



Evaluation of Horizontal Subsurface Flow Constructed Wetland for Treatment of Tannery Wastewater in Kaduna, Nigeria

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ABSTRACT: Tannery wastewater is often characterized by their complexities in terms of contaminants and require specialized treatment technologies. Hence, the objective of this paper is to explore the performance evaluation of a laboratory-scale horizontal subsurface flow constructed wetland (HSSFCW) in the treatment of tannery wastewater in Kaduna, Nigeria using appropriate standard techniques. Out of the tree replica systems, two were respectively vegetated with *Phragmites australis* and *Polygonum salicifolium* + *Ipomoea carnea*, while the last was left un-vegetated and used to treat tannery effluent. Characteristics such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrates (NO_3^-), phosphates (PO_4^{3-}), suspended solids (TSS) and chromium (Cr) analyzed using standard methods were used as indicators of the treatment efficiency under a 6-day Hydraulic Retention Time. The results showed that the system vegetated with *Phragmites australis* had the best performance in the removal of BOD, COD, NO_3^- , PO_4^{3-} and Cr (97.9%, 94.2%, 54.4%, 44.1% and 98.4% respectively). The system vegetated with *Polygonum salicifolium* + *Ipomoea carnea* on the other hand had the best performance for SS removal (92.6%) while the system vegetated with *Phragmites australis* had a SS removal efficiency of 92.3%. The performance indices for unvegetated cell, *Phragmites australis* vegetated cell and *Polygonum salicifolium* + *Ipomoea carnea* vegetated cell were respectively, 4, 9 and 8 which shows that the cell vegetated with *Phragmites australis* had the best performance in the treatment of tannery wastewater. It also showed that the performance of the cell vegetated with *Polygonum salicifolium* + *Ipomoea carnea* was also comparable with that of *Phragmites australis*. This study demonstrated that the HSSFCW vegetated with both *Phragmites australis* and *Polygonum salicifolium* + *Ipomoea carnea* can effectively treat tannery wastewater. There is however a need to investigate the efficiency of the system over a longer period with consideration of microbial characteristics.

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With the rapidly increasing rate of urbanization across the world, and significant population growth especially in developing nations, the pressure on freshwater resources is on the increase (Alfa *et al.*, 2014; Boretti and Rosa, 2019). This is forcing many nations to consider recovery of water from wastewater

as a means of augmenting the dwindling freshwater resources. More so, the indiscriminate discharge of wastewater from industrial, commercial and domestic sources have contributed significantly to the population of the receiving water bodies and the environmental at large. Tannery industries have been

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in existence all the world from the earliest days of industrialization due to the strategic role of leather value addition (Blench, 2010; Chowdhury *et al.*, 2013; Muktadir and Rahman, 2022). This has however seen an astronomical increase especially in the northern part of Nigeria as a result of the abundant hides and skin within the region (Haruna *et al.*, 2022, Odejobi *et al.*, 2022). These activities often result in significant production of high strength wastewater. Notwithstanding the long history of tanning, the adverse environmental impact of these activities only received attention in recent years. For instance, in Kano which is one of the leading cities with a lot of tanning activities, the disposal of the wastewater accruing from these activities have been largely indiscriminate and unregulated until recently (Akan *et al.*, 2008; Nabegu, 2010; Adeniyi, 2023). Tanning refers to the processing of hides and skins of animals to produce leather materials which are often durable and less susceptible to microbial degradation (Liu *et al.*, 2018). The process converts the skin and hides which primarily biological into leather which is a stable material that is resistant to microbial degradation (Carsote *et al.*, 2021). Activities in a tannery involves the beam house operation, the tan yard operation, the post tanning operation and the finishing operation (Ali *et al.*, 2013). Each of these operations produce diverse quantity and quality of contaminants in its effluents. Hence, treatment of tannery effluent necessitates the combination of physical, chemical and biological processes. Physicochemical methods such as but not restricted to precipitation, coagulation/flocculation, adsorption, membrane filtration, ion exchange, advanced oxidation, have been extensively used for removal of chromium and other objectionable materials from tannery wastewater (Shrestha *et al.*, 2021). Though, methods like chemical precipitation are used for removal of chromium, it is undesirable as a result of the production of secondary by-products (Bano *et al.*, 2020). Constructed wetlands are wastewater treatment systems usually made up of single or multiple cells in a built and partially controlled environment. It has found application in treatment wastewater from different sources and at various levels of treatment (Hassan *et al.*, 2021). They are planned systems designed and constructed to employ wetland vegetation to assist in treating wastewater in a more controlled environment than occurs in natural wetlands (Bastian *et al.*, 2020). Wetlands are areas on land where the ground maintains saturated conditions for much of the year.

The development of constructed wetlands systems can be at varying level of control with regards various aspects of operation especially where there is a need to

establish experimental treatment facilities (Bastian *et al.*, 2020; Hassan *et al.*, 2021). Constructed wetland system has some advantages over natural wetlands amongst which the ability to select suitable site, the flexibility in designing appropriate size for the expected wastewater flow and ability to control the hydraulic characteristics and retention time. Hence, the objective of this paper is to explore the performance of a laboratory-scale horizontal subsurface flow constructed wetland (HSSFCW) in the treatment of tannery wastewater in Kaduna, Nigeria

MATERIALS AND METHODS

The Study Area: The study was carried out at the Department of Water Resources and Environmental Engineering Ahmadu Bello University, Samaru Campus, Zaria, Sabongari Local Government Area, Kaduna State Nigeria located on Latitude 11.16 °N and Longitude 7.64 °E (Fig. 1). The Nigerian Institute of Leather and Science Technology (NILEST), a foremost institute of leather research in Nigeria which is involved in both the training of experts in leather work and commercial scale production is located adjacent Ahmadu Bello University as shown in Fig. 1. Zaria is a historical city in Northern Nigeria that shares boundary with the ancient Kano city. It is home to a lot of small-scale tannery industries ranging from local tanners to highly industrialized ones (Mohammed *et al.*, 2017).

Sample Collection: The tannery wastewater sample used for this study was collected from the Nigerian Institute of Leather and Science Technology (NILEST), Samaru, Zaria in Kaduna State of Nigeria, located on Latitude 11.17 °N, Longitude 7.66 °E and at an approximate altitude of 670m above mean sea level. The institute has a tannery which is made up of a beam house, lime yard, tan yard and finishing yard. Mineral and vegetable tannages and the types of tannages used in the tannery. The mineral tannage is however, the most frequently used which has great implication on the wastewater characteristics as it utilizes chromium in the tannery process. The tannery wastewater for this study was obtained from NILEST throughout the 60-day period the experiment. A volume of 100 litres of wastewater was collected every six (6) days (HRT) for batch loading into the model CWs. At the end of 60 days, a total volume of 1,000 litres of the tannery effluent had been collected for the experiment. Every batch of the wastewater obtained from NILEST was collected in five (5) of 20 litres capacity sterile plastic cans, and transported to the experimental site.

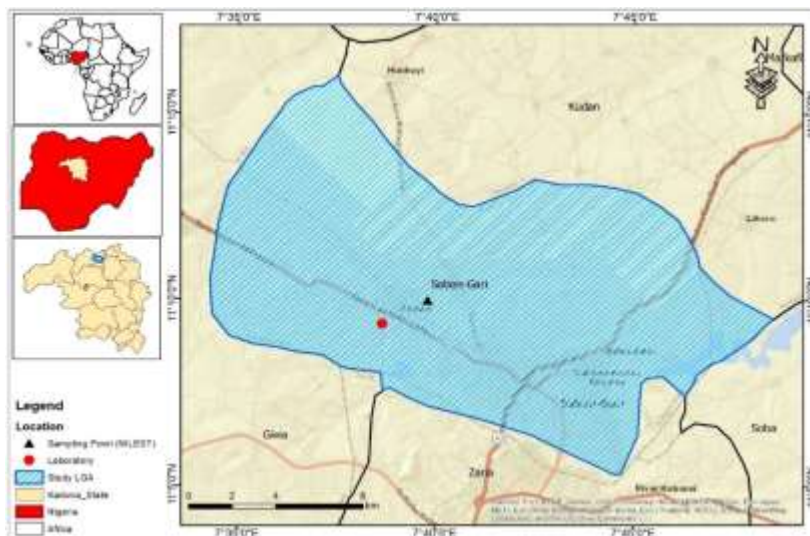


Fig. 1: Map of Study Area
(Adapted from Administrative Map of Nigeria, Igboro et al., 2017)

Experimental set-up: A horizontal sub-surface flow constructed wetland (SSF CW) model was developed and utilized for this experiment. Three identical wetland models developed using locally available material within the study location with the following details (Figs. 2 and 3).

- i. Model Capacity of 0.054m^3 (Length = 0.6m, Width = 0.3m, Depth = 0.3m)
- ii. The treatment media (2mm-5mm) and the inlet and outlet gravels (10mm-30mm) in the HSSF CWs. These ranges of gravel were obtained by using sieve sizes of effective size D10mm of 32 and effective size D10mm of 16 respectively.
- iii. A 100 litre storage tank for collection of the tannery wastewater which doubled as a primary sedimentation or settling tank.
- iv. A 30 liter capacity equalization tank which receives wastewater from the storage tank and feeds the treatment media. The equalization tank maintained water level in the system and prevented shock loading from the storage tank as a result of pressure differences in the tank.
- v. Three identical 9 liters capacity plastic tanks for effluent collection.

The three identical wetlands were setup as models under existing atmospheric conditions, within the premises of the Department of Water Resources and Environmental Engineering, main campus of Ahmadu Bello University Zaria. The tannery wastewater was collected from the effluent pit (where the wastewater from all the tan processes in the tannery are channeled) from NILEST, in 20 liters capacity containers. Determination physicochemical characteristics of both the wastewater and treated effluent were carried out in the Water Resources and Environmental Engineering

laboratory and the Soil and Water Management Laboratory, Institute of Agricultural Research (IAR) Ahmadu Bello University in Zaria, using standard methods. The temperature and pH were measured on-site, for every batch loading of the designed retention period of the wetland.

The first wetland was planted with *Polygonum salicifolium* and *Ipomea carnea*, the second was planted with *Phragmites australis* while the last was left unvegetated to serve as control. All the aquatic plants were obtained from the banks of the Ahmadu Bello University dam and identified in the herbarium of the Biological Sciences department of the university.

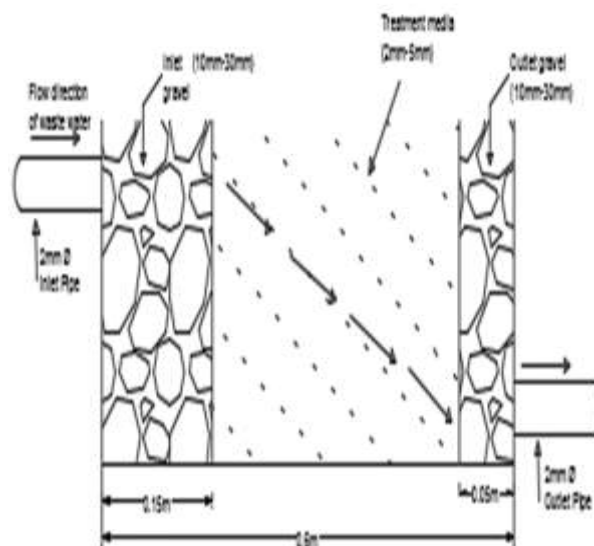


Fig. 2: Horizontal- Section View of the Horizontal Sub-surface Flow Constructed Wetland

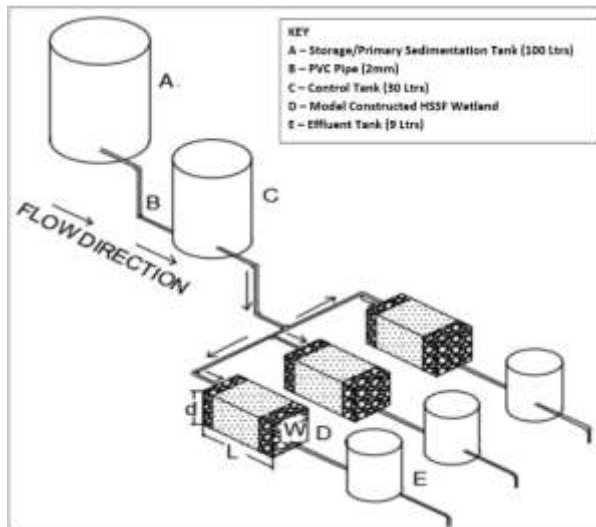


Fig. 3: A 3D view of the setup of a horizontal subsurface flow constructed wetland

Design of HSSFCW: The hydraulic design of the HSSFCW was done using the Manning’s equation expressed as equation 1.

$$Q = \frac{A}{n} R^{2/3} S^{1/2} \quad (1)$$

Where, Q = flow rate (m³/s), A = cross-sectional area perpendicular to flow direction (m²), n = Manning’s roughness coefficient which is dimensionless, S = bottom slope of the wetland, R = hydraulic radius.

The rectangular shape was adopted for this study. A flow rate of 0.063x10⁻³ m³/s was adopted for the study.

The determination of the dimensions was then done using the following equations:

But hydraulic radius is given by equation (2) as:

$$\text{Hydraulic radius, } R = \frac{A}{P} \quad (2)$$

Where A = cross-sectional area perpendicular to flow direction (m²), and P = wetted perimeter

For a rectangular channel design,

$$\text{Cross – sectional Area, } A = by \quad (3)$$

And wetted perimeter (P) by equation (3.4).

$$\text{Wetted perimeter, } P = b + 2y \quad (4)$$

$$\text{Hydraulic radius, } R = \frac{by}{b + 2y} \quad (5)$$

Where b = width wetland and y = wetland depth.

Management of wetland plants used: After the CWs

were set up, they were tested by passing ordinary water through them daily for a week in order to prepare the treatment media for receiving the wetland plants.

Phragmites australis, *Polygonum salicifolium* and *Ipomoea carnea* the wetland plants, were all harvested from the banks of the Ahmadu Bello University dam, placed in large polyethylene bags (the root ends) and transported immediately to the experimental site for immediate transplanting on two of the three CWs. *Phragmites australis* only was transplanted in one CW, and *Polygonum salicifolium* and *Ipomoea carnea* were transplanted in the other wetland. After transplanting, the wetlands were successfully managed by continually watering them for three weeks to ensure proper establishment of the plants. Thereafter, tannery wastewater was introduced into the wetlands to commence treatment.

Performance Evaluation of the HSSFCW Systems:

The performance evaluation of the HSSFCW systems was carried out using the physicochemical characteristics of tannery wastewater and treated effluent. The physicochemical parameters of influent and effluent were determined using Standard Laboratory methods for Examination of Water and Wastewater (APHA, 1995). Chromium was determined using the Atomic Absorption Spectroscopy (AAS) method using the Acid Digestion Method. The BOD, COD, suspended solids, nitrate – nitrogen and phosphate were determined using the standard methods described in APHA (1995). The temperature and pH were determined using a thermometer and pH meter respectively.

The level of conformity to both the NESREA and WHO standards were used to develop relative performance indices. Similar, the performances of the aquatic plants were determined using their relative performance compared to the control.

RESULTS AND DISCUSSION

The design parameters of the HSSFCW are presented in Table 1 shows all the design parameters and respective values used for the model CW at a glance. The results of the performance evaluation of HSSFCW in the treatment of tannery wastewater is presented in Tables 2 and 3 and Fig. 4.

Table 1: Model Constructed Wetland Design Parameters and their respective Values

Parameter Value	Symbol	Design Value
Flow rate (m ³ /s)	Q	0.063 x 10 ⁻³
Aspect ratio (m)	L : W	2:1
Bed slope (%)	S	0.5
Flow depth (m)	d	0.25
Hydraulic Retention time (days)	HRT	6

Table 2: Characteristics of the Raw and treated Tannery Wastewater

Parameter	Raw Waste water	Treated Wastewater					Standards		
		CW Un-vegetated (Control)	Efficiency (%)	CW <i>Phragmites australis</i>	Efficiency (%)	CW <i>Polygonum salicifolium + Ipomoea carnea</i>	Efficiency (%)	NESREA	WHO
pH	8.5	7.6		7.8		7.9		6 - 9	7 - 8.5
BOD (mg/L)	1405	148	89.5	30	97.9	50	96.4	50	50
COD (mg/L)	2821	1264	55.2	163	94.2	797	71.7	164	40
SS (mg/L)	391	30	92.3	30	92.3	29	92.6	30	30
NO-3 (mg/L)	84	46	45.2	31	63.1	44	47.6	20	20
PO43- (mg/L)	22	16	27.3	12	45.5	15	31.8	5	5
Cr (mg/L)	28	1.43	94.9	0.44	98.4	0.66	97.6	1	1
Overall			67.4		81.9		73.0		

Table 3: Performance Index of the HSSFCW with various Vegetation options

Parameter	CW Un-vegetated (Control)		CW <i>Phragmites australis</i>		CW <i>Polygonum salicifolium + Ipomoea carnea</i>	
	NESREA	WHO	NESREA	WHO	NESREA	WHO
	pH	1	1	1	1	1
BOD (mg/L)	0	0.0	1	1.0	1	1.0
COD (mg/L)	0	0.0	1	0.0	0	0.0
SS (mg/L)	1	1.0	1	1.0	1	1.0
NO-3 (mg/L)	0	0.0	0	0.0	0	0.0
PO43- (mg/L)	0	0.0	0	0.0	0	0.0
Cr (mg/L)	0	0.0	1	1.0	1	1.0
Total	2	2	5	4	4	4
Overall Score	4		9		8	

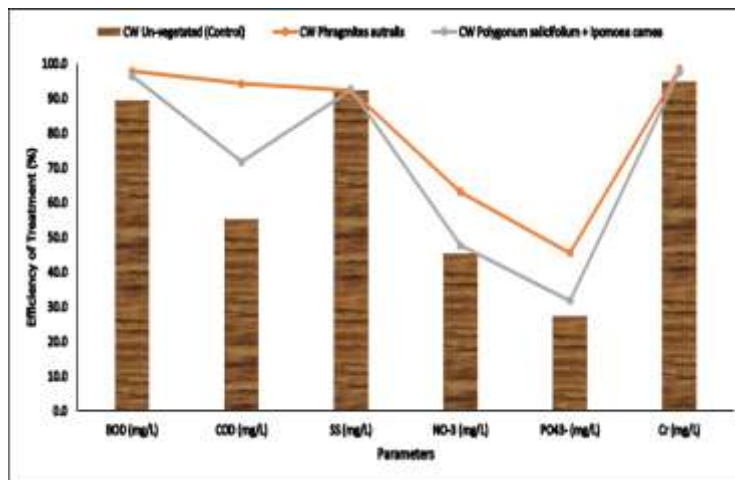


Fig. 4: Efficiency of the aquatic plants in the treatment of tannery wastewater

Three identical models of HSSFCW were developed and utilized for treatment of tannery wastewater from NILEST, Samaru Zaria, Kaduna State. The wetland vegetated with both *Phragmites australis* and *Polygonum salicifolium + Ipomoea carnea* were able to reduce the chromium and BOD of the tannery wastewater to both the NESREA and WHO limits but unable to meet the requirements for COD. This notwithstanding, they were able to reduce the COD by 94.2% and 71.7% respectively. This result agrees with the findings of García-Valero *et al.*, (2020) who reported an 80% efficiency with constructed wetland vegetated with *Phragmites australis*.

The relative score of nine (9) obtained for the *Phragmites australis* greater than the eight (8) obtained for *Polygonum salicifolium + Ipomoea carnea*. These was also buttressed by the respective percentage efficiencies of 81.9% and 73.0%. While both overall efficiencies were greater that the unvegetated wetland, *Phragmites australis* had better performance and is recommended for application. Parde *et al.*, (2021) and García-Valero *et al.*, (2020) in separate experiments have demonstrated results that showed similar patterns.

Conclusions: This study has demonstrated that vegetated horizontal subsurface flow constructed wetland is a cost effective, eco-friendly system for

treating tannery wastewater that is well suited for developing economies. The study demonstrated that *Phragmites australis* is a better aquatic plant that can archive up to 81.9% efficiency of treatment of tannery wastewater which can reduce chromium up to 98.4% and is therefore recommended for application.

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