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Performance of Common Reed (*Phragmites australis*) in a Constructed Wetland for Greywater Treatment in Akure, Nigeria

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ABSTRACT

Shortage of freshwater is becoming a growing problem in both dry and semi-dry regions of the world, hence the need to make use of other source of water for agricultural production. The study was conducted to examine the performance of common reed in a constructed wetland for greywater treatment in Akure, Nigeria. Raw greywater was collected from Jadesola Hostel, Federal University of Technology, Akure, and pretreated through a combination of gravel of diameters < 32 mm, 24 mm and 16 mm with fine sand of diameter 0.2 mm arranged accordingly. The filtered water was thereafter released to a plastic constructed wetland (CW) which also consisted of same combination of layers of gravel and sand with common reed planted on it for complete treatment. The raw and treated greywater were analyzed for Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solid (TDS), and heavy metals. It was discovered that CW planted with common reed was effective in the treatment of greywater with reduction in BOD by 91.4%, COD by 91.5% and TDS by 38.7%. CW had appreciable removal effect on heavy metals with reduction in: manganese (Mn) from 0.100 ppm to 0.012 ppm, iron (Fe) from 0.014 ppm to 0.002 ppm, lead (Pb) from 0.05 ppm to 0.001 ppm and zinc (Zn) from 0.154 ppm to 0.148 ppm. Therefore, the use of common reed in constructed wetland for greywater treatment is recommended for farmers involved in irrigation with greywater, especially during dry seasons, and most importantly under the rising global water scarcity due to climate change.

1. Introduction

Owing to endlessly growing population, enormous bulk of domestic wastewater is being formed in cities. Undiscriminating dumping of such water causes pollution of air, soil and groundwater supplies. Rivalry for freshwater among different water-use parts already exists in several arid and semi-arid regions, causing dwindled distribution of freshwater to agriculture. For this reason, declining supplies of water quality for irrigation and growing demand from other handlers are forcing farmers to use non-conventional water resources [1]. Amongst these various non-conventional sources, the use of treated wastewater (TWW) has taken on greater significance. Indeed, this quality of water for agriculture offers the greatest scope for application because it usually has the potential to meet growing water demands, conserve potable supplies, reduce disposal of pollution effluent into

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surface water bodies, allow lower treatment costs and enhance the economic benefits for growers due to reduced application rates for fertilizer [2].

Greywater refers to all wastewater that is discharged from a house, without blackwater (toilet water). This includes water from showers, bathtubs, sinks, kitchen, dishwashers, laundry tubs, and washing machines [3]. It commonly contains soap, shampoo, toothpaste, food scraps, cooking oils, detergents and hair. Greywater makes up the biggest proportion of the total wastewater flow from households in terms of volume [4]. Typically, 50-80% of the household wastewater is greywater. If a composting toilet is also used, then 100% of the household wastewater is greywater. Greywater is a replication of the household activities and its characteristics are strongly dependent on living standards, social and cultural habits, number of household members and the use of household chemicals [5]. Greywater from bathtubs, showers and hand-wash basins is considered as the least polluted greywater source [6]. The average greywater contribution to the total organic load (BOD_5) amounts to about 40 – 50%. Greywater also contributes to one fourth of the total suspended solids and up to two thirds of the total phosphorous load.

Despite the foregoing, the usage of greywater for agricultural irrigation purposes has become a common practice globally, because of water shortage and population growth [7]. The treated greywater can be supplied for irrigation of indoor plants as the greywater is most suitable for this purpose. The treated greywater can also be used for irrigating agricultural crops and turfs and for maintaining decorative fountains or landscape impoundments. However, such applications must meet the strict requirements from possible exposures to greywater. This suggests that reclaim of greywater for irrigation purposes must follow the attainment of certain levels of treatment. One common, but efficient way of achieving such a requirement is through the use of constructed wetlands (CW). Constructed wetlands are engineered systems intended to exploit natural processes for water quality developments. They perform this function by eliminating contaminants in wastewaters through a mixture of physical (filtration, sedimentation), biological (microbial processes, plant uptake) and chemical (precipitation, adsorption) mechanisms. They naturally have impermeable clay or synthetic liners, and engineered structures to control the flow direction, liquid confinement time and water level. Depending on the type of system, they may or may not contain an inert porous media such as rock, gravel or sand. In constructed wetlands, vegetation plays an incomplete part during the treatment process, because it helps in providing oxygen to the microorganisms in the rhizosphere, decrease the volume of nutrients in the system by uptake and perhaps provide more surface area in the rhizosphere for the microorganisms Constructed wetlands are classified as either Free Water Surface (FWS) systems or Subsurface Flow (SSF) systems. Any wetland, in which the surface of the water flowing through the system is exposed to the atmosphere, is classified as FWS system. In SSF systems water is designed to flow through a granular media, without coming into contact with the atmosphere.

Different researchers have investigated the wide use of constructed wetland for different types of wastewater, including domestic [8,9], industrial [10,11], agricultural runoff [12], dairy [13] and polluted river water [14,15]. In all these applications, significant improvements in water quality were reported. In spite of the wide suitability of the success of constructed wetlands for the treatment of variations of wastewater [9,16], information is scarce in the literature as regards the use of the technique in Nigeria. Thus, the need for a research with a focus in this particular area of wastewater management cannot be over-emphasised.

Likewise, bearing in mind that different macrophytes plants are used in constructed wetland (CW) to attain the numerous requisite treatment levels [17], it has become imperative to assess the specific performance of the varieties of macrophytes. This is very important, because studies have shown that the performance of macrophytes varies under hypertrophic waterlogged conditions, local climate, pests, diseases and pollutants [16]. Moreover, for a satisfactory performance, plants must be readily propagated, establish easily, and spread and grow rapidly [18]. In addition, they must exhibit a high pollutant removal capacity, either through direct assimilation and storage, or indirectly by enhancement of microbial transformations such as nitrification (via root-zone oxygen release) and denitrification (via production of carbon substrates) [18]. Currently, the most frequently used plants in CW are common reed (*Phragmites australis*), rushes *(Juncus spp.*), bulrushes *(Scirpus spp.),* narrow-leaved cattail *(Typha angustifolia L.),* broad-leaved cattail *(Typha latifolia L.),* yellow flag *(Iris pseudacorus L.),* sweet flag (*Acorus calamus L.)* and reed grass *(Glyceria maxima)*. However, of all the afore-mentioned plants, the use of common reed seems most prevalent amongst researchers, because it can be found almost in all parts of the world [19-21]. Reed plant can be found across the globe except in Antarctica, but its main dispersal area is Europe, the Middle East and America [22]. Moreover, the plant is extremely prolific grass with an above-ground net primary production ranging from less than 3 t ha^{-1} y^{-1} to as much

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as 30 t ha^{-1} y^{-1} [23]. *Phragmites australis* is one of the most commonly circulated wetland plant worldwide. Reed grass is an emergent perennial, herbaceous and flood-tolerant grass that is widely spread through tropical Africa as well as tropical and subtropical area of New Guinea, Australia and the Pacific. However, despite the widespread use of common reed in CW technology for greywater treatment around the world, to the best of our knowledge, its performance with respect to studies in Nigeria, is rare in the literature. Therefore, the aim of the present study was to investigate the performance of common reed in a constructed wetland for greywater treatment in Akure, Nigeria.

2. Materials and Methods

The study was carried out at the Experimental Farm located behind Jadesola Female Hostel, Obanla Campus of the Federal University of Technology, Akure (FUTA), Nigeria. FUTA is located in Akure which lies on Latitude 7°14' N and Longitude 5°08' E. The city is noted for its heavy rainfall with climate following the usual tropical pattern. The climate is humid with a rainy season which usually commences in March/April and ceases around October/November, while the dry season is from November to February or March. Mean annual rainfall varies between 1300 and 1600 mm and mean daily temperature is about 27.5 °C, with a relative humidity of about 58%. Akure is largely agrarian with common food crops including cocoyam, tomato, maize, plantain, and cash crops such as cocoa and timber commonly grown in the city.

Raw greywater (RGW) was sourced from the Jadesola Hostel (FUTA) of about 200 occupants. The RGW was drained to the experimental field through pipes of diameter 128 mm to an underground 500 litres water reservoir that served as a holding/sedimentation tank for the greywater. Pre-treatment of the collected RGW took place inside the 500 litres cylindrical plastic container, where food bits and other suspended objects (hair and lint) were sieved through stratums of gravels (diameters < 32 mm, 24 mm, and 16 mm) and a final layer of fine sand (diameter 0.2 mm), accordingly. The filtered RGW was released into the underground constructed wetland (CW) vertically through a pipe by gravity. The CW is a plastic container of surface diameter 1.5 m and depth 0.6 m. It also consisted of filters as in the sedimentation tank with common reed planted on it (Figure1). After retention time of two (2) days, the effluent from the wetland was assumed to have been treated and subsequently collected as treated greywater (TGW). Selection of the type of Constructed Wetland (CW) to develop depends on the pollutants the greywater is likely to contain, that is, Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), heavy metals, and fats, oils and greases (FOG). The desired quality of effluent from CW would also determine the type of wetland to be developed. Thus, a Vertical Flow Constructed Wetland (VF-CW) was selected. A VF-CW has the ability to remove large amounts of BOD, remove nitrogen from the effluent (through anaerobic reactions), limit evaporation and water loss, and limits the surface area necessary for construction along with preventing possible safety hazards. The water types used were collected for water quality analysis.

Water is purified by reedbeds when entire reed stubbles start bacterial activity by carrying air (i.e. oxygen) to the roots *via* the aerenchyma. The retention time of the filtered greywater in the CW was calculated to be 2 days before being collected for analysis.

Samples of the RGW and treated greywater (TGW) were collected in two different 1 litre polyethylene bottles and analyzed. The used polyethylene bottles had been pre-washed with acid and distilled water and thereafter dried. The parameters determined were biochemical oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solid (TDS), manganese, iron, zinc and lead. The tests were carried out at the Chemistry and Analytical Laboratory of the University.

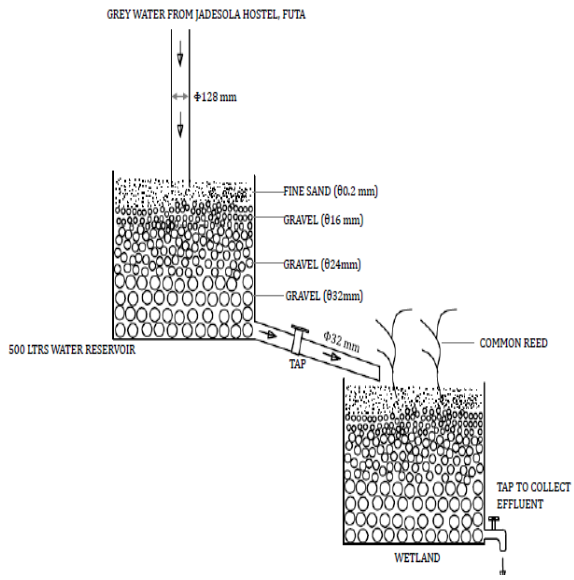

Figure 1. Greywater Treatment Setup

3. Results and Discussion

3.1 Wetland Performance

Pollutants removal efficiencies for biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total dissolved solid (TDS) were 90.92%, 91.46% and 38.73% (Table 1), respectively. These values are in conformity with Ridderstolpe (2004) [24], who reported 90 – 99% removal efficiencies for both BOD and COD. Previous report by Deguenon *et al.* (2013) [25] also showed that COD and BOD had removal efficiencies of 93% and 92%, respectively, when common reed was used to treat a campus domestic sewage. Similar report by Marzec *et al.* (2018) [26] showed that more than 95% of BOD and COD were removed in a tested hybrid CW system planted with common reed. Thus, the results of the present study show the high efficiency of common reed in the removal of large amounts of pollutants when used in CW. Meanwhile, the high removal efficiency of pollutants by the plant has been attributed to high oxygen transfer through the substrate media at which its vertical configuration promote better contact with microorganism and substrate aeration [27].

Further analysis of TGW showed slight to moderate salinity as TDS was 1226 mg/L and EC was 2.43 dS/m. Pescod (1992) [28] had recommended that wastewater for irrigation water should contain EC (0 - 2.0 dS/m) and TDS of the range 450 – 2000 mg/L (Table 1). On the contrary, the EC of the TGW was above the permissible limit, thus suggesting that irrigation with the TGW may cause slight to moderate problems of deterioration to the physical structure of the soil, which in turn may cause reduction in plant growth [29], root and shoot length and overall yield [30]. Nonetheless, combating this salinity is possible by applying more normal water than the plant needs to remove the salts from the root zone by leaching [31].

On the other round, results also showed that the TGW is suitable for irrigation given that both the BOD value of 24.50 mg/l and COD value of 35.51 mg/l (Table 1) are within the FAO acceptable levels [28]. Comparatively, the present results are similar to those of Bilha (2006) [32] and, Seswoya and Zainal (2010) [33] in their separate studies. The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) levels in the TGW were low probably due to the pre-treatment that occurred in the sedimentation tank and low levels of degradable organic matter entering the CW systems.

3.2 Heavy Metals

The results of heavy metal analysis showed that their concentrations in TGW are in the WHO acceptable limits (Table 2) and, as such, the use of the TGW for irrigation may not have deleterious effects on both soil and crop. It should be noted that some heavy metals are essential to plant growth at low concentrations, but they become toxic and harmful at high concentrations. Our results further showed the removal efficiencies of Mn, Fe, Pb and Zn as 88%, 85.71, 98% and 3.90%, respectively. These removal efficiencies are in line with those of previous studies [34-40]. Meanwhile, efficient removal of heavy metals from wastewater has been attributed to the added rhizobacterium and adsorbents used in the CW systems [38,39]. In overall, heavy metals were predominantly removed through rhizofiltration, at which the metals were extracted from the wastewater through adsorption on the root. Following the adsorption through the root's membrane, the metals are either stored within the root itself or translocated to the other part of the plants where they undergo tissue localization [40].

Table 1. Pollutants removal efficiency of common reed in CW

Parameter	Raw Greywater	Treated Greywater	Removal efficiency (%)	FAO Standards (Pescod, 1992)
BOD (mg/l)	286.40	26.00	90.92	0.7 – 3.0
COD (mg/l)	415.77	35.51	91.46	450 – 2000
TDS (mg/l)	2001.00	1226.00	38.73	60
EC (dS/m)	4.02	2.26	43.78	200

Table 2. Concentrations of heavy metals in RGW and TGW

Element	Raw greywater	Treated Greywater	WHO limits (WHO, 1995) [41]
Fe (ppm)	0.014	0.002	0.300
Mn (ppm)	0.105	0.021	0.400
Pb (ppm)	0.050	0.001	0.010
Zn (ppm)	0.173	0.156	3.000

4. Conclusions

The research was conducted to investigate the performance of common reed in greywater treatment in Akure, Nigeria. First, we found a very high performance in the ability of common reed to remove pollutants from greywater when used in CW. Moreover, effectiveness of the CW was further emphasized as concentrations of heavy metals such as Mn, Fe, Pb and Zn were significantly reduced to permissible limits. In addition, both the BOD and COD of the TGW from CW fell within the standard limits, thereby confirming the suitability of the TGW for irrigation. These results are in conformity with previous studies, thus underscoring the effectiveness of constructed wetland (CW) in the treatment of greywater. However, the salinity of the TGW was slightly above the permissible limit, suggesting poor ability of the system to remove EC and, therefore the need for additional treatment measure. The foregoing notwithstanding, it

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was concluded that common reed has the potential to effectively treat greywater and its use in CW should by embraced. Nevertheless, further research is recommended to investigate the removal of salinity in RGW using CW and, the effects of the use of TGW for irrigation on soil properties and growth and yield of different varieties of vegetable.

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