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Research Article

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Study on the Potential of Macrophytes in a Two Stage Filtration of Domestic Wastewater for Irrigation Purposes

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Abstract The conventional method for treating wastewater for agricultural reuse requires high levels of technical know-how and is unaffordable for some rural farmers. The aim of this research was to treat domestic wastewater through the adoption of an ecologically sustainable, easy and affordable treatment system for irrigation purposes. The treatment involves the use of sand and gravel of different sizes as filters (as a control) and Cyperus rotundus-assisted filters in a hybrid treatment stage. The study was carried out for 40 days with laboratory analysis of the effluent at every 10-day interval at a hydraulic loading rate and hydraulic retention time of 0.75 m/day and 10 hours, respectively. The pollutant removal efficiencies for the turbidity, TDS, BOD, and total nitrogen of the treated wastewater by the biofilter are between (70.2–80.6%, 66.2–69.8%, 68.9–77.1%, and 49.5–54.4%, respectively), while that of the macrophytes assister biofilter is between (81.1–94.5%, 75.8–81.9%, 90.6 – 93%, 72 –77.8% respectively. The result of the study shows that the macrophyte-assisted biofilter treated wastewater better for irrigation purposes compared to the biofilter. The pH of the treated domestic wastewater for both filters is within the recommended standard for irrigation purposes.

Keywords Biochemical Oxygen Demand, Turbidimetre, Effluent, Biodegradability

1. Introduction

The rapid growth in urbanization and population in developing countries has placed pressure on the availability of freshwater needed to satisfy increased domestic and industrial needs. This also led to increased wastewater generation [1]. There are few efforts towards the preservation of worldwide water resources, but this preservation is a real need. Besides global erratic water distribution and losses in the pipe system, there is a global setback in sewage treatments. The use of quality wastewater in agriculture, such as sewage treatment effluent, preserves water's good quality, avoids waterborne diseases, recycles nutrients, saves chemical fertilizers, expands irrigated areas, promotes recovery of degraded or unproductive areas, and minimizes sewage discharge into surface water and its contamination and eutrophication impacts [2].

There is presence of parasites in domestic sewage, which invariably results in food contamination or waterborne diseases through irrigation of raw-eaten vegetables with untreated sewage, thereby breeding the issue of public health risk [3]. There are numerous varieties of pathogenic organisms and chemical constituents with high toxicity present in sewage. So, because the possibility of transmission of disease is a major concern in reuse, it is imperative to make provisions for adequate treatment that will be in line with the quality criteria [3-4]. Despite the challenges attributed to the required care of the sewage, utilizing treated effluent in agriculture is an alternative for water resource management. It allows the management of good-quality water as well as the prevention of water bodies' contamination.

In other words, various techniques are used for the removal of pollutants from wastewater, which include physical, chemical, and biological methods [5]. However, some of these approaches are expensive and require high technical know-how [6]. Several studies suggest that the plant plays an important role in the treatment of domestic sewage through filtration: (i) the absorption of minerals pollutants into their tissues; (ii) acting as a catalyst during the wastewater filtration process; and (iii) encouraging the growth of microorganisms needed to achieve better effluents [7]. Until now, the use of plant media wastewater filtration techniques for the purpose of irrigation in Nigeria has been limited, and it is imperative to encourage the local farmers towards the adoption of the system. However, this study involves the utilization of macrophytes' plants in the treatment of domestic sewage through a filtration process for irrigation purposes.

2. Methodology

2.1 Evaluation of wastewater treatability

It is important to investigate the treatability of sewage water; this can be achieved by using the approach adopted by Tchobanoglous et al., [8] who propose a BOD_5/COD ratio of 0.3–0.8 for a treatable wastewater. A BOD_5/COD value of 0.5 indicate wastewater that can be treated through biological means.

2.2 Experimental Design

2.3 Estimation of hydraulic retention time

The adopted theoretical HRT for the two stage substrate media was determined using:

$$HRT = \frac{\rho \, X \, V}{Q} \qquad (1)$$

HRT = Theoretical hydraulic retention time (hrs)

ρ = porosity of the filter bed

V = Volume of the filter bed (m^3)

Q = Wastewater flow rate through the filter bed (m^3/hr)

2.4 Estimation of hydraulic loading rate

$$HLR = \frac{V}{A \, X \, T} \qquad (2)$$

HLR = Hydraulic loading rate (m/day).

V = Volume of the wastewater.

A = Area of the exposed profile of the soil.

T = Theoretical hydraulic retention time (hrs). [9]

Low hydraulic loading rate (HLR) leads to increased hydraulic retention time (HRT) in soil and will improve treatment efficiency. Hydraulic loading rates vary from one soil to another. The rate of infiltration depends on the characteristics of the soil, which define pore sizes and distribution, soil morphological characteristics, including texture, structure, bulk density, and clay mineralogy [10].

2.5 Estimation of pollutant removal efficiency

The treatment efficiency of the two filters was assessed using the equation below.

$$R = \frac{ci - c0}{ci} \, X \, 100 \qquad (3)$$

R = percentage reduction/removal efficiencies

C_i = influent value (mg/l)

C_0 = effluent value (mg/l) [9, 11-12]

2.6 Treatment and dosage procedure

Domestic sewage was collected from the hostel sewers of Auchi Polytechnic, Auchi, Edo State, Nigeria. Experiments were carried out by implanting Cyperus rotundus in a two-stage (vertical and horizontal flow basin) filled with washed sand and gravel, which were adopted as wastewater filters. The substrate is composed of four layers of of garden soil, washed sand and gravel of different particle sizes [9]. Cyperus rotundus was inoculated on the February 10, 2023 into the vertical and horizontal components of the substrate-filled basin while domestic wastewater was discharged from the influent container through the vertical and horizontal components of the substrate profile at a constant hydraulic loading rate of 0.75 m/day and a hydraulic retention time of 10 hours. The treated effluent was collected for laboratory analysis on Turbidity, TDS, BOD, pH, and total nitogen at every 10-day interval (Yahiaoui et al., 2018) for 40days.

A B

Plate 1: Image (a & b) Soil and gravel filters for domestic wastewater treatment

C D

Plate 2:Image (c & d) Complete set up (vegetative/non vegetative filters) for domestic wastewater treatment unit and macrophyte inclusion in wastewater filtration system.

3. Results and Discussion

3.1 Turbidity

The turbidity of wastewater refers to its cloudiness as a result of tiny particles or suspended solids. It expressed the level of clarity in water, and in the laboratory, it was measured through the use of a turbidimeter (NTU). A wastewater with high turbidity can affect the efficiency of the irrigation system, it can reduce the hydraulic conductivity of the soil, thereby polluting the soil [13]. Fig. 1 below shows that the turbidity of the treated domestic sewage decreased with considerable treatment time while the macrophytes-assisted filtration media treated the sewage better with a turbidity removal efficiency of 81 to 95% as compared to the non-vegetative filter (control) removal efficiency of 70 to 81% for the treatment period considered. The turbidity of the treated sewage was in line with irrigation guidelines according to the FAO and USEPA with macrophyte-assisted filtration procedures at 30 and 40 days of treatment. The USEPA recommends a treatment level lower than 2 NTU only for directly consumed crops and unrestricted irrigation, and Spain recommends a level lower than 10 NTU for vegetables. The MOE sets the standards at under 2 NTU for food crops and under 5 NTU for processed food crops. Most countries that do not have a standard for turbidity have one for suspended solids instead [13].

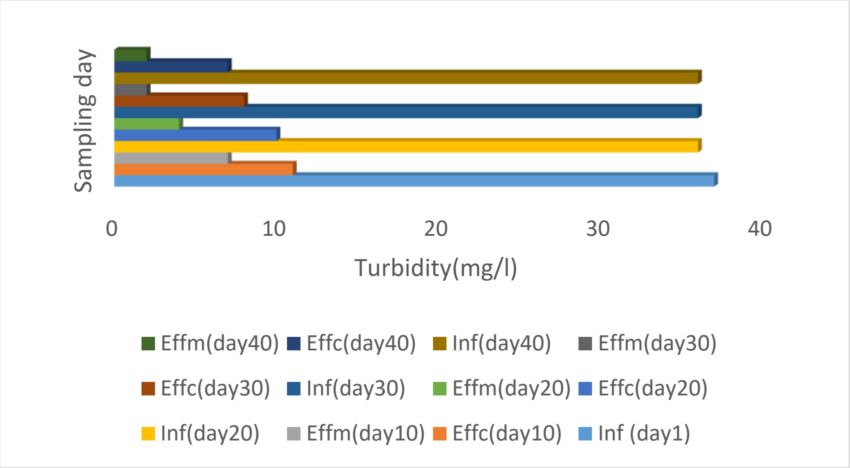

Figure 1: Presentation of treated effluent turbidity and sampling day

3.2 Total Dissolve solid (TDS)

It is recommended that the dissolved solids be small enough to pass through filters with 2-micrometer nominal size pores during the wastewater filtration process [14]. The TDS removal efficiency of the non-vegetative filter (control) is between 68.7 and 69.8%, and that of the macrophyte-assisted filtration system is between 75.9 and 81.9%, respectively. According to Fig. 2 below, the range of the treated effluent is in line with the irrigation guidelines as recommended by the FAO classification for both media, with the macrophyte-assisted filter performing best at 30 days of treatment.

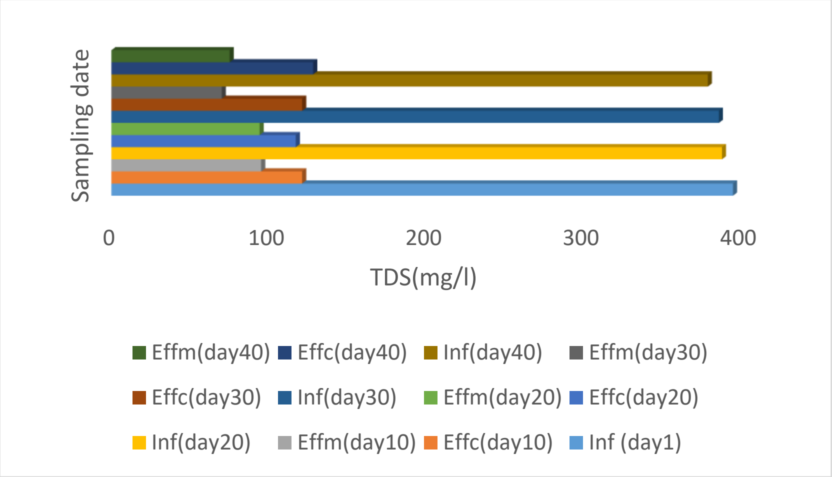

Figure 2: Presentation of treated effluent TDS and sampling day

3.3 Biochemical Oxygen Demand (BOD)

The result of the experiment reveals that the BOD removal using a macrophyte-assisted filter is higher than the control (Fig. 3). The BOD removal efficiencies of the non-vegetative filter (control) and macrophyte-assisted filters are between 68.9 and 77.1% and 90.6 and 93%, respectively. It was observed that the efficiency of both filters increases with time, for the time interval considered. Similar results were reported by Lavrova and Koumanova [15]; Panrare et al., [16]. The better performance of the macrophyte assisted filter indicates that the process of oxygenation was improved by the plant as a means of aiding the treatment system. The biodegradation of organic matter was aided by the activity of microbes within the plant filter. The USEPA recommended a BOD level of less than or equal to 10mg/l for food crops and less than or equal to 30mg/l for processed food crops. All the BOD values of the treated sewage through macrophyte assisted filter is in line with the recommended guidelines for wastewater reuse in agriculture, while the values observed for the control are below the standard [13].

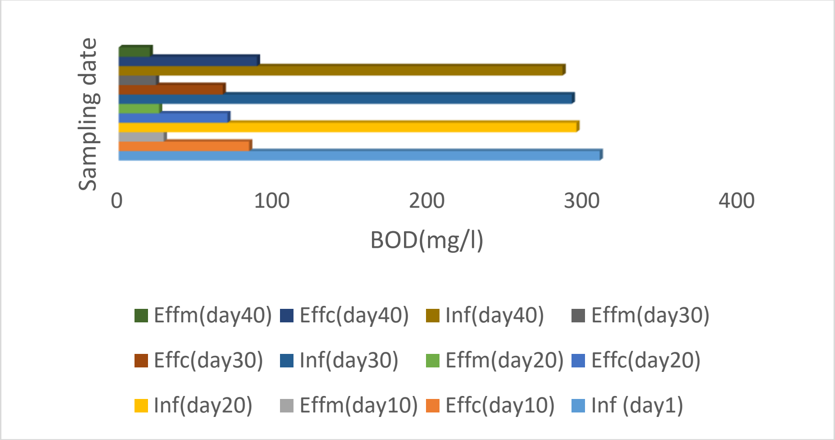

Figure 3: Presentation of treated effluent BOD and sampling day

3.4 pH

Figure 4 shows the pH range of treated wastewater. The pH increases for both non-vegetative filter (control) and macrophyte assisted filter at 10 to 30 days of treatment, the pH decreases at 40days of treatment for the two media. The increase in value of pH was as a result of plant respiration by the plant and photosynthetic activity consuming of H^+ protons while the decrease in pH values was as a result of accumulation of H^+ protons from the activity of nitrifying bacteria and the CO_2 discharge from the biodegradation of organic matter by heterotrophic bacteria and plant respiration [17]. The pH of the treated domestic sewage is in line with irrigation standard as recommended by USEPA, Israel, Italy and Portugal standard [13].

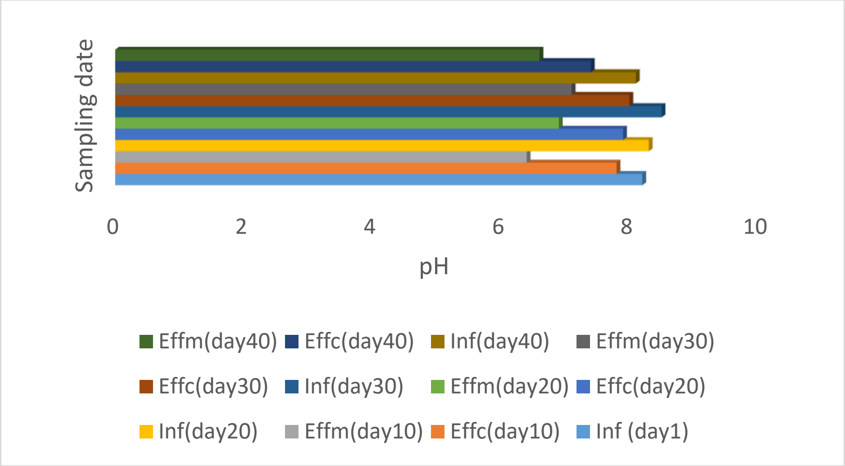

Figure 4: Presentation of treated effluent pH and sampling day

3.5 Total Nitrogen (TN)

According to Fig. 5 above, it was observed that there was no significant difference in the value of nitrogen for the raw and treated sewage from the non-vegetative filter (control) for the interval of days considered. There was a consistent reduction (significant difference) in the nitrogen value of the treated sewage for the macrophyte-assisted filter. The nitrogen removal efficiencies of the control and macrophyte-assisted filters are between 49.5 and 54.4% and 72.0 and 77.8%, respectively. Ammonia and organic nitrogen (NH_3-N) represent the specific types of nitrogen that can be found in any wastewater. The reduction in the value of nitrogen was a result of processes like volatilization, nitrification, and denitrification, as well as hydrophyte uptake by the macrophyte plant. The nitrogen value of the treated domestic wastewater for the interval of days considered by the plant-assisted filter is in line with the recommended guidelines for wastewater use in irrigation according to Israel's and Italy's classification [13].

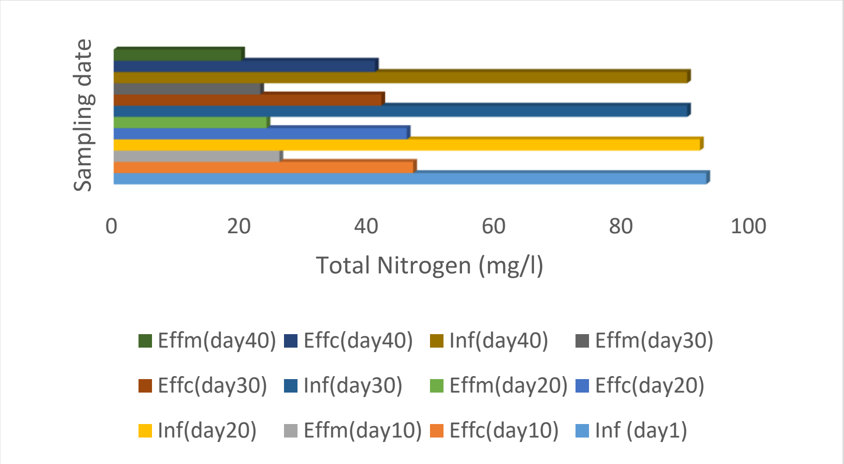

Figure 5: Presentation of treated effluent total nitrogen and sampling day

4. Conclusion

Many literature reviews utilized different types of macrophytes and filtering media in wastewater treatment; the ability of these plants to treat domestic wastewater relies on factors such as the response of the plant in the filtration system, the properties or concentration of the wastewater influent, the integrated filtration stage, the designed hydraulic loading rate, and the retention time. The outcome of the study revealed that the pollutant removal efficiencies of macrophyte inclusion during wastewater filtration systems provide a better treatment option for domestic wastewater compared to the filter without vegetative cover (control). The parameters of the treated effluent by the integrated filtration system, such as turbidity, TDS, BOD, pH, and nitrates, are within the stipulated guidelines for irrigation purposes compared to the control. The integrated filtration system can therefore be recommended for rural farmers in Nigerian communities because of its affordability, low level of technical know-how, and environmental friendliness.

Declaration and Conflict of Interest

The authors declare that they do not have competing research, personal, or financial interests that could have appeared to influence the work reported in this paper.

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