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Efficiency of Constructed Wetland (CW) Established with Common Reed aimed at Greywater Treatment in Akure, Nigeria

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***Abstract**: The growing scarcity of freshwater resources is becoming a significant concern in dry and semi-dry areas globally, underscoring importance of household greywater treatment to mitigate this issue. This study focused on evaluating the efficiency of a Constructed Wetland (CW) established with Phragmites australis for the treatment of greywater in Akure, Nigeria. Raw greywater was obtained from the Jadesola female hostel at the Federal University of Technology, Akure (FUTA), and then underwent initial treatment in a 500-liter filtration reservoir that contained multiple layers of pebbles and fine sand. Following this initial treatment, greywater was transferred to a Vertical Flow Sub-Surface Constructed Wetland (CW) established with Phragmites australis for the main treatment phase. Both raw and treated greywater samples were analyzed for Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), pH, Total Dissolved Solids (TDS), Electrical Conductivity (EC), and heavy metals. The results demonstrated that the CW effectively lowered all measured chemical factors, rendering the treated greywater suitable for irrigation by meeting local wastewater reuse standards. Notably, the CW achieved impressive reductions, with BOD decreasing by 91.4%, COD by 91.5%, and TDS by 38.7%, thereby proving its effectiveness in pollutants removal. The treated greywater complied with local standards for wastewater reuse, making it appropriate for irrigation and other outdoor applications. These outcomes are particularly beneficial for farmers who rely on irrigation during the dry season. Hence, additional studies should be carried out to explore the potential use of treated greywater effluents for irrigating certain types of vegetable crops.*

***Keywords:** Common Reed, Constructed Wetland, Electrical Conductivity, Greywater, Irrigation*

1. INTRODUCTION

As the population continues to grow, cities are generating large amounts of internal wastewater. The improper disposal of this water contributes to the contamination of air, soil, and groundwater. In many dry and semi-arid regions, there is competition for freshwater among various sectors, resulting in decreased availability for agriculture. Consequently, the declining quality and quantity of water for irrigation, combined with rising demand from other users, is pushing farmers to utilize non-conventional water sources. Among these water management strategies, the use of treated wastewater has gained significant importance [1]. This approach not only helps meet increasing water demands but also safeguards potable water supplies, reduces pollution discharge into surface water, lowers treatment charges and also enhances the economic benefits for farmers by decreasing fertilizer application requirements [2, 3]. Greywater refers to all wastewater produced from households, excluding toilet waste. This includes water from bathtubs, kitchens, sinks and washing machines, often containing shampoo, food scraps, soap and cooking oils. Greywater accounts for the major percentage of total household wastewater. Typically, greywater constitutes 50-80% of domestic wastewater [4-6]. If a composting urinal is included, this can raise the percentage to 100% [7-9]. Greywater is a by-product of domestic activities, and its composition is heavily influenced by lifestyle choices, social and cultural norms, the number of individuals in a household, and the usage of home amenities. Greywater generated from bathtubs, showers, and hand-wash basins is typically the least contaminated source. Moreover, it constitutes approximately 25% of total suspended solids and can contribute up to two-thirds of the total phosphorus found in wastewater [10-13]. Laundry detergents and soaps serve as the main contributors to phosphorus levels in greywater. However, in nations that employ phosphorus-free detergents, the concentrations of phosphorus in greywater tend to be significantly lower. Galley greywater is the main contributor to nitrogen in domestic greywater, while for agricultural irrigation is becoming more common due to water shortages and population growth [14]. Bathroom and washing greywater typically have the lowest nitrogen levels. The use of treated greywater is particularly suitable for irrigating indoor plants, although this use must adhere to strict safety guidelines regarding potential contact. Additionally, treated greywater can be employed for irrigating agricultural crops and lawns, as well as for maintaining ornamental fountains and landscape features. Utilizing greywater for agricultural irrigation is a well-established practice in arid and semi-arid regions to enhance crop production.

Constructed Wetlands are designed systems that utilize natural processes to improve water value. These wetlands are effective systems for treating wastewater through a mixture of physical, chemical and biological processes. Physical mechanisms comprise filtration and sedimentation, while biological processes are driven by microbial activity and plant nutrient uptake. Chemical mechanisms, such as precipitation and adsorption, also play a key role in pollutant removal [15]. Typically, constructed wetlands incorporate impermeable liners made of clay or synthetic materials, along with engineered components to control flow paths, water retention times, and levels. Depending on the design, these systems may also contain inert materials like sand, gravel, or rock to aid in filtration and provide structural support. In constructed wetlands, plants are integral to the treatment process as they enhance microbial activity by supplying oxygen to the root zone (rhizosphere), reduce nutrient levels through uptake, and offer additional surface area for biofilm formation [16]. The main objective the constructed wetlands have is to leverage the natural purification properties of wetland ecosystems to reduce contaminants such as BOD, TSS, TN, phosphorus and pathogens as the wastewater gradually passes through the vegetated wetland surface [17-23]. Constructed wetlands are generally classified into Free Water Surface (FWS) systems and Subsurface Flow (SSF) systems. FWS wetlands are characterized by an open water surface open to the atmosphere as the water moves through the system. They can be further subdivided based on the predominant type of vegetation, that is, emergent macrophytes, free-floating macrophytes, or submerged macrophytes. In contrast, SSF wetlands are designed such that water flows through a porous media, such as gravel or sand, without direct exposure to the atmosphere. SSF wetlands are typically planted with emergent macrophytes and can be categorized based on their flow pattern: either horizontal flow or vertical flow systems. Among the wetland plants commonly used in constructed wetlands, *Phragmites australis*, or common reed, is one of the most widespread species globally. This highly productive perennial grass, belonging to the family Poaceae, exhibits a net primary production that can vary from less than 3 tons per hectare per year to as much as 30 tons per hectare per year, depending on environmental conditions [24]. *Phragmites australis* can thrive in diverse climates and is found on every continent except Antarctica, with its primary distribution areas being Europe, the Middle East, and the Americas [25]. Its robust growth and adaptability make it an ideal candidate for use in constructed wetlands, where it enhances pollutant removal efficiency and provides a stable habitat for microbial communities that contribute to the overall treatment process. It is characteristic of wet sites, most often with water level ranging from slightly below the soil surface to one metre above ground level [26-33] and grows mostly at the shores of lakes and gulfs, along riverbanks. Despite the widespread implementation of constructed wetlands for wastewater treatment, research on their efficiencies specifically for greywater treatment remains limited in Nigeria. Therefore, this study aims to investigate the efficiency of constructed wetlands established with common reed for treating greywater in Akure, Nigeria.

2. MATERIALS AND METHOD

This research was done behind the Jadesola female hostel of the Federal University of Technology, Akure (FUTA), Nigeria. The university is located in a humid climate region at a latitude of 7.30430 N and a longitude of 5.13700 E, characterized by a tropical humid climate with two separate seasons: a wet season and a dry season. Greywater was collected from the female hostel, which houses approximately 200 residents. Water from baths, showers, kitchens, and bathrooms was channelled through 128 mm diameter pipes into a concealed 500-liter reservoir, which acted as both a holding tank and filtration unit for the greywater. During the experimental process, a pre-treatment phase occurred in a cylindrical 500-liter container designed to sieve out food particles and other suspended solids. This was accomplished through multiple layers of pebbles with varying diameters (less than 32 mm, 24 mm, and 16 mm), topped with a fine sand layer (0.2 mm in diameter), as illustrated in Figure 1. The setup began with PVC pipes from the hostel leading into the collection and sedimentation tank, where suspended solids were eliminated, allowing for the settling of biochemical oxygen demand (BOD), heavy metals, and other nutrients. The filtered greywater was then directed into the constructed wetland (CW) through a vertical pipe, relying on gravity for flow. The CW consists of a plastic container with a surface diameter of 1.5 m and a depth of 0.6 m, containing filtration layers akin to those found in the sedimentation tank, with common reed plants distributed throughout. The purification of water occurs in the reedbeds, where the reed stubble enhances bacterial activity by delivering oxygen to the roots via specialized air-filled structures called aerenchyma.

Nitrogen (N) removal in the system primarily takes place through processes such as ammonification, nitrification, and denitrification, while phosphorus (P) is eliminated through chemical adsorption and biological transformation [34, 35]. The retention time for the filtered greywater in the CW was established at 2 days before samples were collected for subsequent analysis. Water samples were gathered from both the raw and treated greywater using 1-liter polyethylene bottles sourced from the study area. Prior to use, these bottles were thoroughly cleaned with acid and distilled water and subsequently dried to ensure contamination-free sampling.

The study measured various parameters, including physical factors like pH and several chemical factors, such as Chemical Oxygen Demand (COD), Electrical Conductivity (EC) Biochemical Oxygen Demand (BOD), Total Nitrogen (TN), and Total Dissolved Solids (TDS). The pH and EC values were evaluated on-site immediately after sample collection using a pH meter and an EC meter, respectively. Heavy metals were analyzed at the University's Analytical Laboratory. The concentrations of sodium (Na) and potassium (K) were measured using a flame photometer, while chloride levels were determined through titration with silver nitrate (AgNO3). BOD and COD were assessed at the Sustainable Laboratory in Akure, Nigeria, following the standard Open Method and conducted within a few hours of sample collection. Total Suspended Solids (TSS) were quantified using gravimetric testing to measure "total suspended non-filterable solids."

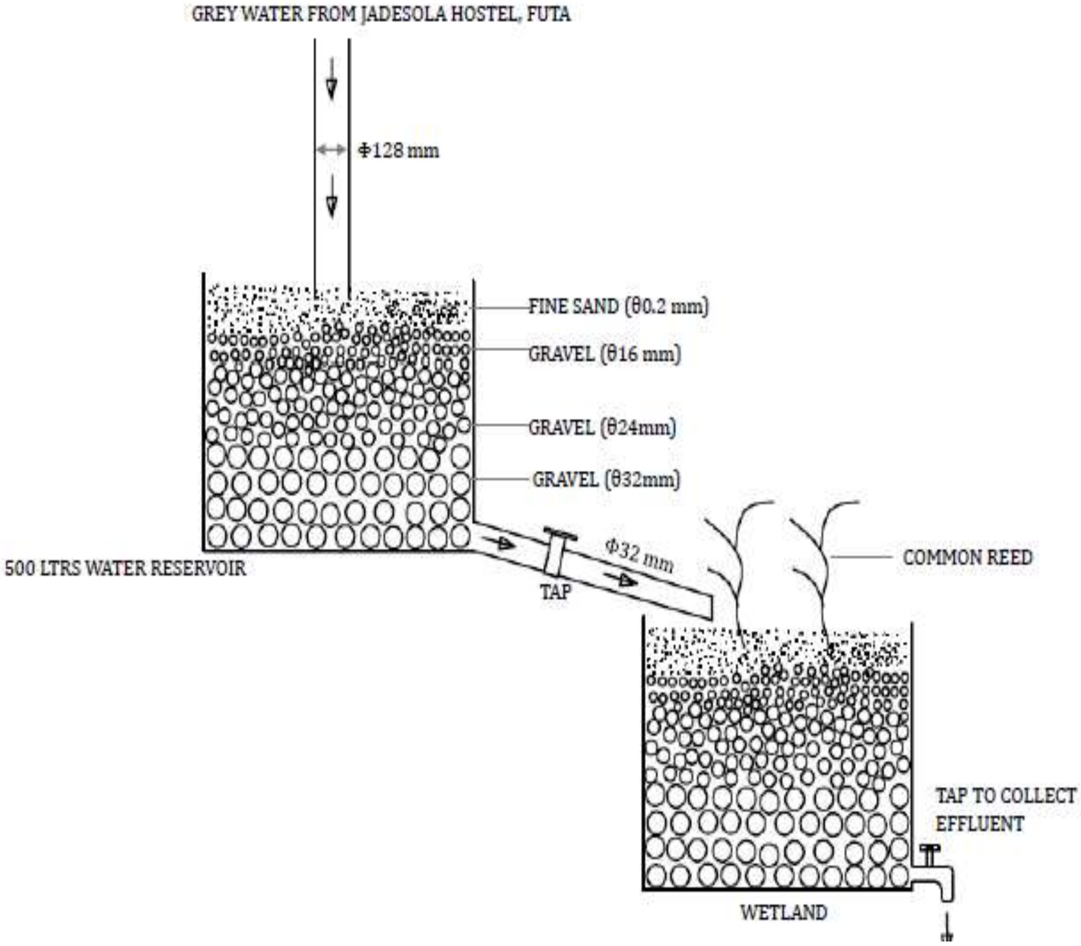

Figure 1: Greywater treatment setup

Figures 2 – 3 shows the various stages involved in collection and treatments of greywater during the field work at the study area.

Figure 2: Raw greywater coming from the hostel to the sedimentation tank at the experimental field

Figure 3: Constructed wetland planted with common reed at the experimental field

3. RESULTS AND DISCUSSION

3.1 Wetland Performance

The results revealed that the removal efficiencies for various pollutants were: 90.92% for BOD, 91.46% for COD, 38.73% for TDS, and 47.01% for Nitrogen (see Table 1). These findings are consistent with the ones by Patel *et al*. [36] that achieved removal efficiencies of 87.5% for BOD and 70% for COD through an electrocoagulation treatment process for greywater. Furthermore, Ridderstolpe [37] documented removal efficiencies ranging from 90% to 99% for BOD and COD respectively, with nitrogen removal around 30% in vertical subsurface flow systems. Prior research by Deguenon *et al*. [38] indicated that the use of common reed for treating domestic sewage resulted in removal efficiencies of 93% and 92% for COD and BOD respectively. Similarly, Marzec *et al*. [39] observed that over 95% of both BOD and COD were removed in an amalgam constructed wetland system established with common reed. Thus, the constructed wetland utilizing common reed proved to be highly effective in eliminating a substantial amount of contaminants from the water.

Table 1: Performance of constructed wetland (CW) planted with common reed

Parameter((mgl^{-1})	Raw Greywater	Treated Greywater	Removal efficiency (%)
BOD	286.40	26.00	90.92
TSS	107.00	92.00	14.02
SO_4	2551.30	1563.70	38.71
NO_3	23.40	12.40	47.01
Na	60.30	42.40	29.68
K	28.60	7.50	73.78
TDS	2001.00	1226.00	38.73
COD	415.77	35.51	91.46
NO_3	23.40	12.40	47.01

3.2 pH

The pH levels of 7.46 and 7.08 were recorded for raw and treated greywater, respectively. According to FAO (1985) [40] guidelines, an ideal pH range for irrigation water is 6.5 to 9.0, while Shoushtarian and Negahban-Azar [41] and WHO [42] recommend a range of 6.5 to 8.5. Based on these standards, both raw and treated greywater are suitable for irrigation in terms of pH. The wetland system had an impact on pH levels, likely due to the presence of vegetation and pebbles that reduce straight sunshine exposure as the greywater flows through. The lower pH observed in treated greywater compared to raw greywater might be attributed to the inability of plants to release or absorb carbon dioxide during the day, as well as the activity of photosynthetic plants and microorganisms [43, 44].

3.3 Salinity Hazard

Salinity denotes the concentration of melted salts in water. Electrical conductivity (EC), measured in dS/m, serves as a reliable indicator of the TDS present in water. High salinity levels in water can be lethal to plants and pose a salinity threat. However, soils with elevated salinity are usually classified as saline soils. The average properties of raw and treated greywater in the study area are summarized in Table 2 below:

Table 2: Average classification of water in the study area

Parameter	Raw greywater	Treated greywater	FAO acceptable level [45]
pH	7.46	7.08	6 – 9
EC (dS/m)	4.02	2.43	0.7 – 3.0
TDS (mg/l)	1998	1226	450 – 2000
K (mg/l)	28.60	7.50	-
Mg (mg/l)	4.84	5.35	60
Na (mg/l)	60.30	42.20	200
BOD (mg/l)	286.40	24.50	60
COD (mg/l)	415.77	35.51	200
SO_4^{2-} (mg/l)	2551.30	1563.70	2000
TC (cfu/ml)	64500	2300	-
FC (cfu/ml)	25700	460	1000
TSS (mg/l)	109.00	92.00	50

Classification of surface water based on salinity hazard according to USEPA/WHO water quality guidelines is shown in Table 3.

Table 3: USEPA/WHO rules for clarifications of water quality for irrigation

Probable Irrigation difficulty	Grade of constraint on use			Treated
Salinity	None	Minor to reasonable	Severe	greywater
EC (dS/m)	<0.7	0.7 – 3.0	>3.0	2.43
TDS (mg/l)	<450	450 – 2000	>2000	1226

The analysis of treated greywater revealed an average TDS of 1226 mg/l and an average EC of 2.43 dS/m (Table 3), indicating a minor to moderate salinity issue for crops. According to FAO [45], the recommended EC range for wastewater used in irrigation is between 0 and 2.0 dS/m. Since the EC of the treated greywater exceeds this range, the effluent could potentially cause minor to moderate issues by deteriorating the soil's physical structure, which may, in turn, negatively affect plant growth, reduce root and shoot length, and decrease overall dry mass. To mitigate salinity, it is possible to apply more fresh water than what the plant requires to flush salts out of the root zone through leaching.

3.4 Sodium Hazard

The average sodium (Na) concentrations in treated and raw greywater were found to be 42.40 mgl^{-1} and 60.30 mgl^{-1}, respectively. As per Pescod, these levels indicate that the treated greywater is suitable for irrigation use.

3.5 Nutrients

According to the results presented in Table 2, treated greywater contains significant concentrations of essential nutrients necessary for plant growth (e.g. nitrogen (N), potassium (K), and phosphorus (P). Therefore, using treated greywater can reduce the need for chemical fertilizers, thereby lowering associated environmental risks

.3.6 BOD COD and TSS

The results show that the treated greywater is suitable for irrigation, with an average BOD of 24.50 mgl^{-1} and an average COD of 35.51 mgl^{-1} (Table 2), both falling within the acceptable FAO limits. However, the average TSS concentration in treated greywater was 92.00 mg/l, which exceeds the FAO recommended level and could potentially cause soil clogging in irrigation systems. The low BOD and COD levels in the treated greywater may be attributed to effective purification processes in the sedimentation tank. These findings are consistent with previous studies by Bilha [46] and Seswoya and Zainal [47]. The lower values observed in this study linked to other reports could be due to reduced levels of degradable organic matter arriving the constructed wetland systems, as much of it may have been removed in the sedimentation tank

3.7 Heavy metals

Heavy metals analyzed include cadmium, copper, lead, zinc, nickel, and manganese [48]. As shown in Table 4, the concentrations of these metals in treated greywater fall within the acceptable limits set by WHO, indicating they are unlikely to negatively impact soil or crops. This is also in line with the findings of Alao *et al*. [49] and Alao *et al.* [50]. While certain heavy metals are essential for plant growth in trace amounts, they become toxic and harmful at higher concentrations. Toxicity can result in reduced plant growth, lower yields, and even plant death. Heavy metals are among the most common inorganic contaminants found in greywater, posing potential risks to soil, plants, animals, and human health. When greywater containing heavy metals is used for irrigation, these metals can accumulate in the soil profile over time.

Table 4: Concentrations of heavy metals present in water in the study area

Element (ppm)	Raw greywater	Treated Greywater	WHO limits
Cd	Nill	Nill	0.003
Cu	0.120	0.030	2.000
Fe	0.014	0.002	0.300
Mn	0.105	0.021	0.400
Ni	0.002	Nill	0.020
Pb	0.050	0.001	0.010
Zn	0.173	0.156	3.000

4. CONCLUSION

This study evaluated the efficiency of a constructed wetland system established with common reed for greywater treatment in Akure, Nigeria. The results disclosed that most of the chemical factors in the greywater samples lies within permissible limits, with the exception of EC, COD, and BOD in raw greywater (RGW), which were effectively treated by the wetland. This confirms the efficiency of the constructed wetland in treating greywater. Specifically, the treatment reduced BOD, COD, and TDS by 91.4%, 91.5%, and 38.7%, respectively. These reductions underscore the significant role played by common reed in improving the quality of treated greywater. From the study's findings, it can be established that Common Reed is an effective and reliable plant species for the treatment of greywater. Moreover, the promising results from this research suggest that additional studies should be carried out to explore the potential use of treated greywater effluents for irrigating certain types of vegetable crops. This approach could provide a sustainable alternative water source for agricultural purposes, further enhancing the viability of greywater reuse.

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