ASSESSMENT OF SUBSURFACE WETLAND SYSTEMS FOR GREY WATER TREATMENT IN MAKURDI METROPOLIS

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(Received 08th August 2024; revised 17th November 2024; accepted 25th November 2024)

Abstract. This study investigates the efficiency of subsurface wetland systems in treating contaminated grey-water in Makurdi Metropolis, Nigeria. Initial and final concentrations of water quality parameters were evaluated before and after treatment respectively, at five different locations. Removal efficiency of contaminants was calculated, and multivariate statistical analysis was conducted to assess treatment performance. Cluster analysis was employed to identify similarities among treated water samples. All sampled gray-water violated the NSDWQ standard limits hence highly polluted. However, significant reductions in most contaminants after treatment were recorded, the system recorded an above average removal efficiency in pH, EC, Fe, TDS, Turb., TSS and total coliform with Tur. 96.97 %. Temp, Cu, Fe, NO2, TH, DO, COD and Feacal coliform were below average for removal efficiency recorded by the system. Principal component analysis reveals changes in water quality profiles before and after treatment. The scree plot of the eigenvalue of each component shows five components with PC1 having eigenvalue greater than one (>1) therefore most significant and account for the dataset total variance. The lower component loading for PC2-PC5 is an indication of anthropogenic activities which came through waste disposal, spills and leaching from hazardous waste dump sites or certain chemicals.
Keywords: *grey-water treatment, subsurface wetland systems, removal efficiency, performance*

Introduction

The demand for water is escalating due to urbanization, industrialization, and population growth, with an estimated 800 million people currently living under water stress; a number projected to reach 3 billion by 2025 (United Nations, 2017; Hanjra and Qureshi, 2010). Providing adequate water does not abate problems with water scarcity, it has to do with both quantity and quality as human health risk is concerned. Water reuses has been adopted but the safety for human consumption remain critical. Grey-water is one of the popular water that can be reuse and it presents a viable solution to water scarcity. Its reuse has been practiced for a long time, especially in water-stressed areas. When properly managed, it can reduce dependence on freshwater resources and mitigate pollution caused when discharge into freshwater sources (Morel and Diener, 2006). It can also serve as a supplementary water source in regions facing acute water crises or in arid climates. It can also be utilized for various water-demanding activities, including non-potable uses such as toilet flushing and agriculture (Abedin and Rakib, 2013).

Grey-water is any wastewater excluding contributions from toilets, originates from laundry, kitchen, bathroom, agricultural processing, and industries. It is characterized as high volume, low strength wastewater with high potential for reuse (Casanova et al., 2001). Originating from domestic activities, it contains various contaminants that pose environmental and health risks if left untreated. Treatment wetlands are natural treatment technologies designed to optimize processes established in natural environments, making them environmentally friendly and sustainable alternatives for wastewater treatment (Maine et al., 2007). They require low operation and maintenance, making them robust against input variations (Vymazal, 2001). These systems effectively treat various types of polluted water, including raw, primary, secondary, or tertiary treated sewage, as well as agricultural and industrial wastewater. This study specifically focuses on domestic wastewater treatment using treatment wetlands. Constructed wetlands (CWs) effectively remove contaminants through a combination of physical, chemical, and biological processes, including adsorption, sedimentation, filtration, oxidation, reduction, decomposition, nitrification, denitrification, microbial degradation, and phytoremediation (Zhi and Ji, 2012). These processes collectively contribute to the efficient removal of contaminants from wastewater. However, caution is needed when employing certain phytoremediation methods, such as phytovolatilization, in densely populated areas due to potential atmospheric contamination transfer.

Grey-water reuse has faced challenges related to public health perceptions and the suitability of reuse technologies. Numerous studies have investigated grey-water characteristics concerning fixtures, lifestyle patterns, and settlement types to address these challenges (Alsulaili and Hamoda, 2015; Katukiza et al., 2015; Do Couto et al., 2013). However, efficiency of wetland system in different urban contexts remains understudied. This research addresses this gap by quantitatively assessing the performance of wetland treatment systems in Makurdi Metropolis. In this context, the objective of this study is to assess wetland treatment efficiency for grey-water contaminant removal. By quantitatively analyzing the performance of wetland treatment systems in Makurdi Metropolis, this research aims to contribute valuable insights into sustainable grey-water management practices for urban environments.

Materials and Methods

The study area

The research was conducted on gray-water from different effluent location within the Makurdi metropolis, situated in the Benue Valley on the banks of River Benue. This area, located approximately at Latitude 7°44' North and Longitude 8°32' east of the Greenwich Meridian, serves as a pivotal point within the North-South transportation network (*Figure 1*). Its geographic coordinates and strategic location make it an ideal area for various studies. It encompasses a land area of 1,094, offering a diverse range of environments for analysis (Akpen and Eze, 2006).The area experiences a tropical climate with well-defined rainy and dry seasons. The rainy season typically spans from April to November, characterized by rainfall ranging from 1270-1397mm annually. Mean temperatures range from 21.6℃ to 32.7℃, with a total crop growing season lasting 215 days (Enokela and Seini, 2013). Southwest maritime winds from the Atlantic Ocean initiate the rainy season, while dry and hot air masses from the Sahara Desert contribute to the dry season. The predominant soil type in Makurdi is sandy loam, known for its porous nature and fertility. This soil composition influences various aspects of agriculture and land use within the study area

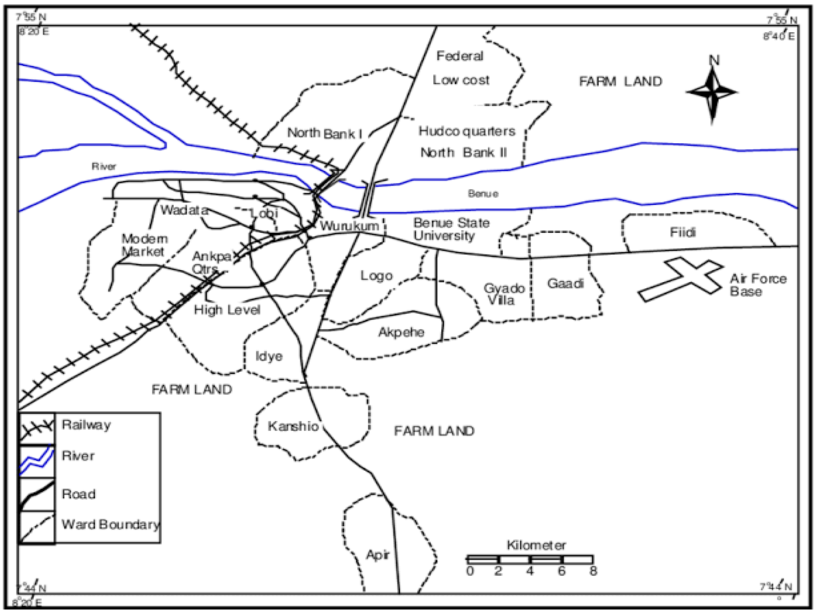

Figure 1. *Sampling areas.*
Source: Akpen and Eze (2006).

Sampling and analytical method

The study employed a quantitative methodology to evaluate the efficiency of wetland treatment systems for gray-water contaminant removal. Sampling sites were strategically selected across Makurdi Metropolis to capture variations in gray-water composition and environmental conditions. Gray-water samples were collected at effluents from five different structures of the Municipality for treatment in wetland systems. Standardized protocols were used to analyze physical, chemical, and biological contents utilizing a Spectrophotometer, Colony Counter, Turbidity Meter, Flocculator, Conductivity Meter, and pH Meter. The wetland system was constructed and setup, as depicted in *Figure 2*. It consist of a Reservoir for grey wastewater storage, PVC pipes for water flow, pH meter for soil pH determination, red oil for wetland, thermometer for soil temperature measurement, turbidity tube meter for soil turbidity measurement, 500 ml measuring cylinder for sample measurement, wood fillings for initial media filtering, coal absorbing media, fine sand for secondary filtering media, and coarse sand and gravel for supporting media. Data analysis was conducted at the Environmental Laboratory of Benue State Rural Water Supply and Sanitation Agency (BERWASSA), and the water quality parameters compared with the Nigerian Standard for Drinking Water Quality (NSDWQ).Treatment efficacy was evaluated by measuring percentages of parameters such as Turbidity, pH, TDS, COD, BOD5, phosphate, and conductance before and after treatment. COD served as the primary parameter for assessing the effectiveness of grey-water treatment by constructed wetlands. The set up consist the wastewater tanks contained samples from each location and the pilot subsurface constructed wetland. Statistical analysis techniques', including percentage to calculate percentage removal efficiency of the contaminants, multivariate statistical analysis were conducted to assess treatment performance. Cluster analysis was employed to identify similarities among treated water samples (*Figure 3*).

Figure 2. *The constructed wetland.*

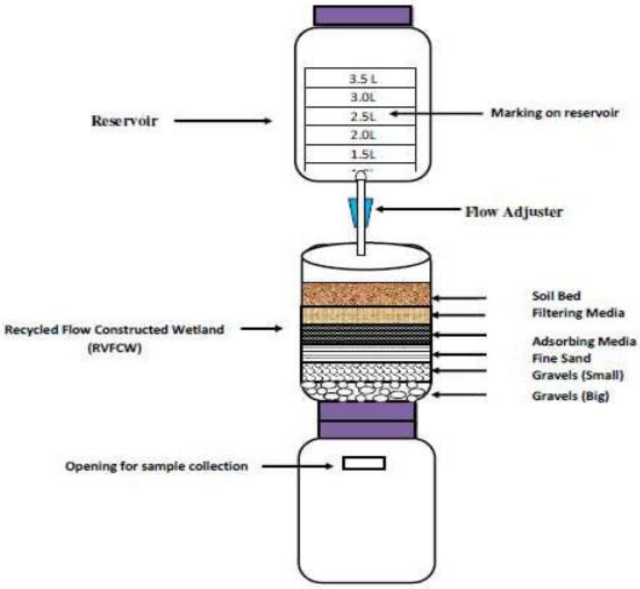

Figure 3. *The experimental setup.*

Results and Discussion

The initial concentration of water quality parameter before treatment is presented in *Table 1*, while *Table 2* presents Final concentration of water quality parameter from the five locations after treatment in subsurface wetland system. *Figure 4* and *Figure 5* are the results of comparism for physical and chemical parameters of gray water quality in Makurdi before and after treatment by subsurface wetland system, physical appreciation of the effect of treatment shows a similarity in the trend of increase or decrease in concentration of the parameters as the case may be after treatment. *Table 3* present the percentage Removal efficiency of contaminants by the constructed system. *Table 4* presents the results of the component analysis by multivariate statistic before and after treatment. *Figure 6* and *Figure 7* shows further analysis from the loading plots of locations in Makurdi. *Table 5* presents Cluster Analysis of Observations after treatment: NB, HL, WD, MM, and WU. *Figure 8* is cluster analyses performance to see the similarity among these parameters

***Table 1**. Initial concentration of water quality parameter before treatment in subsurface wetland system.*

Parameters	North bank (Laundry)	High level (Laundry)	Wadata sanitary	Modern market (Kitchen)	Wurukum (Kitchen)	NSDWQ standard	Remarks
Temperature	29.7	30.2	30.4	29.9	30.3	Ambient	< Ambient
pH	9.71	9.74	8.67	9.84	7.17	6.5-8.5	High
Conductivity	1068	800	341	1496	683	100	Very High
TDS	537	401	172	752	341	5.0	Very High
Turbidity	757	584	767	825	958	500	Very High
TSS	805	752	200	825	420	ND	
Ca	43	85	80	75	130	75	High
Cu	1.40	1.35	0.82	0.94	2.35	0.5	High
Fe	3.50	2.85	1.90	1.75	4.90	0.3	Very High
NO_2	0.90	1.25	0.36	1.40	1.25	100	Very low
T.Hardness	50	125	105	115	460	2.0	Very High
DO	3.1	3.4	3.5	4.0	3.3	500	Very Low
COD	48.32	96.13	84.03	168.14	60.22	1.0-0.5	Very High
BOD	24.01	48.02	54.02	84.03	30.01	10	Very High
Total Col.	280	150	TNC	TNC	328	0	Very High
Feacal Col.	204	74	TNC	TNC	328	0	Very High

Note: TNC=Too Numerous to Count

***Table 2**. Final concentration of water quality parameter after treatment in subsurface wetland system.*

Parameters	North bank (Laundry)	High level (Laundry)	Wadata sanitary	Modern market (Kitchen)	Wurukum (Kitchen)	NSDWQ standard	Remarks
Temperature	35.5	34.9	35.3	34.3	34.9	Ambient	< Ambient
pH	3.77	2.57	2.56	3.73	3.81	6.5-8.5	Low
Conductivity	1876	1680	1755	1275	1038	100	Very High
TDS	938	842	877.5	635	521	5.0	Very High
Turbidity	55.8	5.59	8.57	24.3	23.4	500	Very Low
TSS	708	2134	905	745	765	ND	
Ca	6.00	46.0	48.0	2.00	4.00	75	Very low
Cu	1.88	0.88	0.60	2.12	2.00	0.5	Moderate
Fe	1.98	1.63	2.0	2.50	3.12	0.3	High
NO_2	4.6	4.90	2.80	3.90	3.50	100	Very low
T.Hardness	98	105	85	108	45	2.0	Very High
DO	3.4	3.4	3.5	4.2	4.9	500	Very Low
COD	4.6	94	78	162	66	1.0-0.5	Very High
BOD	25	48	36	84	30	10	Very High
Total Col.	105	80	38	100	98	0	Very High
Feacal Col.	60	55	25	70	68	0	Very High

Note: TNC=Too Numerous to Count

***Table 3**. Removal efficiency of contaminants by the constructed system.*

Parameters	Non treated wastewater	Treated wastewater	% removal efficiency
Temperature	30.2	34.98	15.82
pH	9.026	3.288	63.57
Conductivity	77.6	1524.8	73.84
TDS	440.6	762.7	73.10
Turbidity	778.2	23.532	96.97
TSS	600.4	1051.4	74.95
Ca	82.6	21.2	74.33
Cu	1.372	1.496	8.75
Fe	2.98	2.246	24.83
NO_2	1.032	3.94	28.25
T.Hardness	171	88.2	48.42
DO	3.46	3.88	12.14
COD	91.36	80.92	11.42
BOD	48.01	44.6	7.10

Total Col.	252.66	84.2	66.67
Feacal Col.	202	55.6	42.47

***Table 4**. Principal Component Analysis: NB, HL, WD, MM, WU.*

Category	Before treatment					After treatment				
	PC1	PC2	PC3	PC4	PC5	PC1	PC2	PC3	PC4	PC5
North Bank	-0.111	0.993	0.018	0.021	-0.003	0.444	0.518	-0.450	-0.284	0.502
High Level	0.503	0.051	0.452	-0.008	0.735	0.428	-0.798	-0.239	0.152	0.317
Wadata	0.478	0.078	-0.638	-0.596	0.052	0.453	0.246	-0.230	0.668	-0.484
Mod.Market	0.496	0.049	0.518	-0.207	-0.664	0.455	0.130	0.827	0.129	0.276
Wurukum	0.509	0.046	-0.348	0.775	-0.129	0.455	-0.131	0.067	-0.659	-0.580
Eigenvalue	3.5274	0.968	0.4119	0.0550	0.0368	4.797	0.192	0.007	0.003	0.001
Proportion	0.705	0.194	0.082	0.011	0.007	0.959	0.038	0.001	0.001	0.000
Cumulative	0.705	0.899	0.982	0.993	1.000	0.959	0.998	0.999	1.000	1.000

***Table 5**. Cluster Analysis of Observations after treatment: NB, HL, WD, MM, WU.*

Step	Number of clusters	Similarity level	Distance level	Clusters joined		New cluster	Number of observation new cluster
1	15	99.9451	0.00407	2	10	2	2
2	14	99.9410	0.00438	2	12	2	3
3	13	99.9356	0.00478	8	9	8	2
4	12	99.9243	0.00562	2	8	2	5
5	11	98.7589	0.09219	1	5	1	2
6	10	98.5159	0.11024	2	7	2	6
7	9	98.2456	0.13032	1	2	1	8
8	8	98.1084	0.14051	1	14	1	9
9	7	98.0411	0.14551	1	16	1	10
10	6	97.8458	0.16002	1	15	1	11
11	5	97.3377	0.19776	1	11	1	12
12	4	96.7039	0.24484	1	13	1	13
13	3	70.6270	2.18184	4	6	4	2
14	2	55.8486	3.27959	1	4	1	15
15	1	54.5282	3.37767	1	3	1	16

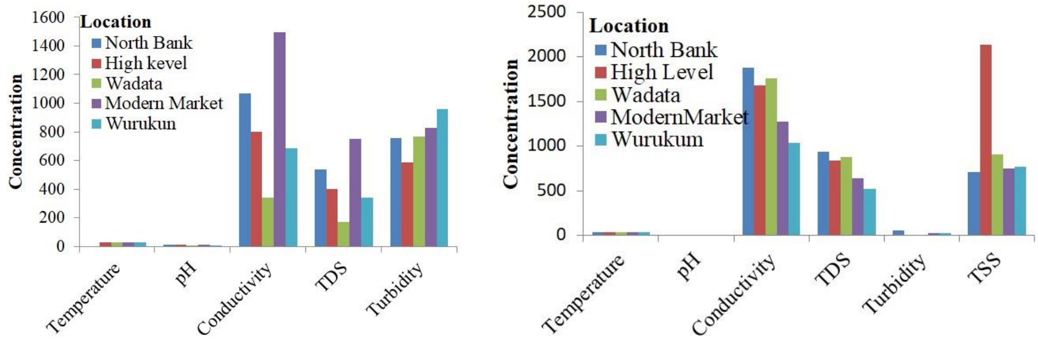

***Figure 4.** Comparism of concentration of physical parameters before (left hand side) and after (right hand side) treatment of gray water from different location of Makurdi.*

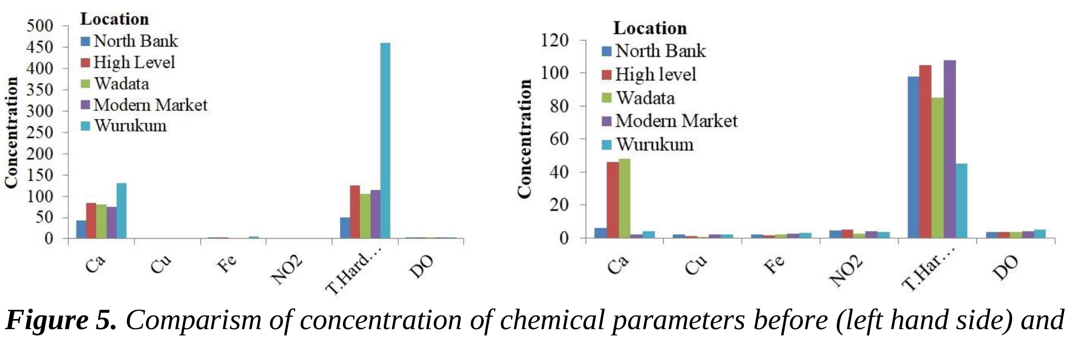

***Figure 5.** Comparism of concentration of chemical parameters before (left hand side) and after (right hand side) treatment of gray water from different location of Makurdi.*

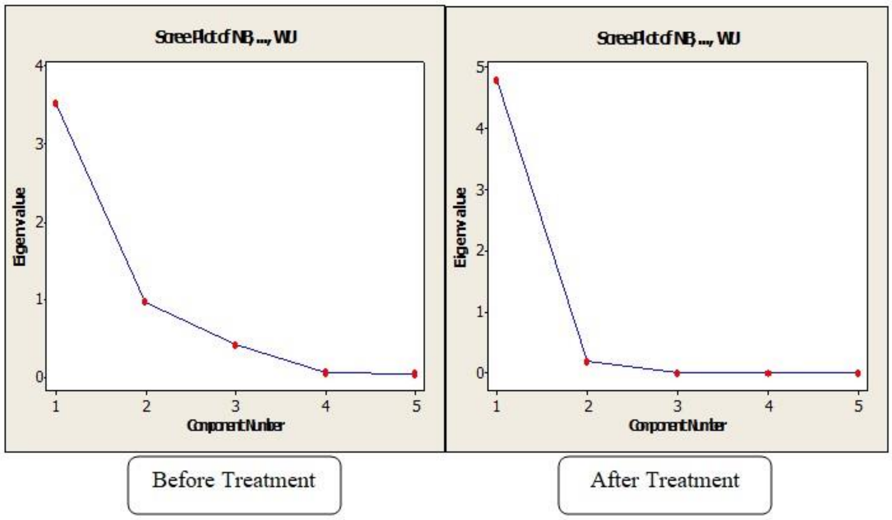

Figure 6. *Scree plot of Locations in Makurdi.*

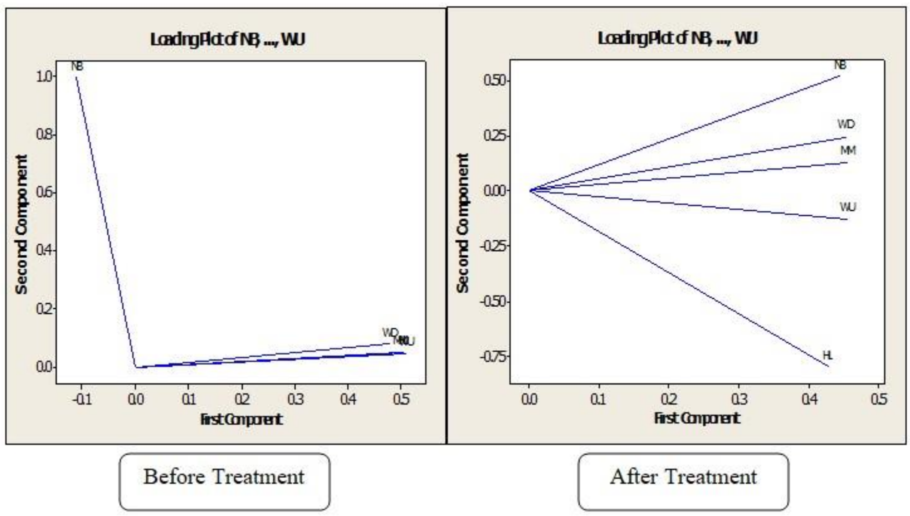

Figure 7. *Loading Plot of Locations in Makurdi.*

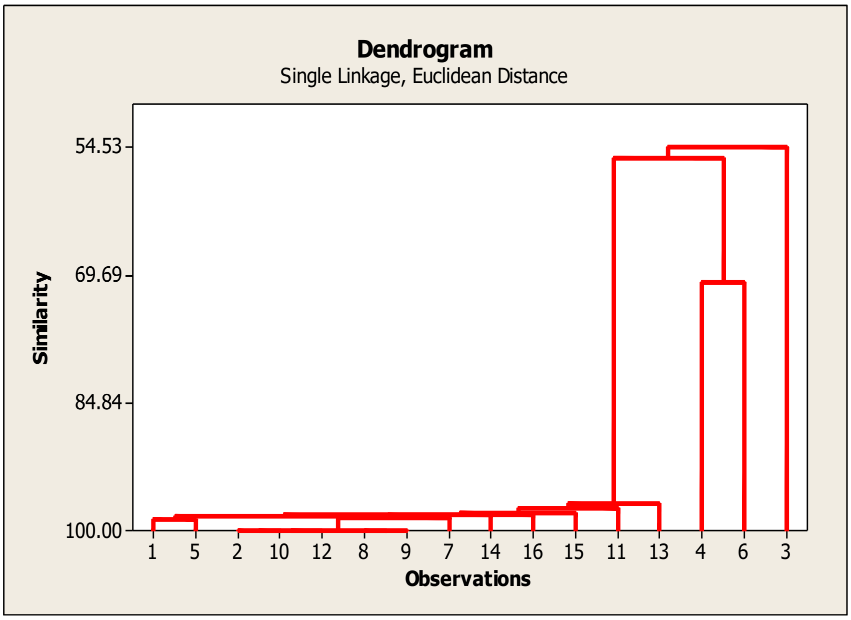

Figure 8. *Dendograme of observations.*

The provided tables offer a comprehensive view of the water quality parameters before and after treatment in a subsurface wetland system, along with the removal efficiency of various contaminants by the constructed system. *Table 1* presents the initial concentrations of various water quality parameters at different sample locations before treatment. The parameters include temperature, pH, conductivity, total dissolved solids (TDS), turbidity, total suspended solids (TSS), concentrations of various ions (e.g., Ca, Cu, Fe), nitrogen compounds (e.g. NO_2), hardness, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), and coliform bacteria counts. Each parameter's concentration is listed for different sample locations within the Makurdi Metropolis, alongside the corresponding Nigerian Standard for Drinking Water Quality (NSDWQ) standard and remarks indicating the level of the parameter concerning the standard. The Temperature: Initial temperatures ranged from 29.7°C to 30.4°C, all within ambient levels. pH levels varied significantly, with readings ranging from 7.17 to 9.84. The pH in all samples exceeded the NSDWQ standard of 6.5-8.5, indicating alkalinity whiles both conductivity and TDS were considerably high across all samples, indicating high levels of dissolved solids. Initial turbidity levels were very high, surpassing the NSDWQ standard of 500 NTU in all samples. The Concentrations of heavy metals such as Calcium (Ca), Copper (Cu), and Iron (Fe) were generally elevated, exceeding NSDWQ standards. Other Parameters such as, Total Hardness (T.Hardness), Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), and Biochemical Oxygen Demand (BOD) also showed high initial levels, with some exceeding NSDWQ standards.

Table 2 displays the final concentrations of water quality parameters after treatment in the same subsurface wetland system. Notably, there are significant improvements in various parameters such as pH, conductivity, TDS, turbidity, and concentrations of ions and metals after treatment. However, some parameters like Ca and Cu show a decrease which might not be desirable, indicating a need for further optimization of the treatment process. Similar to *Table 1*, concentrations are provided for different sample locations, along with the NSDWQ standard and remarks on parameter levels post-treatment. After treatment, the temperatures remained within ambient levels while pH levels significantly decreased after treatment, with most samples falling below the NSDWQ standard range, indicating increased acidity. Both conductivity and TDS decreased after treatment but remained relatively high. The turbidity levels decreased significantly after treatment, reaching very low levels. Concentrations of heavy metals generally decreased after treatment, although some still exceeded standards. Levels of, DO, COD, BOD, and fecal coliforms generally decreased after treatment, but some parameters still exceeded NSDWQ standards. *Table 3* displays the removal efficiency percentages of various contaminants by the constructed subsurface wetland system. It compares the concentrations of each parameter in the untreated wastewater with those in the treated wastewater, calculating the percentage reduction achieved through the treatment process. This table highlights the effectiveness of the treatment system in removing contaminants from the water, with removal efficiencies ranging from moderate to very high across different parameters. This removal efficiency of various contaminants varied: Turbidity showed the highest removal efficiency, with a reduction of 96.97%, pH, TDS, and conductivity also showed significant removal efficiencies. Removal efficiencies for heavy metals varied, with Cu showing the lowest removal efficiency while Parameters like DO, COD, and BOD exhibited moderate removal efficiencies. Also total coliforms and fecal coliforms showed considerable removal efficiencies.

Table 4: This table presents the results of principal component analysis conducted on the data before and after treatment. It shows the loadings of each parameter on the principal components (PC) extracted from the data. Eigenvalues, proportions of variance explained by each PC, and cumulative proportions are also provided, indicating the significance of each PC in explaining the variability in the dataset. The scree plot of the eigenvalue of each component (*Figure 6*) shows that the five components having eigenvalue greater than one (>1) are the most significant and account for the dataset total variance. The scree plot confirms the number of components extracted, with the eigenvalues decreasing to unity. The total % variance explained by the four PCs, their respective loadings, eigenvalues and % cumulative are shown in *Table 4*. PC1 explained highest total variance and shows strong positive loadings on all the locations which are in agreement with (Zhang et al., 2014) findings. The lower component loading for PC2 – PC5 is an indication of anthropogenic activities which came through waste disposal, spills and leaching from hazardous waste dump sites or certain chemicals. *Table 5*: This table displays the results of cluster analysis conducted on the observations after treatment. It shows the number of clusters formed at each step of the analysis, along with the similarity level, distance level, and number of observations joined in each step. The final partition indicates the number of observations within each cluster, the within-cluster sum of squares, and metrics related to cluster centroids and distances. In order to define the similarity in groups between sampling stations, the cluster analysis was applied and a dendrogram (*Figure 8*) was obtained as a result. Accordingly the 16 parameters could be grouped into statistically significant new clusters in a distant connection. Hierarchical clustering was performed according to Ward's method, with a squared Eucledian distance (Varol et al., 2012; Pejman et al., 2009; Singh et al., 2004). The Eucledian distance usually gives the similarity between two samples and the distance can be represented by the difference between analytical values from the samples.

Conclusion

The result obtained in the current study showed that almost all parameters exceed permissible limits set by NSDWQ in grey-water. It is believed that continuous pollution of environment by these substances may lead to some health problems both to humans and animals as it is sometimes experienced by the residents living in Makurdi Metropolis. The locational concentrations of parameters in the water samples were very high at initial conditions but became reduced after treatment with the exception of TDS and Ca. This attested to the significance of subsurface flow wet land technology in the treatment of grey water of different sources in our society. The removal efficiency of Conductivity, TDS, Turbidity, TSS, and Ca were in agreement with the established efficiencies posited by Somanathan et al. (2021) for subsurface flow system. In overall, this study provides valuable insights into the efficiency of subsurface wetland systems for grey-water treatment in Makurdi Metropolis. The significant reductions in contaminants after treatment demonstrate the effectiveness of the constructed wetland system. The findings contribute to the understanding of sustainable wastewater management practices in urban areas. However, further analysis and possibly adjustments to the treatment process may be needed to optimize the removal efficiencies of certain parameters and ensure consistent compliance with water quality standards. Based on the study findings, the following recommendations are proposed: (1) Optimization of wetland design: Further research should focus on optimizing the design parameters of subsurface wetland systems to enhance treatment efficiency; (2) Monitoring and maintenance: Regular monitoring and maintenance of wetland treatment systems are essential to ensure long-term effectiveness; (3) Community awareness: Public awareness campaigns should be conducted to educate residents about the importance of proper grey-water management and the benefits of wetland treatment systems; (4) Policy support: Government policies and regulations should be formulated to promote the adoption of sustainable wastewater treatment technologies, including wetland systems, in urban areas; as well as (5) Public Health Measures: Considering the presence of fecal coliforms even after treatment, additional measures such as disinfection may be needed to ensure water safety for public health.

Acknowledgement

This research is self-funded.

Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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