreasing trend and got minimum values in P3, P6 and P4 and increased in pond 7, 8, FT (effluent) and showed significant spatial variations P<0.05 (Table 5). Similar varied pH values in HSS-CW was also experienced by (16). Significant difference in pH values was not detected in temporal variation this may be because of similar effluent concentrations in each month, although influent values varied a little. In terms of DO, mean concentrations increased gradually over the treatment system and maximum values was recorded in effluent (FT). Plant roots, and diffusion through air increase dissolved oxygen that enhance microbial mediated degradation (12). However temporal variation was not-significant, that also predict absence of plants from P2, P5, P6, P7 during January, February and March at low temperature did not affect DO of surface water. Normally increased DO was o bserved in the presence of plants. (19) High value of DO in December may be due to lower temperature that enhance dissolation of oxygen in water. No significant spatial vatiation were observed in EC value as wastewater moves through treatment system because of low removal rate while significant temporal variation were observed mainly due to high influent values. Similar temporal variation of EC was observed in wastewater stream by Dietler and coworkers in 2019.

TKN is a combination of organic nitrogen and ammonia-nitrogen Figure 1. shows varied TKN values across different sampling points of ICW. Consistent decrease was observed from ST to P8 and lowest value was detected in final effluent. While only in the month of January and March, increased TKN was observed in pond 2.

Table 5: Two way ANOVA among spatial and Temporal and plantation variations

Parameters / IV-Interaction	pH	Temp	DO	EC	Nitrate	Nitrite	TKN	Phosphate
Spatial	**0.00**	1	**0.025**	0.596	**0.03**	0.217	**0.00**	**0.00**
Temporal	0.192	**0.00**	0.11	**0.00**	0.024	0.442	**0.00**	**0.047**
Plantation (p/a)	0.651	0.083	0.091	0.139	0.903	0.178	**0.047**	**0.009**
Plantation* Temporal	0.984	0.962	0.755	0.455	0.994	0.654	0.999	0.493
Plantation* Spatial	0.812	0.975	0.622	0.868	0.427	0.957	0.985	0.004

Influent values varied with time because of variation in wastewater compositionat source. TKN show significant variation ($p<0.05$) during presence and absence of planttion (Table 5). Nitrite shows non significant Spatial and temporal and plantation variation while Nitrate show significant spatial variation. Phosphate removal shows consistent decrease in each sampling point and minimum value recorded at FIITER technology. December shows high influent values while treatment efficiency was consistent and there was no significant difference was detected in effluent values in each month. Minimum influent values were detected in October and February. Significant spatial, temporal and plantation variation was observed $p<0.05$.

4 Conclusions

Results of the study showed that integrated constructed wetland is significant to enhance removal of pollutants like nitrogen and Phosphate through constructed wetlands. HSSF-CW is efficient in removing TKN and Nitrite up to 43% whereas FILTER-technology is efficient in removing nitrate up to 75% than HSSF-CW. Nitrate, Nitrite, TKN and Phosphate showed 77, 47, 55 and 56% removal from ICW respectively. TKN and Phosphate values were significantly varied spatially, temporally and also due to presence or absence of plantation. Weather conditions like Temperature and rainfall had larger effect on the treatment efficiency of large-scale ICW by impacting inflow rate and strength of wastewater. Temperature also effect the microbial degradation. It also concluded that other than structural variations in treatment system, pollutant removal like nitrogen and Phosphate is mainly associated with pH, temperature and aerobic or anaerobic conditions.

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Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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