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DEVELOPMENT OF A PHYTOREMEDIATION SYSTEM FOR DOMESTIC WASTEWATER TREATMENT WITH POTENTIALS FOR ORGANIC FERTILIZER PRODUCTION

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ABSTRACT

Water, sanitation and hygiene are serious global concern. Several pollution sources significantly contribute to the water quality in our environment, these pollutions are releasing an array of hazardous environmental and water matrices which unfortunately affect the ecosystem. Meanwhile, there are inadequate ecologically friendly technologies to handle this menace. In view of the above; an emerging technology referred to as Phytoremediation System was designed and developed to treat municipal wastewater generated from domestic sewage using Water Hyacinth (Eichornia crassipes) as treatment agent. It is a system that consists of physical and biological processes to purity water quality in more controlled and efficient way. The technology also enhances biodiversity in our environment. Influent concentrations were characterized and compared with that of the effluent using standard laboratory testing methods. Some of the pollutant physico-chemical parameters, nutrients and trace elements characterized were TDS, NH_4, PO_4, NO_3, pH, K, and Na. Others are Mg, BOD and Salinity. The Mean Effluent results read 2115mg/L, 8.0mg/L, 14.5mg/L, 52mg/L, 6.4, 11mg/L, 95mg/L, 19mg/L, 27mg/L and 0.95% respectively. A calculated Mean Removal Efficiency (R%) of 65.5% was achieved. The results obtained complies with USEPA (2002) recommended standard for wastewater discharge. The study was necessitated to proffer solutions to high cost of inorganic fertilizer by producing alternative at a low cost for farmers in the country, and by implication environmental sustainability.

Keywords: Development, Wastewater, Phytoremediation, Water quality, Environment.

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INTRODUCTION

Water treatment facilities for municipalities and industries remain one of the principal water quality problems that needed to be addressed, especially on how to manage the used-water. Most times, they are discharged into natural bodies, such as rivers, lakes, and groundwater infiltration; which in most cases pose detrimental impacts on the future use of these natural systems (Peterson, 1998). Phytoremediation system is however an emerging technology that can be employed for the removal of toxic and non-toxic pollutants from wastewater (Cristian et al., 2021). Several conventional methods such as chemical precipitation, bio-sorption, membrane technologies, flocculation and coagulation etc, have been employed to handle wastewater treatment issue. However, most of these techniques are very expensive and requires high energy to operate and maintain (Camarillo et al., 2012). Phytoremediation system is preferable because it is cost effective, simply to operate and does not rely on external energy sources which makes it most environmentally friendly. Domestic wastewater treatment awareness is very low in Nigeria. Most of the wastewater in the septic tanks infiltrate back to the aquifer, while a large amount of used-water as waste are discharged into nearby water bodies. This practice is environmental pollution that can cause outbreak of water-borne diseases attributed to lack of standards in handling these wastewaters in our environment.

In recent years, ground water quality is declining and deteriorating daily due to urbanization and rapid industrial growth. As a result; the discharge of untreated industrial effluent and domestic residuals into the natural water pools or water bodies can have fatal consequences for aquatic ecosystem, posing threats to natural habitats and human health in general (Petrovic et al., 2013). Due to the toxic nature of the pollutants involved; these materials may endanger the habitat and affect cellular functions in plants (Cichy et al., 2019). Phytoremediation technology otherwise referred to as Constructed Wetland is an active biogeochemical, extremely efficient and reliable system for the treatment of wastewater generated from various point and non-point sources (Ayaz et al., 2020). Macrophytes are therefore plants species which can be utilized in carrying out the Phytoremediation study. These plants can survive in water and adjust to their surroundings, they either remain fully submerged in the water or most of their parts remain under the water. Fertilizer is a substance which is applied to planted seeds in order to enrich their growth by increasing the supply of nutrients to the soil. It improves the soil fertility and ensures good crops yield. Fertilizer can help increase crop yield by 10 – 25 percent. In addition; it can protect plants from soil borne diseases to an acceptable degree of tolerance. It supplies essential nutrients to cultivated plants to promote its growth and yield (Kumar et al., 2017).

Recent studies have recommended that more grounds for research, innovation and initiatives are needed for this technology. Phytoremediation as ‘green engineering’ involves the use of herbaceous and woody species to remove contaminants from water and soil or reduce the risks of hazardous environmental pollutants (Mohebi and Nazari, 2021). For instance, a study carried out by Ogwuche et al., (2023) who used agro waste (*discorea spp*) as remediating agent to enhance biodegradation of Crude oil polluted soil. In designing and construction of this system; one need to consider various important factors since many contaminants do not have the same chemical structures, formation and characteristics which is a limiting factor for the system (Cristian et al., 2021). Halicki and Halicki, (2022) reported that natural treatment systems for wastewater is not only very important in reducing environmental pollution from sewage handling, but also to facilitate the reuse process of the water when treated to meet the requirements of the end users, which could be to recycle the treated water back for domestic

purposes. Invariably, wastewater has been beneficial economically and environmentally (Omole et at., 2020).

MATERIALS AND METHODS

The system was designed and constructed within the residential quarters of the Nigerian Army College of Environmental Science and Technology, Makurdi in Benue State of Nigeria. The raw water samples for the study was collected within the residential homes at the study area, and analyzed in the Laboratory. In course of conducting this study; there was need to consider certain environmental factors which may influence its performance, they are; hydrological data and topography of the study area, others factors include public health and safety concerns. However, to ensure holistic system performance, quantity of wastewater generated from the study area was estimated, knowing that 80% of water per capita usage constitutes a suitable wastewater flow volume (Mohammed, 2006). Parameters of the raw water for this study were identified to be from point source mentioned in Table 1. They were characterized in the laboratory before commencement of the process.

Table 1: Pollutant Parameters tested

S/N	Categories	Parameters
1.	Physico-chemical parameters	TDS, pH, BOD and Salinity.
2.	Nutrients	NH_4^+, PO_4^-, NO_3^-
3.	Trace metal elements	K, Na^+, and Mg^+

Phytoremediation Technologies

Phytoremediation technologies that influence its system performance are explained below. Table 2 shows summary of the whole processes involved in phytoremediation technologies.

Phytoaccumulation/Extraction mechanism simply refers to the uptake of contaminants such as metals, and other nutrients and water by plant roots, and subsequent translocation or accumulation (Phytoextraction) of the contaminants into the plant shoots and leaves which later may be harvested for disposal. This mechanism allows the plants or algae to remove contaminants from soil or water into harvestable plant biomass.

Phytodegradation is the means of degradation of organic contaminants through the releases of enzymes from the roots, under this process; contaminants are taken up by roots and metabolized in the plant tissue.

Phytostabilization involves the establishment of plant cover on the surface of the contaminated site in order to reduce the mobility of the contaminants. It involves the reduction of the mobility of heavy metals present in soil.

Phytostimulation is a technique applied to remediate areas contaminated with herbicides, aromatics and pesticides.

Phytovolatilization process is mainly driven by evapotranspiration which involves the uptake of contaminants by plant roots, and convert it to a gaseous state which is then released into the atmosphere.

Phytofiltration is a technique that uses plant roots (rhizofiltration), shoots, or seedlings (blastofiltration) to remove pollutants from contaminated soil and wastewater, and then releasing it into the air. This involves the process in which

organic compounds are emitting from the above ground section of a plant into the atmosphere (Oliver, 2003).

Table 2: Showing Summary of Phytoremediation Technologies

Type	Chemicals/Pollutants treated
Phytoaccumulation/Extraction	Cd, Cr, Pb, Ni, Zn, Radionuclides Benzene, Toluene, Ethyl benzene, Xylenes, Pentachlorophenol, short chained aliphatic compounds
Phytodegradation/Transformation	Nitrobenzene, Nitroethane, Nitrotoluene, Atrazine, Chlorinated solvent (DDT, chloroform)
Phytostabilization	Heavy metals in ponds, Phenols, Chlorinated solvents.
Phytostimulation	Polycyclicaromatic hydrocarbon, Polychlorinated biphenyl, Tetrachloroethene
Phytovolatilization	Chlorinated solvent, Hg, Se
Phytofiltration	Heavy metals, Organic and Radionuclides, Plant nutrients

Source: Nwoko, 2010

Selection of Macrophytes for Phytoremediation

In the work of Ugya (2019), plant macrophytes from different ponds were sampled and found that *Lemna minor L., Azolla pinnata, Pistia strtiotes, Eichornia crassipes and Salvinia molesta* were recommended as good macrophytes due to their ability to double their size within the space of three weeks. Amongst which *Eichornia crassipes* commonly known as Water Hyacinth was most suitable for remediating industrial wastewater. See Table 3 for macrophytes and their accession numbers. These macrophytes are regarded as popular aquatic phytoaccumulators against various water pollutants under study (Awuah et al., 2004 and Lu et al., 2010). Meanwhile, *Eichhornia crassipes* is reported to be the most interesting because of the fast growth rate, robustness, invasiveness, and ability to thrive in extreme environmental conditions compared to other macrophytes (Malik, 2007). Water Hyacinth is therefore a Phytoremediator of high potentials for industrial effluents which can create secondary pollution risks. As it accumulates pollutants; the contaminants may remain stored within the biomass. Conversely, the harvested plants may release the contaminants back into the environment as it decomposes if not properly managed (Adedeji, et al., 2021). When *Eichhornia crassipes* (Water Hyacinth) matured, the water plant's biomass is potentially useful in producing fertilizer, animal feed and biogas (Gunnarsson and Petersen 2007). Likewise, when it dies, sinks, and decomposes; the host water body becomes more eutrophic due to the massive release of nutrients, which makes it a potential fertilizer (Gao and Li, 2004). Hence, it was selected as a suitable macrophyte for this work.

Table 3: Macrophytes used for Phytoremediation

S/N	Plants	Common Name	Accession Number
1.	Lemna minor L.	Duckweed	L. 6935
2.	Eichornia crassipes	Water Hyacinth	3268
3.	Pistia stratiotes	Water Lettuce	1977
4.	Azolla pinnata	Water velvet	0678
5.	Salvinia molesta	Kariba weed	01689

Source: Ugya (2019)

Design of the System Components and Experimentation

The system components were constructed with the aid of dimensional analysis in order to achieve accuracy of results. Mini Septic tank was designed to accommodate the generated wastewater that flows with gravity. Wastewater generated from the study area was determined using Equation 1. The capacity of the septic tank was determined by calculating water demand of the study area. Compost bed which is a major component in the process of removing organic matter from the raw water was also designed, it consists of three separate beds, each having different daily hydraulic loads. Denitrification bed was also incorporated into the system to remove nitrates from the raw water. Hydraulic retention time was determined to know when changes begin to occur in the process (Equation 2). Then, Equation 3 was used to calculate the Removal Efficiency of the sample under study, Removal efficiency determines performance of the treatment. This was made possible by analyzing the wastewater in the laboratory before and after subjecting it through the treatment facility. Figure 1 shows the schematic working diagram of a typical Phytoremediation technology in use.

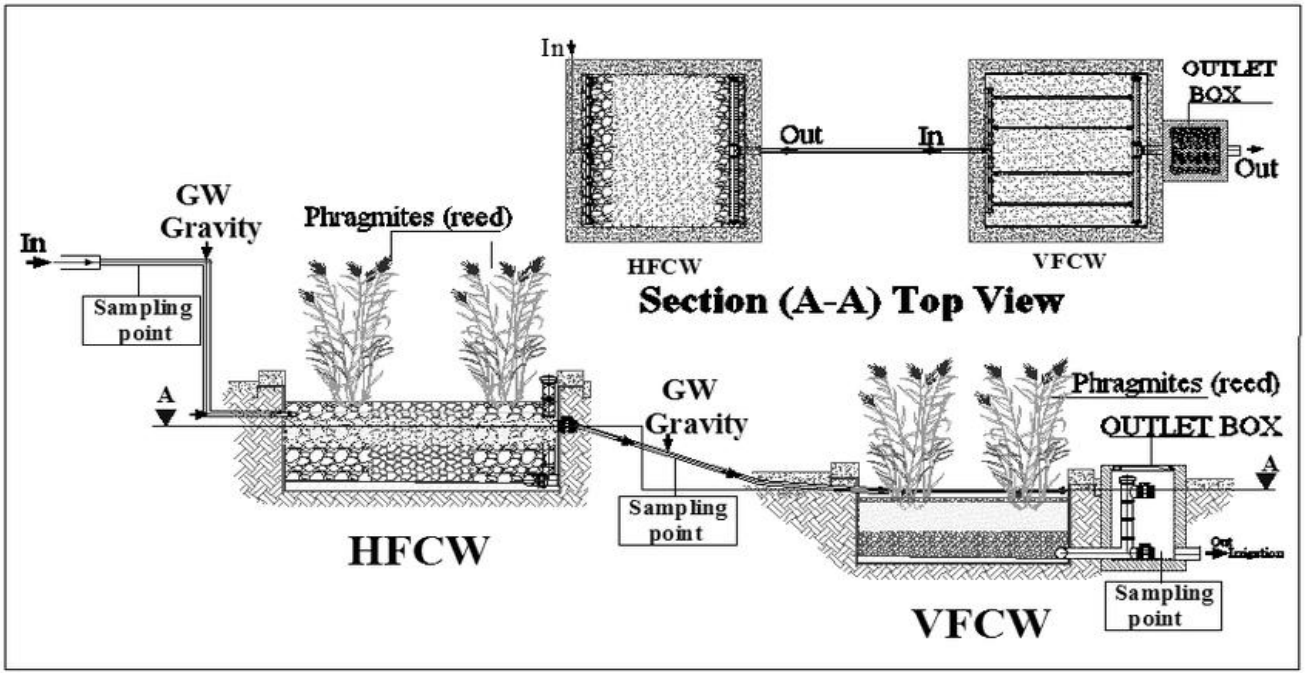


Fig 1: Schematic diagram of a Phytoremediation system
Source: Hussein and Ahmed, (2014)

Equations for the System

The following equations were used to obtain accuracy of results:

- Water Quantity Estimation is water consumption is the quantity of water directly utilized by the consumers which generates variable flows. Water Demand is derived from overall water quantity, which is typically calculated by measuring the flow rate of the wastewater and the concentration of contaminants in the wastewater. 80% of water use is usually converted to wastewater (Isiorho and Oginni, 2008).

$$\text{Wastewater generated (Qwc)} = \frac{80}{100} \times Qwd \ (m3/d) \qquad (Eq.\ 1)$$

where, Qwc = Wastewater generated
Qwd = Water Demand

- Hydraulic Retention Time (HRT) = $\frac{V}{Q}$ (m^3/L) *(Eq. 2)*

where, V = Volume of the septic tank, and
Q = Quantity of influent flow rate.

- Removal Efficiency (R%) is given as R (%) = $\frac{C\ in - C\ out}{C\ in}$ $x\ 100$ *(Eq. 3)*

where, *C in* = Influent concentration
C out = Effluent concentration

RESULTS AND DISCUSSION

From the field experiment conducted, the results obtained from the raw water before subjecting to the treatment system (Influent concentration), and that after the treatment (Effluent concentration) is in Table 4.

Table 4: Influent and Effluent Concentration Rate

S/N	Parameter	Influent concentration	Effluent concentration	Recommended Standard (USEPA, 2002)	Unit
1.	TDS	3800	2115	Less than 3000	mg/L
2.	NH_4	12.5	8.0	Less than 10	mg/L
3.	PO_4	32	14.5	Less than 30	mg/L
4.	NO_3	65	52	Less than 50	mg/L
5.	pH	13	6.4	Less than 8.5	---
6.	K	18	11	Less than 10	mg/L
7.	Na	163	95	Less than 150	mg/L
8.	Mg	26	19	Less than 20	mg/L
9.	BOD	58	27	Less than 30	mg/L
10.	Salinity	12	0.95	Less than 15	%

The results illustrated in Table 4 shows that almost all the physico-chemical contaminants tested for such as Total Dissolved Solids (TDS), Ammonium (NH_4^+), Phosphate (PO_4), Nitrate (NO_3), pH, Potassium (K), Sodium (Na), Magnessium (Mg), Biochemical Oxygen Demand (BOD), and Salinity fall within the recommended limits for effluent. This infers that Water Hyacinth (*Eichhornia crassipes*) has remediated influent from domestic wastewater by lowering the raw concentrations of its contaminants content. Water Hyacinth is therefore accepted as efficient and effective agent to purify pollutants from domestic wastewater. Though, it took hydraulic retention period of five weeks to achieve such recorded phytoremediation efficiency. Simultaneously, it was discovered that the reduction in quantity of Salinity rate from 12% to 0.95% assisted in the growth of the Water hyacinth plant which aided the success of this work, this conformed to a report by Sooknah and Wilkie, (2004) that high quantity of salinity in water can hinder the growth of Water Hyacinth. A calculated Mean removal efficiency (R%) of 65.5% was also achieved by the macrophyte. This signifies a significant improvement of the macrophyte's performance which compared to a study by Valipour et al., (2011) and Adelodun et al., (2021) who also used it to treat similar domestic wastewater and achieved 4% and 51.5% removal efficiency respectively. Figures 1 – 3 showed the effects of pollutant concentration before treatment as Influent and after the

treatment as effluent compared to USEPA recommended value. Bilal, (2019) achieved a research standard using a pilot-scale constructed wetland as a tertiary treatment for domestic wastewater using local plants as treatment agents. Meanwhile, Rodrigo (2021) in his research advised conducting an experiment out-site (culture room) and on-site (wetland mesocosms) before embarking on a larger scale initiative in order to clear negative factors that can prevent the success of the project. Study on Phytoremediation can be applied to both organic and inorganic contaminants present in soil (solid substrate), water (liquid substrate) and air quality (Oti, 2017).

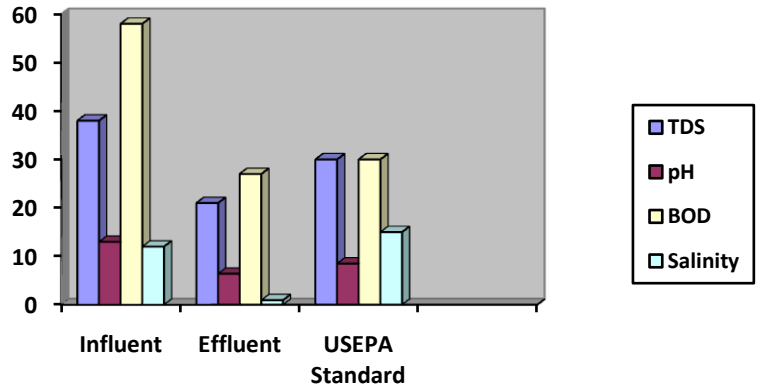


Figure 2: Effects of concentration on Physico-chemical parameters

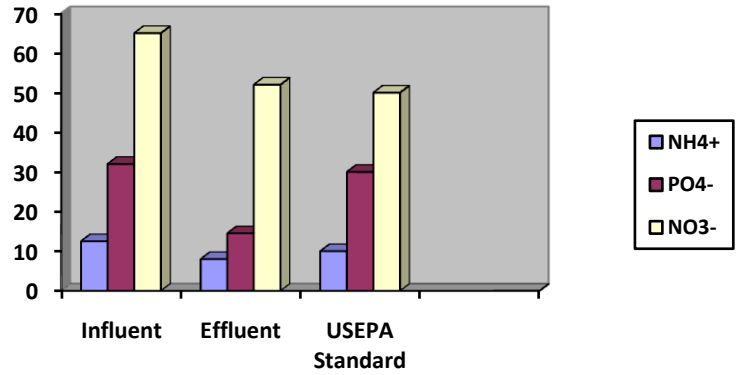


Figure 3: Effects of concentration on Nutrients

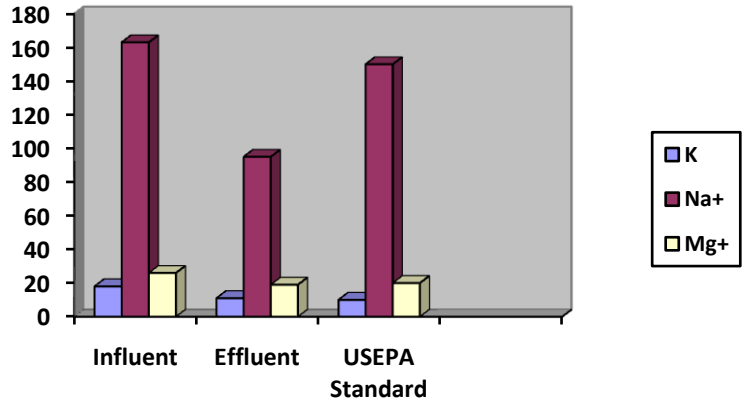


Figure 4: Effects of concentration on Trace Elements

From the result also, there was a reported reduction in alkalinity value, this is attributed to breakdown and release of CO_2 from dead and decaying water hyacinth (Ayyasamy et al. (2009). Also, Shah et al., (2010) made similar observations in significant decrease in hardness while carrying out a research on treatment of dye effluent using Water Hyacinth as treatment agent. Likewise, high presence of NH_4, PO_4 and K, reading 8.0mg/L, 4.5mg/L and 11mg/L respectively, together with other trace metal elements have affirmed a good fertilizer potential from the system. This is in agreement with the findings by Gunnarsson and Petersen (2007), and Gao and Li, (2004) that whenever *Eichhornia crassipes* (Water Hyacinth) matures, the water plant's biomass is potentially useful in producing fertilizer, because when it dies and decomposes; the host water body becomes more eutrophic due to the massive release of nutrients, which makes it a potential fertilizer. In another study by Arega, (2020) revealed that a good amount of Potassium (K) value is necessary for living organism functioning, hence it is found in all human and animal tissues which aids photosynthesis, improves fruits quality as well reduces diseases.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Domestic wastewater treatment awareness is critical in our environment. Improper management of domestic wastewater can result to environmental pollution which can cause outbreak of water-borne diseases. The release of untreated influent directly into the natural water bodies affects the aquatic ecosystem. From the results obtained, maximum contamination levels were reduced to tolerable amount that is in accordance with the recommended standards. It ensures clean environment through proper sanitation and hygiene, which is an important factor for environmental safety and to promote good health.

Recommendations

Consequent upon this research, Phytoremediation system using Water Hyacinth *(Eichhornia crassipes)* as macrophytes is hereby recommended to treat domestic wastewater due to its efficiency, availability, potential for fertilizer production, and environmental friendliness. Therefore, more grounds for researches and innovations on this technology should thrive particularly for developing countries due to its operational and easy to manage nature.

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