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Turkey's Significance Approach on the Impacts of Hydraulic Loading Rates and Hydraulic Retention Time on the Quality of Treated Sewage Water

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Abstract The effectiveness of composite filters made from treated sand, activated carbon, and granite in reducing pollutants in sewage water collected from a student hostel at Federal Polytechnic Auchi, Edo State, Nigeria was assessed in this study. The composite filters were arranged at a fixed depth of 15cm each in three composite filter drums. The sewage water was released from the influent drum into the composite filters' drums at hydraulic loading rates of 1.0, 1.5, and 2.0 m/day and hydraulic retention periods of 10, 20, and 30 days, respectively. Physicochemical parameters such as BOD, TDS, pH, EC, and Sodicity of the collected sewage water were evaluated before and after treatment. The results showed that the treated sewage water had BOD, TDS, pH, EC, and sodicity values ranging between 32 - 219mg/L, 51 - 223mg/L, 6.9 - 7.8, 2.7 - 4.9ds/m, and 8.8 - 11.8 SARS, respectively. The pollutant reduction efficiency ranged between 36.5 - 90.7%, 56.3 - 90.0%, 2.5 - 10.0%, 9.3 - 50.0%, and 12.6 - 34.8% for BOD, TDS, pH, EC, and sodicity, respectively. The hydraulic loading rate of 1.0m/day and hydraulic retention time of 30 days yielded the highest pollutant reduction efficiency for the selected physicochemical parameters of the sewage water considered in the study. Honest significant test approach revealed that hydraulic loading rate and hydraulic retention time are significant on the BOD, TDS, EC, sodicity at $p>0.05$ and significant for pH of the treated sewage at $p<0.05$. This study demonstrates the potential of composite filters as a promising approach to reducing the turbidity and toxicity of sewage water for irrigation purposes. The findings provide valuable insights for the treatment of sewage water using composite filters made from treated sand, activated carbon, and granite.

Keywords Biochemical oxygen demand, Electrical conductivity, Toxicity, and Treatability.

1. Introduction

Earth's freshwater resources are sufficient to meet human needs, but just around 1% of freshwater's total volume is good for human consumption. If it could be divided equally, the readily available water would be sufficient to meet the demands of a population ten times larger than the available water [21]. More than 70 percent of the freshwater that is available globally is used for agriculture [24]. In advanced countries, water shortages occur as a result of industrial effluents polluting ground and surface water. In developing nations, sewage from built-in and urban areas is a primary cause of water degradation [15;20]. To meet the needs of agriculture in areas with limited freshwater supplies, alternate sources of water must be sought. Sewage and industrial effluent are possible alternatives to address this [13,18]. The utilization of recycled water minimizes the amount of wastewater that is discharged on the soil's surface and eases social and political pressure on the water sources that are currently in use [6].

Crops can be harmed by the trace metals and high levels of inorganic nutrients discovered in wastewater sources used for irrigation. Because of this, there are still concerns in some regions of the world about the safety of recycled wastewater. As a result, wastewater must be treated before being used in agricultural settings. The only method to reduce the possible harm from applying wastewater to agricultural land over an extended period is through treatment. When freshwater for agricultural use becomes scarce over time or in some areas where water scarcity is prevalent, the importance of reclaimed water from wastewater sources is greatly important. Thus, there is a direct correlation between the advancement of technology for producing water for reuse and the scarcity of water in certain areas. [4,3] have successfully provided comprehensive information on this approach. Additional research studies [17,1,8] have addressed the recent advancements in wastewater treatment methods in developing nations; however, these studies have not given wastewater recycling for agricultural land reclamation adequate attention, particularly when considering different degrees of water scarcity.

The advantage of an on-site wastewater treatment system is that it protects against bacterial contamination of the receiving water in addition to being an efficient means of eliminating biogenic and organic chemicals. According to [14], a sand filter can be used as a third step of sewage treatment in order to eliminate microorganisms from faeces. It appears that a system with a settling tank and a vertically flowing sand filter is a more economical option that enables a very successful reduction of bacterial, chemical, and physical contaminants [7]. An elimination level of 1 × 102 – 2 × 104 CFU/100 cm3 for Escherichia coli and 5 × 103– 3 × 105 CFU/100 cm3 for coliform bacteria may be obtained by using sand as the filter filler [22]. The aim of this research was to study the effects of hydraulic loading rates and hydraulic retention time on the quality of treated sewage water.

2. Research design and Methodology

2.1 Collection of sewer water and experimental materials

Domestic wastewater was collected from the sewer of Auchi Polytechnic hostel and transported to the project set up. The wastewater was collected with four pre-cleaned plastic containers of 0.03m3 capacity each and poured into 0.12 m3 capacity influents' containers. The sample of the raw wastewater was taken to a water laboratory to assess its treatability in terms of BOD5/COD ratio [11]. Other accessories for the setup include three 0.025m3 capacity containers for the housing of composite filters, an average-size steel support for all the influent containers, an influent and effluent outlet, a control valve, and netting mesh. The steel support was fabricated at the workshop of the Mechanical Engineering Department, Federal Polytechnic Auchi while other materials for the project set-up were purchased within Auchi town.

2.2 Design of experimental components

2.2.1 Percentage of contaminants removed

The efficiency of the treated composite filters with consideration to wastewater loading rate was expressed below.

$$\mathrm{C}\ (\%) = \frac{\mathrm{ai} - \mathrm{a0}}{\mathrm{ai}} \mathrm{X}\ 100 \qquad [\text{equ1}]$$

R = percentage reduction/removal efficiencies

ai = influent value (mg/l)

a0 = effluent value (mg/l)

2.2.2 Design for hydraulic loading rate (HLR) of sewage influent

$$\mathrm{HLR} = \frac{\mathrm{Vw}}{\mathrm{As\ X\ Tt}} \qquad [\text{equ2}]$$

HLR = The rate of hydraulic loading of the wastewater.

Vw = Volume of wastewater influent.

As = Area of surface biofilters.

Tt = adopted hydraulic retention time (hrs).

2.2.3 Design for wastewater retention time

The adopted hydraulic retention time for the composite filters' drums was determined using:

$$\text{HRT} = \frac{\rho \text{ X Vs}}{\text{Qf}} \qquad \text{[equ3]}$$

HRT = Adopted or theoretical hydraulic retention time (hrs)
ρ = porosity of composite filters
Vs = Volume of the filter bed (m3)
Qf = Wastewater flow rate through the filter bed (m3/hr) [11].

2.3 Experimental design

The experimental procedure was statistically designed using a random complete block design (RCBD) to minimize bias and estimate the interactive effects of the adopted hydraulic loading rates (HLR) and adopted hydraulic retention time (HRT) for the raw sewage water. Their impacts on the quality of treated domestic sewage water was also investigated. The hydraulic loading rates (HLR) of 1.0, 1.5, and 2.0m/day and hydraulic retention time of 10 days, 20 days, and 30 days were considered for the study respectively. The replication of the adopted factors was also considered. The total experimental runs were nine (9) with three (3) replicates each. Each experimental run is a reflection of the adopted factors.

2.4 Experimental procedure

The treatment set up for the study includes one influent drum of 0.12m3 capacity, three separate composite drums for the housing of composite filters and an outlet for the collection of effluent. The composite filters consist of granite, treated sand, and activated carbon of particle sizes 3.5mm, <200µm, and 1mm, respectively. The influent drum was connected to three composite filter drums with an average slant plastic pipe of size 20cm protruding at 450. The sewage wastewater was released at a preset rate to the composite filter drum with the aid of a control valve and at hydraulic loading rates of 1.0, 1.5, and 2.0m/day and hydraulic retention times of 10, 20, and 30 days. A shower outlet was incorporated into the experimental set-up through plumbing work. The composite filters (granite, treated sand and activated carbon) are arranged in the composite drums at a fixed depth of 15cm for each of the filters for composite drum1, drum2 and drum3, respectively. The composite filters are arranged in the order of treated sand layer, activated carbon layer, and granite particles placed beneath and at a depth of 40cm. The surface diameter of the composite filter for the three selected composite filter drums was 36cm, while the opening diameter of the composite filter drums was 28cm. Some space was provided in each of the adopted composite filter drums to allow for wastewater turbulence, aeration and proper filtration. Also, a net mesh of 0.5mm pore size was placed in between each layer of the well-arranged composite filters to prevent the mixing of adopted composite filters and to integrate the filtration process. Some properties of the composite filters were evaluated before and after the experiment.

Plate1: *Wastewater source,* ***Plate2****: Research set up,* ***Plate3&4:*** *Geofilters,* ***Plate5:*** *Raw and treated water*

2.5 Statistical analysis

The data collected from this study was interpreted using bar charts' display from Excel page. Also, the values from the laboratory analysis of the treated sewage water were subjected to statistical analysis using analysis of variance (ANOVA) with consideration to Turkey's Karmer approach at P<0.05 level of significance.

3. Results & Discussion

(A) BOD values of raw and treated sewage water (B) TDS values of raw and treated sewage water (C) pH values of raw and treated sewage water (D) EC values of raw and treated sewage water (E) Sodicity values of raw and treated sewage water.

The Fig A above represents the impacts of hydraulic loading rates and hydraulic retention time on the values of biochemical oxygen demand (BOD) of treated sewage water. The concentration of DO that microorganisms consume during the breakdown of organic materials is measured with BOD. It can be used to determine the overall quality of the water as well as the extent of contaminants that degrades and pollutes it [2]. The BOD values of the raw and treated sewage water are more than the recommended standard of wastewater for irrigation [5,9,10,19]. It was recommended that the BOD value of wastewater use in irrigation should be less or exactly 10mg/L for food crops and less than or exactly 30mg/L for processed food crops [10]. The graph also revealed a steady reduction in the BOD values of the treated sewage water at the lowest hydraulic loading rate of 1.0m/day and highest hydraulic retention period of 30 days. The BOD value of the raw sewage water was 345mg/L while the BOD values of the treated sewage water were 110, 83, and 32mg/L, 192, 121, and 93mg/L, 219, 154, and 98 for the treatment retention period of 10, 20, and 30days and hydraulic loading rate of 1.0, 1.5, and 2.0m/day, respectively. According to FigA, the BOD value of the sewage water was at a minimum at a hydraulic loading rate of 1.0m/day and a hydraulic retention period of 30 days. The BOD value of 32mg/L of the treated sewage at a hydraulic loading rate and hydraulic retention period of 1.5m/day and 30days was close to the BOD value of the recommended guideline of wastewater use for irrigation purposes. Turkey's Honest Significant Test (THST) was adopted for the analysis of variance on the level of significance of the adopted factors (hydraulic loading rate and hydraulic retention time) on the BOD values of the treated sewage water at P < 0.05, the statistical analysis revealed the existence of a statistically insignificant value at p<0.05 of the adopted factors or independent variables on the BOD values of the treated sewage water.

The total dissolved solid (TDS) of 510mg/L of the raw sewage water was within the moderate range for wastewater use in irrigation and according to FAO classification [10] while the total dissolved solids (TDS) of the treated sewage water was 115, 98, and 51mg/L, 173, 111, and 84mg/L, 223, 182, and 136mg/L for hydraulic loading rate and hydraulic retention time of 1.0, 1.5, 2.0m/day and 10, 20, 30days, respectively. The lowest hydraulic loading rate (1.0m/day) and highest hydraulic retention time (30 days) yielded the most reduced value of 51mg/L of TDS as shown in Fig B above. There was a steady reduction in the TDS values of the treated sewage water for each of the hydraulic loading rates and hydraulic retention times adopted in the study. The result of the study according to Turkey's HST revealed an analysis of variance that was statistically insignificant at p<0.05 between the adopted hydraulic loading rates, hydraulic retention time and the TDS values of the treated sewage water.

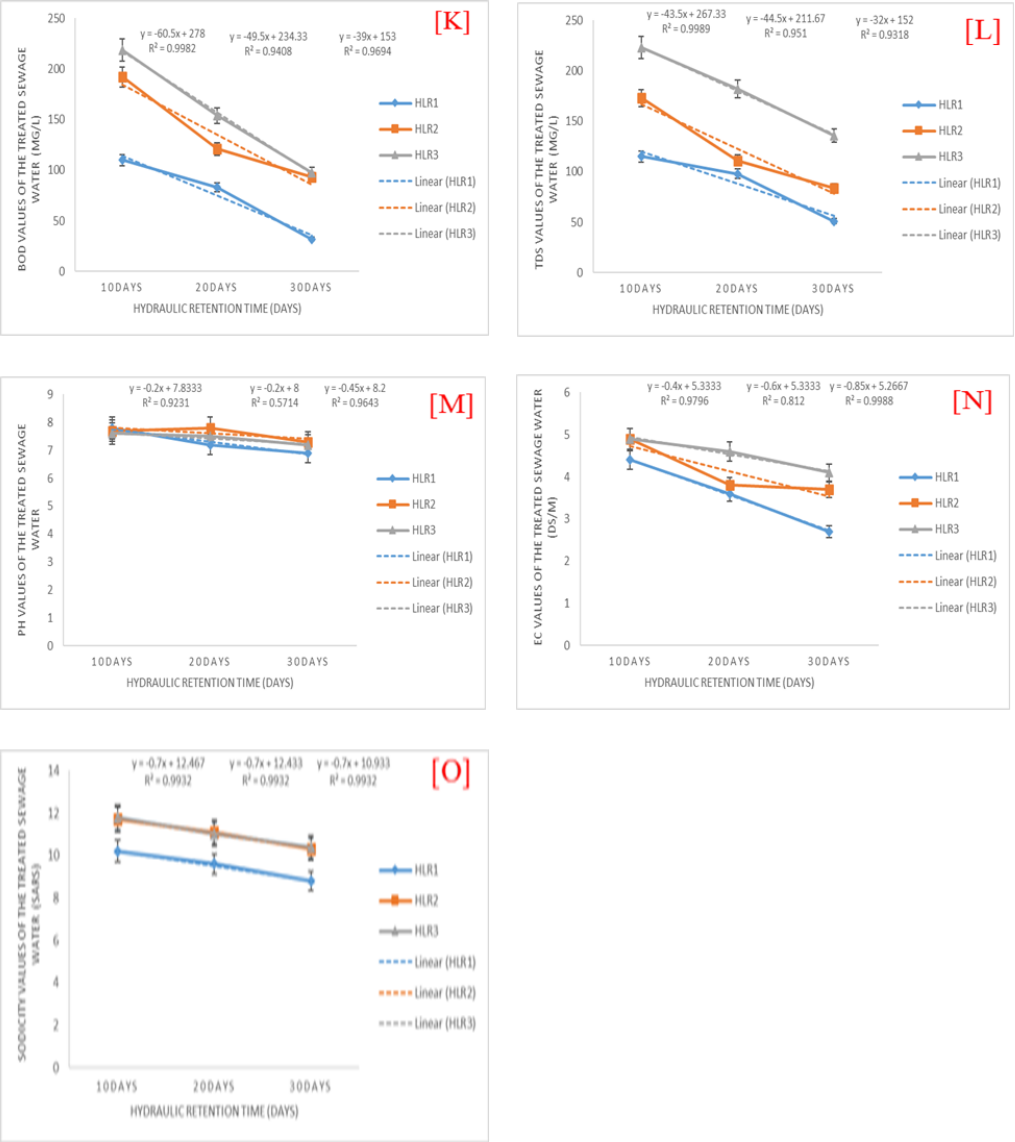
The pH of the raw sewage water was extremely alkaline with a value of 8.0 according to the World Health Organization (WHO) standard, The USEPA recommends the appropriate pH range of 6.0 to 9.0, FAO 6.0 to 8.5, Israel 6.5 to 9.5, Italy 6.0 to 9.5, and Portugal 6.5 to 8.4 for wastewater use in irrigation. A low pH level can affect the distribution of heavy metals in agricultural soil, accumulated by plants through absorbtion and pollute the body of nearby water [13]. The pH of the treated sewage water for all the hydraulic loading rates and hydraulic retention times adopted are all within the recommended standard for irrigation use. The extremity in alkalinity of the raw sewage reduces for all treated sewage respectively. Turkey's Honest Significant Test revealed a significant level for the adopted factors on the pH of the treated sewage water at p<0.05.

An accurate measure of the wastewater's total dissolved solids concentration is electrical conductivity (EC). The concentration of salt in the soil increases when irrigation water is added. The high level of these salts will raise the potential for osmotic change in the soil solution, which will hinder the plant's ability to absorb water. Salinity may also increase as a result of toxic effects [16]. The recommended standard for electrical conductivity of any wastewater used in irrigation is between 0.7 and 3.0ds/m. According to Fig D above, the electrical conductivities of the treated sewage water are reduced compared to the raw sewage water with electrical conductivity (EC) of 5.4ds/m which was above the recommended standard. The electrical conductivities of the treated sewage were 4.4, 3.6, 2.7ds/m, 4.9, 3.8, 3.7ds/m and 4.9, 4.6, 4.1ds/m, for hydraulic loading rates and hydraulic retention time of 1.0, 1.5, 2.0ds/m and 10, 20, 30 days. The adopted factors are insignificant on the EC of the treated sewage water at p<0.05 according to Turkey's Honest Significant Test.

The salinity (ECw) of the irrigation water is what mainly restricts plant growth. In some soil textural circumstances, the application of water that is imbalanced in sodium might further lower yield. When irrigation water has a high salt content in comparison to its calcium and magnesium contents, there could be reductions in the rate of water infiltration. This phenomenon is referred to as sodicity and it usually leads to a large quantity of sodium building up in the soil. The sodicity of the raw sewage (13.5SAR) was above the standard while the sodicity (8.8SARS) of the lowest hydraulic loading rate (1.0m/day) and highest hydraulic retention time (30 days) was within the recommended standard. There was reduction in the sodicity of the treated sewage water with decreasing hydraulic loading rates and increasing hydraulic retention time. The Turkey's Honest Significant Test on the values of electrical conductivities of the treated sewage water revealed that the adopted factors are statistically insignificant on ECw of the treated sewage water at p<0.05.

F, G, H, I & J): Impacts of HLR & HRT on BOD, TDS, pH, Electrical Conductivity and Sodicity reduction of the treated sewage water.

The charts (F, G, H, I and J) above show the efficacy of wastewater hydraulic loading rates and hydraulic retention on the quality of treated sewage water. It was revealed from the charts that there were better treatment efficiencies or pollutant reduction efficiencies (90.7, 90.0, 13.8, 50.0, and 34.8%) for BOD, TDS, pH, EC, and sodicity at the lowest hydraulic loading rate of 1m/day and hydraulic retention time of 30 days. The efficiencies of all the treatment factors adopted are between 36.5 to 90.7, 56.3 to 90.0, 2.5 to 13.8, 9.3 to 50, and 12.6 to 34.8%, respectively.



(K, L, M, N &O): The graph showing the regression coefficient between HLR, HRT and BOD, TDS, pH, Electrical Conductivity, and Sodicity of the treated sewage water.

The graphs for Fig KLMNO above represent the level of interconnection of the adopted factors (hydraulic loading rates and hydraulic retention times) with treatment response (BOD, TDS, pH, EC, and sodicity) of the treated sewage water. The results from the graph revealed that the independent variables establish a better relationship with treatment response at a hydraulic loading rate of 2.0m/day for BOD and TDS and a hydraulic loading rate of 1.0m/day for pH and EC.

4. Conclusion

This study revealed the impacts of hydraulic loading rates and hydraulic retention time in reducing the turbidity and toxicity of sewage water. The selected physicochemical properties of the sewage water considered in the study were reduced to a considerable level at a lower hydraulic loading rate and high hydraulic retention time for proper application to agricultural fields through an irrigation system. All the wastewater hydraulic loading rates and hydraulic retention times considered in the study perform better compared to the value of the sewage water before treatment (control). Further studies should be carried out by adopting hydraulic loading rates, hydraulic retention time and composite filters that are different from the ones considered in this study while investigating their impacts in the treatment of sewage water.

Declaration and conflicts of interest

The authors of this research contributed significantly to the study and there was no conflicting interest during and after the research.

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